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Reviewing the Status of the Ministry of Health's Public Health Policy on the Use of Smart Technologies for Monitoring and Controlling COVID-19

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ABSTRACT

The COVID-19 pandemic has highlighted the necessity of redesigning public health policies and integrating smart technologies to enhance health systems' capacity for infectious disease surveillance, prevention, and control. This study aims to assess the status of public health policies within the Ministry of Health, Treatment, and Medical Education regarding the application of smart technologies for COVID-19 management and future health crises. The research is applied in purpose and employs a descriptive-survey methodology. The statistical population included experts in health policy, digital health, health information technology, artificial intelligence in healthcare, and health system management, selected through purposive sampling. Data were collected using a researcher-made questionnaire, and validity and reliability were confirmed through expert assessment, Cronbach's alpha, composite reliability, and average variance extracted indices. Data analysis was conducted using partial least squares structural equation modeling (PLS-SEM). The findings validated a multidimensional framework comprising four dimensions: facilitating participation in disease control, managerial and organizational policy orientation, individual-oriented public health policies, and health technology policies. The results indicate that effective smart health governance requires the integration of technological, organizational, and social capabilities rather than merely developing digital infrastructure. Within this framework, artificial intelligence, digital twins, and immersive health environments are identified as enabling technologies that support predictive analytics, real-time decision-making, simulation-based policy development, and stakeholder collaboration. Therefore, strengthening digital health governance, ensuring secure data management, improving digital health literacy, and promoting participatory approaches are essential for developing resilient and adaptive health systems capable of managing future global health challenges. ©authors

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Introduction

The COVID-19 pandemic, as one of the most critical public health crises in recent decades, confronted global healthcare systems with unprecedented challenges in disease prevention, monitoring, control, and rapid decision-making (Semi et al, 2026). This crisis demonstrated that relying solely on traditional epidemic management methods is insufficient for emerging biosecurity threats. Consequently, nations must leverage smart technologies and accelerate digital transformation to enhance diagnostic speed, contact tracing, outbreak prediction, resource allocation, and evidence-based policymaking (Budd et al., 2020; Ting et al., 2020; Nasaru et al, 2026).

In recent years, the paradigm of healthcare has shifted toward advanced digital ecosystems. Technologies such as Artificial Intelligence (AI), big data, the Internet of Medical Things (IoMT), cloud computing, and smart tracking applications have played a vital role in managing the COVID-19 crisis. By providing real-time data, these technologies enable rapid analysis, epidemic forecasting, hotspot identification, and policy support, thereby enhancing healthcare system efficiency (Budd et al., 2020; Sucahyono et al, 2026). From a broader digital transformation perspective, these tools serve as the foundation for immersive health technologies, digital twins of hospitals, and the emerging medical metaverse, which are reshaping health crisis simulation and remote clinical management (Omar, 2025).

Recognizing this shift, the World Health Organization (WHO) has identified digital transformation as a core strategy for strengthening health systems. In its Global Strategy on Digital Health 2020–2025, the WHO emphasizes that digital health development must be integrated into national policies, data governance, standardization, system interoperability, and evidence-based decision-making (World Health Organization [WHO], 2021). Furthermore, the organization asserts that digital and immersive technologies can only improve public health when deployed within coherent, accountable, and evidence-based policy frameworks (WHO, 2021; Zainal et al., 2025).

Despite the rapid adoption of smart technologies during the COVID-19 pandemic, studies indicate that the success of these digital innovations depends less on the technology itself and more on the quality of public policy, data governance, inter-sectoral coordination, information infrastructure, data protection laws, public trust, and institutional capacity (Labrique et al., 2020; Budd et al., 2020; Osman et al, 2025). Therefore, alongside technological deployment, reforming digital health policies and preparing regulatory frameworks for virtual and smart health spaces have become top priorities for governments worldwide (Ssebububu et al, 2026).

In Iran, the Ministry of Health, Treatment, and Medical Education implemented various digital initiatives during the pandemic, including electronic screening registries, electronic health records, and statistical dashboards (Kanwendo et al, 2025). However, it remains unclear to what extent national public health policies have successfully institutionalized these smart technologies—and their transition toward virtual, decentralized health environments—in a systematic and evidence-based manner. Most domestic studies have focused strictly on the technical or clinical aspects of health technologies, largely neglecting the evaluation of public health policy, technology governance, policy coherence, institutional capacity, and administrative mechanisms (Li et al., 2025).

Furthermore, in its document Ethics and Governance of Artificial Intelligence for Health, the WHO stresses that utilizing smart technologies in healthcare must align with transparency, accountability, privacy protection, data security, equitable access, and public trust; otherwise, technology adoption may introduce new systemic challenges rather than improving health governance (WHO, 2021; Avraham et al., 2026).

In recent years, digital transformation in healthcare systems has shifted public health policymaking from traditional reactive approaches toward smart, predictive, and data-driven governance models. In this context, emerging technologies such as artificial intelligence, big

data analytics, the Internet of Medical Things (IoMT), digital twins, and metaverse-based health environments have created new opportunities for improving infectious disease surveillance, epidemic scenario simulation, real-time decision-making, and interactive stakeholder engagement. The COVID-19 pandemic demonstrated that effective health crisis management is no longer dependent solely on the expansion of medical infrastructure; rather, it requires the development of an intelligent health ecosystem in which health data, artificial intelligence algorithms, organizational capabilities, and citizen participation are integrated. Accordingly, reviewing the status of the Ministry of Health, Treatment, and Medical Education's public health policies regarding the adoption of smart technologies for COVID-19 monitoring and control can provide valuable insights into the readiness of the health system for transitioning toward digital health governance and a new generation of crisis management. In this emerging paradigm, technologies such as the health metaverse and immersive environments can play a complementary role in enhancing health system resilience by enabling interactive virtual spaces for remote healthcare delivery, professional collaboration, public health education, and simulation-based policy planning (Achواني et al., 2026).

Considering the challenges associated with the institutionalization of smart technologies in public health policies, the core issue is not merely the lack of technological infrastructure, but rather the absence of an integrated framework for data governance, institutional collaboration, stakeholder engagement, and the effective utilization of emerging digital technologies. Within this perspective, the health metaverse, as an advanced manifestation of digital transformation, is not simply a virtual environment for delivering healthcare services; rather, it represents an integrated ecosystem that enables the convergence of health data, artificial intelligence, digital twins, real-time interactions, and participatory decision-making. The lack of policy and institutional readiness for adopting such technologies may create a gap between technological capabilities and the managerial capacity of health systems. In other words, the major challenge in leveraging the health metaverse is not technology development alone, but the establishment of governance mechanisms, data interoperability standards, digital trust frameworks, cybersecurity measures, and cross-organizational coordination. Therefore, examining public health policies regarding the application of smart technologies for COVID-19 management provides a foundation for identifying the requirements of transitioning from conventional digital health approaches toward smart health governance and metaverse-enabled healthcare environments. In this emerging paradigm, immersive technologies can serve as supportive infrastructures for pandemic prediction, policy simulation, interactive health education, remote healthcare delivery, and enhancing the overall resilience of health systems (Chansanguan et al., 2025). Consequently, the primary research gap lies in the lack of a comprehensive evaluation of the Ministry of Health's public health policies regarding the deployment of smart technologies and digital transformation frameworks for pandemic monitoring and control. Investigating this issue identifies policy readiness, institutional capacity, strengths, and bottlenecks. Ultimately, this study provides a foundational framework for reforming digital health policies, advancing smart and virtual health governance, and enhancing health system resilience against future global crises.

Literature Review

Ecosystems

Health Data Governance in Virtual and Smart Ecosystems

Health data governance encompasses the comprehensive frameworks of laws, policies, standards, processes, and managerial mechanisms that dictate how health data is collected, stored, shared, analyzed, secured, and utilized within healthcare systems. The primary objective of data governance is to ensure quality, integrity, security, transparency, accountability, and ethical use of health information to support evidence-based decision-

making. In the era of the COVID-19 pandemic and the subsequent acceleration of digital transformation, robust data governance frameworks became the cornerstone for real-time epidemiological analysis, disease monitoring, and inter-organizational collaboration.

Furthermore, as healthcare systems transition toward virtual environments, decentralized networks, and the medical metaverse, data governance must adapt to manage immersive user data, virtual identity privacy, and decentralized patient records. The World Health Organization (WHO) emphasizes that digital transformation in healthcare cannot succeed without effective data governance frameworks, privacy protection, system interoperability, and public trust (WHO, 2021). Similarly, Leslie (2020) highlights that data governance is the fundamental infrastructure for the responsible deployment of Artificial Intelligence (AI) and other smart technologies in health systems, playing a vital role in enhancing public trust and the efficacy of health policies (Leslie, 2020; Mohammed et al., 2025).

Smart Health Monitoring and Immersive Healthcare Technologies

Smart health monitoring refers to the deployment of emerging technologies—such as AI, the Internet of Medical Things (IoMT), big data analytics, cloud computing, smart biosensors, and real-time data integration—to collect, process, and interpret health data at both individual and population levels. The goal of this paradigm is to rapidly identify health threats, predict disease trajectories, continuously monitor patient vitals, and support clinical decision-making. During the COVID-19 crisis, smart monitoring served as a critical tool for contact tracing, forecasting outbreak trends, managing hospital bed capacity, allocating critical resources, and mitigating transmission (Lakhan, 2025).

In the context of modern virtual technologies, smart monitoring has evolved to incorporate digital twins of patients and hospitals, as well as spatial computing interfaces, which allow healthcare administrators to simulate pandemic scenarios in immersive virtual environments. According to Budd et al. (2020), smart technologies have significantly enhanced the decision-making quality of health systems by analyzing massive datasets and offering real-time actionable insights. Additionally, Ting et al. (2020) assert that the integration of AI, big data, and digital platforms forms the core infrastructure of modern smart monitoring systems for global health crisis management (Budd et al., 2020; Ting et al., 2020; Wandasari et al., 2025).

Recent empirical literature demonstrates that smart and virtual technologies have become indispensable tools for health systems in combating public health crises. However, while most historical research focuses heavily on the technical, engineering, or immediate clinical outcomes of these systems, few studies evaluate the overarching public health policies governing their deployment.

A study, conducted by Ndayishimiye et al. (2023), examined the application of digital health technologies during the COVID-19 pandemic. Through a scoping review of 46 studies, the authors found that telemedicine, digital health information systems, AI, and mobile health (mHealth) applications improved healthcare access, enhanced clinical care quality, and accelerated decision-making processes. However, the researchers stressed that the sustainable efficacy of these technologies depends on institutional infrastructure, active policymaker support, and the formulation of coherent digital health policies (Ndayishimiye et al., 2023).

Donelle et al. (2023) investigated the role of digital technologies in public health surveillance during the pandemic. Their findings indicated that big data, AI, geospatial tracking, social media analysis, and online reporting systems played a critical role in early outbreak detection and policy formulation. Nevertheless, they highlighted that privacy concerns, information security, data opacity, and the lack of robust information governance frameworks remain significant barriers to digital health integration (Donelle et al., 2023).

Amiri and Nadri (2023) identified the success factors of mobile health initiatives during the COVID-19 pandemic. Their systematic review revealed that IT infrastructure, executive

leadership, user trust, and digital health literacy are key facilitators for smart health deployment. Conversely, regulatory gaps, confidentiality concerns, financial constraints, and a lack of inter-agency coordination serve as primary barriers (Amiri & Nadri, 2023).

A study, by Irwin et al. (2024), evaluated digital contact tracing technologies. This systematic review demonstrated that Bluetooth, GPS, and QR-code-based tracking systems successfully mitigated disease transmission. However, their adoption and effectiveness were heavily mediated by public trust, data privacy protections, clear regulatory policies, and governmental support. They concluded that technological deployment without adequate public policy governance fails to achieve its intended public health outcomes (Irwin et al., 2024).

Kemajou et al. (2024) explored post-pandemic emerging health technologies. Their findings indicated that AI, IoMT, big data analytics, and remote monitoring systems are becoming the pillars of future healthcare delivery. The authors argued that maximizing the potential of these tools requires national digital health strategies, effective data governance, infrastructure investment, and cross-sector collaboration (Kemajou et al., 2024).

While literature widely documents the operational and technical utility of smart technologies during public health crises, a significant gap remains regarding the evaluation of public health policy frameworks, institutional readiness, data governance quality, and policy coherence within Ministries of Health. Most research treats technology as an isolated tool rather than an integrated component of national health governance.

By focusing on the evaluation of the Ministry of Health, Treatment, and Medical Education's public health policies regarding smart technologies, this study addresses this critical gap. The findings provide empirical evidence needed to reform digital health policies, advance smart health governance, and prepare health systems for integration into next-generation virtual, decentralized health environments (such as the healthcare metaverse) to ensure resilience against future global health crises.

Although this study primarily examines the Ministry of Health's public health policies regarding the use of smart technologies for COVID-19 management, its theoretical contribution extends beyond conventional digital health perspectives by identifying the policy and governance foundations required for the transition toward metaverse-enabled healthcare systems. In this regard, metaverse readiness is not considered solely as a technological capability, but as a multidimensional construct influenced by digital governance maturity, data management capacity, organizational agility, technological infrastructure, stakeholder participation, and institutional coordination. The COVID-19 pandemic revealed that the successful adoption of immersive health environments and virtual governance mechanisms depends on the prior establishment of robust smart health policies and integrated digital ecosystems. Therefore, the present research investigates the underlying policy dimensions that shape the readiness of health systems for future adoption of advanced technologies, including health metaverse platforms, digital twins, and immersive decision-support environments. From this perspective, virtual governance is conceptualized as an evolutionary stage of smart health governance in which artificial intelligence, real-time data analytics, virtual collaboration spaces, and participatory digital ecosystems support proactive and adaptive public health management. Accordingly, the findings of this study provide a policy-oriented foundation for understanding how health systems can move from basic digital transformation toward metaverse-oriented and intelligent healthcare governance.

Method

In this section, the research method of the present study will be examined separately. The statistical population of this study included 120 specialist physicians active in the treatment of Covid-19 in public hospitals. Sampling was carried out using a stratified random method. Structural equation modeling was used for data analysis and modeling. A researcher-made

questionnaire was used as a measurement tool, which is considered the most common tool for collecting information in survey studies. This questionnaire was designed based on a five-point Likert scale. The process of creating the questionnaire included the steps of identifying the key dimensions and components of the Ministry of Health's public health policies by examining theoretical foundations and conducting interviews with experts, validating the content of the questionnaire by calculating the content validity ratio based on the opinions of experts, confirming the reliability of the questionnaire by calculating Cronbach's alpha coefficient, and after going through these steps and ensuring the validity and reliability of the tool, the questionnaire was distributed among the statistical sample.

This study uses a field approach to collect the required data and information. In the field method, two field tools were used to collect primary data related to the research objectives, which include interviews, i.e., conducting structured or semi-structured interviews with key and knowledgeable individuals in the research area, and questionnaires and designing, distributing, and collecting standard or researcher-made questionnaires from the target statistical population. The simultaneous use of these two methods allows for a more comprehensive and deeper understanding of the research topic. In this study, two categories of descriptive and inferential statistics were used to analyze the collected data. SPSS version 24 and Smart PLS version 3.0 software were used for this purpose.

To test the hypotheses of this study, the powerful structural equation modeling technique was used. The components of the structural equation model include the measurement model, which is equivalent to confirmatory factor analysis and shows how latent variables are measured through observed variables, as well as the structural model, which specifies the causal relationships between latent variables and shows how exogenous variables affect endogenous variables. For this purpose, software and evaluation indicators, including Smart PLS 3.0 software, have been used due to its advanced capabilities in testing complex models.

Findings

In this section, the quantitative data collected were analyzed. Confirmatory factor analysis was used to ensure the validity and reliability of the variables and measurement tools (questionnaires). SPSS and Smart PLS statistical software were used as the main analysis tools. The significance level (α) for all tests was set at 0.05.

Sampling adequacy check

In the first step, to determine whether the data were sufficient for factor analysis, the Kaiser-Meier-Olkin sampling adequacy test, abbreviated as KMO, was used. Also, the Bartlett test was used to examine whether the variance of the research variables could be affected by the common variance of the latent and basic factors. In other words, this test determines whether the observed changes in the set of variables are due to the presence of some underlying factors and not simply all variables independently.

Table 1. Sampling adequacy check

Keiser-Meier-Olkin Sampling Adequacy		0.833
Bartlett's Test of Sphericity	Chi-square	8825.968
	Degrees of freedom	820
	Significance level	0.000

Referring to Table 1, the value of the Keiser, Meyer, and Olkin test is very close to 1, indicating that the sample size is sufficient for factor analysis. In addition, the significance level of the Bartlett sphericity test is less than 0.05, which also confirms the ability to use factor analysis to estimate variables. In this section, the relationships between variables have been examined using the second-order confirmatory factor analysis method and through the Smart PLS software.

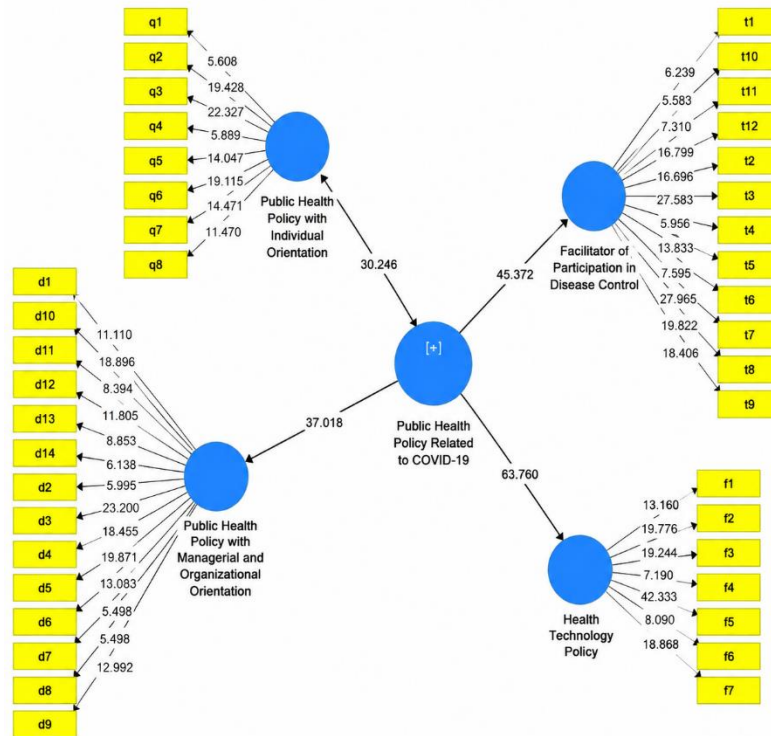


Figure 1. T-values for relationships between research variables of the structural model in the significant state (t-value)

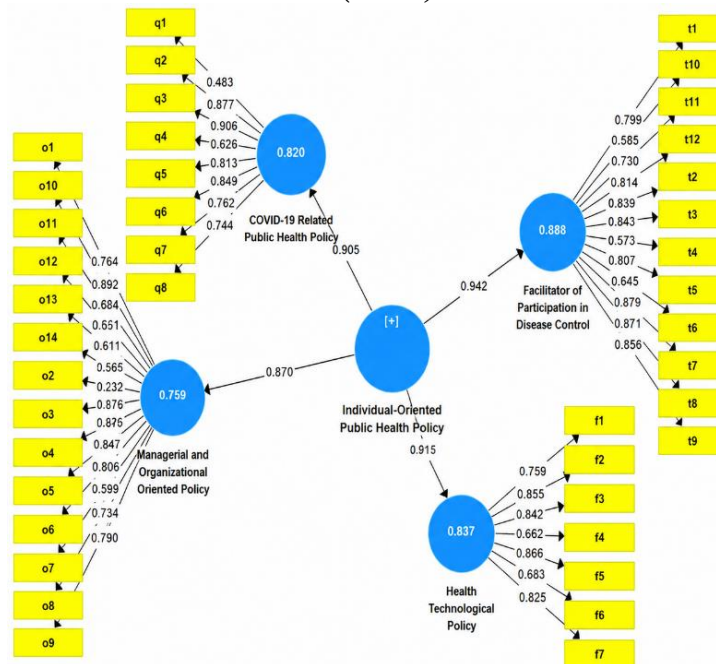


Figure 2. Study of the effect of research variables with the structural model in the case of standardized coefficients

As can be seen in Figures 1 and 2, the overall validity of the dimensions, components, and indicators has been confirmed. Based on the information in Figure 1, the t value for the dimensions, components, and indicators related to the Ministry of Health's general health policies in the context of COVID-19 is greater than the critical value of 0.05 (1.96); therefore, the validity of these dimensions, components, and indicators can be confirmed. Also, the standardized coefficients of the variables are shown in Figure 2.

The results of the first and second order factor analysis are presented in Tables 2 and 3, which show the validity and confirmation of the items and variables extracted for the “Ministry of Health’s General Health Policy” in the face of COVID-19.

Table 2. Results of factor loadings and collinearity index (first-order confirmatory factor analysis)

Item	Indicators and items	Standard coefficient	Standard deviation	T-statistics	Significance level
The Ministry of Health uses AI-based decision-support systems to improve managerial decisions during health crises.	d1 <- Policy with managerial and organizational orientation	0.764	0.069	11,110	0.000
Digital dashboards and real-time data analytics are used for monitoring and controlling infectious diseases.	d10 <- Policy with managerial and organizational orientation	0.892	0.031	28,896	0.000
The health system has effective digital governance mechanisms for managing health data.	d11 <- Policy with managerial and organizational orientation	0.684	0.081	8,394	0.000
Healthcare organizations have sufficient capacity to integrate emerging technologies into crisis management.	d12 <- Policy with managerial and organizational orientation	0.661	0.056	11,805	0.000
The Ministry of Health promotes interoperability among digital health information systems.	d13 <- Policy with managerial and organizational orientation	0.611	0.069	8,853	0.000
Big data analytics are used to identify health risks and predict disease outbreaks.	d14 <- Policy with managerial and organizational orientation	0.561	0.091	6,138	0.000
AI-based predictive models support strategic planning and policy formulation.	d2 <- Policy with managerial and organizational orientation	0.275	0.069	3,996	0.000
Digital transformation strategies are incorporated into public health management policies.	d3 <- Policy with managerial and organizational orientation	0.876	0.038	23,200	0.000
Virtual collaboration platforms support coordination among health organizations.	d4 <- Policy with managerial and organizational orientation	0.852	0.046	18,456	0.000
Digital twins can be used for simulation and evaluation of health crisis scenarios.	d5 <- Policy with managerial and organizational orientation	0.847	0.043	19,871	0.000
Managers are trained to use intelligent technologies for evidence-based decision-making.	d6 <- Policy with managerial and organizational orientation	0.800	0.061	13,083	0.000
Cybersecurity and data protection policies are integrated into digital health governance.	d7 <- Policy with managerial and organizational orientation	0.569	0.090	6,330	0.000
The Ministry of Health has organizational readiness for adopting immersive health environments.	d8 <- Policy with managerial and organizational orientation	0.726	0.085	8,498	0.000
AI-enabled governance improves institutional agility during pandemics.	d9 <- Policy with managerial and organizational orientation	0.790	0.061	12,992	0.000
The Ministry of Health supports the adoption of artificial intelligence technologies in public health services.	f1 <- Health technology policy	0.759	0.058	13,160	0.000
Digital health platforms are developed to improve disease surveillance and prevention.	f2 <- Policy Health technology	0.855	0.043	19,776	0.000
Internet of Medical Things (IoMT) technologies are utilized for continuous health monitoring.	f3 <- Health technology policy	0.842	0.044	19,244	0.000
Cloud-based infrastructures are used for secure storage and processing of health data.	f4 <- Health technology policy	0.662	0.092	7,180	0.000
Digital twins are considered in health system planning and pandemic simulation.	f5 <- Health technology policy	0.866	0.020	42,338	0.000
The development of health metaverse platforms is included in future health technology policies.	f6 <- Health technology policy	0.683	0.084	8,090	0.000
Immersive technologies (VR/AR) are used for healthcare education, training, and remote services.	f7 <- Health technology policy	0.825	0.044	18,888	0.000
Digital health services enable personalized healthcare interventions for citizens.	q1 <- Public health policy with individual orientation	0.483	0.086	5,608	0.000
AI-based systems support personalized disease risk assessment.	q2 <- Public health policy with individual orientation	0.877	0.045	19,428	0.000
Citizens have access to digital platforms for receiving health information and services.	q3 <- Public health policy with individual orientation	0.906	0.041	22,327	0.000

Telemedicine services are integrated into public health policies.	q4 <- Public health policy with individual orientation	0.620	0.105	5.889	0.000
Digital health literacy programs are developed to improve citizens' technology adoption.	q5 <- Public health policy with individual orientation	0.813	0.058	14.047	0.000
Virtual healthcare environments improve patient engagement and accessibility.	q6 <- Public health policy with individual orientation	0.849	0.044	19.319	0.000
Individuals' health data are used ethically to provide personalized services.	q7 <- Public health policy with individual orientation	0.762	0.053	14.471	0.000
Mobile health applications support preventive behaviors and disease management.	q8 <- Public health policy with individual orientation	0.744	0.065	11.470	0.000
Digital platforms facilitate citizen participation in disease surveillance programs.	t1 <- Facilitator of participation in disease control	0.703	0.113	6.230	0.000
Mobile applications enable individuals to report symptoms and health conditions.	t10 <- Facilitator of participation in disease control	0.685	0.123	5.583	0.000
Social media analytics are used to understand public health behaviors.	t11 <- Facilitator of participation in disease control	0.730	0.100	7.310	0.000
AI-powered communication systems improve public engagement during health crises.	t12 <- Facilitator of participation in disease control	0.814	0.048	16.799	0.000
Citizens participate in digital health ecosystems through online platforms.	t2 <- Facilitator of participation in disease control	0.839	0.050	16.696	0.000
Virtual communities support knowledge sharing and disease prevention.	t3 <- Facilitator of participation in control Disease	0.848	0.031	27.583	0.000
Digital tools increase transparency and trust between citizens and health authorities.	t4 <- Facilitator of participation in disease control	0.572	0.145	3.936	0.000
Online education platforms improve public awareness about infectious diseases.	t5 <- Facilitator of participation in disease control	0.807	0.058	13.833	0.000
Digital feedback mechanisms enable citizens to contribute to health policy improvement.	t6 <- Facilitator of participation in disease control	0.646	0.085	7.595	0.000
Metaverse-based environments can support interactive public health education.	t7 <- Facilitator of participation in disease control	0.879	0.031	27.965	0.000
Virtual health communities enhance collective participation in disease control.	t8 <- Facilitator of participation in disease control	0.878	0.044	19.822	0.000
Immersive technologies facilitate collaboration between citizens and healthcare providers.	t9 <- Facilitator of participation in disease control	0.850	0.046	18.406	0.000

Table 3. Results of second-order factor analysis loadings

	Standard coefficient	Standard deviation	Statistics	Significance level
COVID-19-related public health policy -> Facilitator of participation in disease control	0.942	0.021	45.372	0.000
COVID-19-related public health policy -> Policy with managerial and organizational orientation	0.870	0.024	37.018	0.000
COVID-19-related public health policy -> Public health policy with individual orientation	0.905	0.030	30.246	0.000
COVID-19-related public health policy -> Health technology policy	0.915	0.020	46.760	0.000

Factor loadings were used to analyze the structure of the questionnaire and identify the factors that make up each variable. The results of factor loadings are shown in Tables 2 and 3. Factor loadings indicate the amount of variance in the indicators that is explained by the latent variable. In evaluating the external models, three criteria of reliability, convergent validity, and divergent validity were used. In the reliability section, both the reliability at the level of the questionnaire items and the reliability of the total latent variables should be examined. The reliability of the items was assessed by measuring the factor loadings, and the reliability of the latent variables was assessed through composite reliability. The minimum reliability value at the item level is equal to or greater than 0.5, which indicates that at least half of the variance of the indicator is explained by the latent variable. Therefore, factor loadings greater than 0.7 are considered desirable, while loadings less than 0.4 need to be eliminated. Factor

loadings between 0.4 and 0.7 are removed if this increases the convergent validity value. In all latent variables, all indicators had factor loadings greater than 0.4 and were significant at the 95% confidence level ($t > 1.96$), and the results finally confirm that all items have acceptable reliability.

The R^2 value is calculated only for endogenous variables and is zero for exogenous constructs. The higher the R^2 value for endogenous constructs, the better the model fit. Chin (1998) has introduced values of 0.19, 0.33, and 0.67 as weak, moderate, and strong criteria for model fit, respectively.

Table 4. R^2 Coefficient of Determination

Variables	Coefficient of determination
Participatory facilitator in disease control	0.888
Management and organizational-oriented policy	0.758
Individual-oriented public health policy	0.820
Health technology policy	0.837

By examining the values in the table, it is clear that the coefficient of determination of all variables exceeds 0.25; this indicates that the model has a good fit and an appropriate level of quality. The second index used to evaluate the fit of the structural model is the Q^2 index. This criterion, which was first introduced by Stone and Geiser (1975), measures the ability of the model to predict endogenous constructs. These researchers believe that models with acceptable structural fit should be able to predict their endogenous variables; in other words, if the relationships between the constructs in the model are correctly defined and the constructs have sufficient influence on each other, the hypotheses will be correctly confirmed. Hensler et al. (2009) have determined the values of 0.15, 0.20 and 0.35 as weak, medium and strong predictive power, respectively. The Q^2 index is calculated using the blindfolding technique.

Table 5. Stone-Geisser Q^2 Index

Variables	Q^2
Participatory facilitator in disease control	0.516
Management and organizational-oriented policy	0.381
Individual-oriented public health policy	0.459
Health technology policy	0.493

Based on the values presented in the table, the Q^2 index (referred to in the previous text as the Stone Geiser index) for all variables is above 0.15, indicating a moderate to high and acceptable fit for the model.

Table 6. Results of Cronbach's alpha test, composite reliability and extracted variance

Variables	Average variance extracted AVE>0.4	Combined reliability $\alpha > 0.7$	Cronbach's alpha $\alpha > 0.7$
Alpha>0.7	0.604	0.947	0.938
$\alpha > 0.7$	0.527	0.937	0.924
AVE>0.4	0.591	0.918	0.894
Facilitator of participation in disease control	0.622	0.919	0.896

Convergent Validity

After examining the reliability criteria, the second criterion for evaluating measurement models is convergent validity. The Average Variance Extracted - AVE, which indicates the average common variance between each construct and its indicators, is used as a criterion for convergent validity. A value of 0.4 or higher for this index is considered sufficient. According to the values presented in the table, the reliability and validity status of the model is confirmed.

Table 7. Calculation of Discriminant validity (Fornell and Larker index - Heterotrait-Monotrait Ratio (HTMT))

	1	3	2	5
Facilitator of participation in disease control	0.777			
Policy with managerial and organizational orientation	0.883		0.926	
Public health policy with individual orientation	0.771	0.869	0.695	

Health technology policy	0.860	0.740	0.757	0.912
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In Table 7, it can be seen that the square root of the average extracted variance of each latent variable is larger than its correlations with other latent variables. This indicates the existence of discriminant validity in the model, which means that the main constructs of each dimension assess different and independent aspects. In addition, the Fornell and Larker index emphasizes that the square root of the average extracted variance of each latent variable should be greater than the highest correlation of that variable with other constructs. In other words, the square root of the extracted variance of the latent variables in the present study, which are located in the main diagonals of the matrix, should be greater than the values of their correlations with other constructs in the lower and left cells of the main diagonal. The logic is that each construct should obtain more variance with its indicators than other constructs

In the present study, COVID-19-related public health policy is conceptualized as an AI-enabled smart health governance framework rather than a conventional policy structure. Accordingly, the dimension of Facilitating Participation in Disease Control is interpreted as AI-driven participatory disease surveillance and control, where citizens contribute through mobile health applications, wearable devices, digital platforms, and real-time reporting systems. The Managerial and Organizational Orientation dimension is linked to intelligent and immersive health governance, emphasizing data-driven decision-making, AI-powered dashboards, inter-organizational coordination, and virtual collaboration environments. The Individual-Oriented Public Health Policy dimension reflects citizen-centered smart health services, including personalized healthcare, telemedicine, remote monitoring, and AI-supported preventive interventions. Finally, Health Technology Policy is expanded into smart health technology and digital innovation policy, encompassing artificial intelligence, digital twins, cloud computing, Internet of Medical Things (IoMT), big data analytics, and health metaverse infrastructures. Through this perspective, the proposed framework demonstrates how public health policies can evolve from traditional administrative mechanisms toward predictive, adaptive, and metaverse-ready health governance capable of supporting future pandemic preparedness and resilient healthcare systems.

Discussion

The Lens of the Healthcare Metaverse and Immersive Governance

1. Synthesis of Core Dimensions and Systemic Alignment

The structural equation modeling (PLS-SEM) analysis reveals that the evaluation of public health policies—specifically concerning the Ministry of Health’s deployment of smart technologies for pandemic surveillance and mitigation—is fundamentally shaped by four core dimensions: Facilitating Participation in Disease Control, Managerial and Organizational Policy Orientation, Individual-Oriented Public Health Policy, and Health Technology Policy. These findings demonstrate that the successful transition toward digital and immersive health ecosystems cannot rely solely on the technological sophistication of digital assets. Instead, it demands systemic alignment among decentralized governance structures, citizen engagement, organizational capabilities, and cyber-physical infrastructures. This systemic view aligns directly with the World Health Organization’s Global Strategy on Digital Health, which posits that sustainable digital health transformation requires robust, evidence-based governance, active multi-stakeholder participation, and scalable digital foundations (WHO, 2021; Crawford-Holland, 2025). Furthermore, as Budd et al. (2020) argue, smart technologies yield their maximum epidemiological efficacy only when embedded within coherent, agile policy frameworks and coordinated organizational architectures. In the context of next-generation health systems, this requires integrating traditional tele-health into the broader paradigm of the Healthcare Metaverse, where virtual spatiality and digital twins serve as the operational canvas for public health policies.

2. Immersive and Virtual Facilitation of Public Participation

A pivotal finding of this research is the critical role of “Facilitating Participation in Disease Control” as a core dimension of the policy model. This underscores that public health policy must move beyond top-down dissemination, framing citizens, healthcare professionals, and civic institutions as active co-designers of the virtual health space. During the COVID-19 pandemic, nations that cultivated public trust and localized community agency achieved significantly higher compliance with smart tracking, digital self-reporting, and virtual monitoring systems. Within the Healthcare Metaverse, this participation can be significantly enhanced through spatial computing, gamified community wellness hubs, and avatar-represented public health portals. As Roberts and Kelman (2023) emphasize, digital health governance during acute infectious crises is structurally compromised without robust social participation, transparency, and multi-sectoral collaboration; a lack of these elements inevitably diminishes the social license and efficacy of digital interventions. Consequently, future health policies must conceptualize public participation not merely as compliance, but as interactive, immersive co-governance where citizens contribute to and navigate real-time digital twins of their epidemiological environments.

3. Managerial and Organizational Governance in Immersive Health Systems

The prominent weight of the “Managerial and Organizational Policy Orientation” dimension highlights that the implementation of spatial, virtual, and smart health tools is governed primarily by institutional readiness. Establishing immersive public health platforms requires sophisticated data governance, standardized interoperability protocols, inter-organizational coordination, and administrative support. The integration of virtual clinics and 3D medical simulation spaces into traditional public health infrastructure calls for clear regulatory and structural adaptations. This is consistent with Gilbert et al. (2023), who argue that deploying advanced artificial intelligence and algorithmic models within clinical settings necessitates structured governance frameworks, institutional accountability, risk-management protocols, and organizational alignment. Moreover, as Bayram et al. (2020) assert, digital health policies only translate into resilient public health outcomes if managerial capacities and institutional capabilities are updated in tandem with technical tools. Without these structural foundations, the deployment of virtual reality (VR), augmented reality (AR), or digital twins remains isolated and fails to deliver systemic resilience.

4. Individual-Oriented Policies: Trust, Ethics, and Spatial Privacy

The third critical dimension, “Individual-Oriented Public Health Policy,” highlights the human-centric focus of digital health transformation. The adoption of metaverse platforms, immersive health apps, and digital twin monitoring is contingent upon individual digital literacy, user trust, perceived utility, and the protection of cognitive and data privacy. In immersive environments, where spatial audio-visual data and biometric telemetry (IoMT) are continuously harvested, the ethical implications of data surveillance escalate. As Wagner et al. (2024) argue, the governance of AI and advanced computing in healthcare must strike a delicate equilibrium between collective public health benefits and individual civil liberties. Upholding ethical standards, ensuring equity in access, and securing digital trust are absolute prerequisites for the viability of any digital health policy. This perspective aligns with the WHO guidelines on the Ethics and Governance of Artificial Intelligence for Health, which call for transparency, accountability, demographic inclusivity, and rigorous data protection as the ethical baseline for deploying predictive and smart health models (WHO, 2021; Pilosof et al., 2025).

5. Health Technology Infrastructure: Laying the Spatial and Digital Foundation

Finally, the “Health Technology Policy” dimension constitutes the structural baseline of the proposed model. Managing future health crises relies heavily on the maturity of cyber-physical systems, including the Internet of Medical Things (IoMT), cloud-edge computing,

AI-driven epidemic forecasting, and immersive virtual command centers. However, this study demonstrates that tech infrastructure policy must go beyond hardware procurement to address data standardization, semantic interoperability, and legal frameworks for spatial data transmission. This is corroborated by the syntheses of Budd et al. (2020), Bayram et al. (2020), and the WHO (2021), which collectively argue that technological interventions are only effective when embedded in an evidence-based, policy-driven, and highly integrated governance structure.

To foster a resilient, metaverse-ready public health ecosystem, ministries of health must balance their technological investments with comprehensive governance frameworks. Policy initiatives should focus on:

- Enhancing organizational readiness for digital twin modeling and spatial simulation;
- Formulating ethical regulations for biometric data privacy within virtual spaces;
- Promoting digital health literacy to foster immersive public participation;
- Establishing open-standard API structures to facilitate cross-sectoral interoperability.

The findings of this study extend the current understanding of smart public health governance by demonstrating that the successful adoption of emerging healthcare technologies is not solely dependent on technological advancement, but also on the development of integrated governance capabilities. The identified dimensions highlight that digital transformation in public health requires the simultaneous alignment of organizational readiness, data-driven decision-making, citizen engagement, and technological innovation. In particular, the role of citizen participation indicates that future health systems should move beyond one-way communication models toward interactive digital ecosystems in which individuals actively contribute to disease surveillance, prevention, and health decision-making. Furthermore, the emphasis on health technology policy suggests that artificial intelligence, digital twins, immersive environments, and health metaverse platforms should be viewed as components of a broader digital governance architecture rather than isolated technological solutions. From this perspective, the transition toward immersive healthcare ecosystems requires not only advanced technological infrastructures but also regulatory frameworks, data governance mechanisms, digital trust, and institutional agility. Therefore, the findings provide a conceptual foundation for understanding how public health systems can progress from conventional digital health approaches toward adaptive, participatory, and intelligent governance models capable of supporting future pandemic preparedness and resilience.

Although the empirical model developed in this study evaluates public health policies related to the use of smart technologies for COVID-19 management, the validated dimensions also provide a conceptual basis for understanding the policy conditions required for future digital transformation in healthcare. Specifically, the dimensions of managerial and organizational orientation, health technology policy, citizen participation, and individual-oriented public health policy collectively represent the governance capabilities necessary for the adoption of next-generation digital health innovations. Consequently, the discussion of health metaverse platforms, digital twins, immersive healthcare environments, and predictive artificial intelligence should be interpreted as forward-looking conceptual implications rather than direct empirical findings of the study. These technologies are presented as potential applications that may emerge from the policy, organizational, and technological capacities identified in the validated framework. Accordingly, the proposed recommendations do not imply that the empirical analysis has verified the effectiveness of metaverse-based healthcare systems; instead, they identify the institutional and governance prerequisites that can facilitate their future implementation. Future empirical research is therefore needed to examine the adoption, effectiveness, and policy impacts of immersive healthcare technologies in real-world public health settings.

Conclusion

This research evaluated the public health policy landscape of the Ministry of Health and Medical Education (MOHME) regarding the adoption of emerging digital technologies and artificial intelligence-based solutions for COVID-19 surveillance, prediction, and mitigation. The PLS-SEM analysis validated a multidimensional framework consisting of four interconnected pillars: Facilitating Citizen Participation in Disease Control, Managerial and Organizational Policy Orientation, Individual-Centered Public Health Policy, and Intelligent Health Technology Policy. The findings reveal that the transformation toward a resilient and adaptive healthcare system requires moving beyond the conventional perception of technology adoption as a purely infrastructural investment and embracing a comprehensive AI-enabled socio-technical ecosystem in which data, algorithms, human capabilities, and governance mechanisms operate synergistically.

In this context, artificial intelligence, machine learning, big data analytics, Internet of Medical Things (IoMT), cloud computing, and digital twins can enhance pandemic preparedness by enabling predictive surveillance, early warning systems, automated risk assessment, and evidence-based policy optimization. The results emphasize that future public health governance should evolve from reactive crisis management toward anticipatory and intelligent governance, where AI-driven platforms continuously analyze heterogeneous health data sources, simulate potential outbreak scenarios, and support policymakers through real-time decision intelligence. Such an approach requires the integration of virtual healthcare environments, immersive technologies, and intelligent dashboards to create dynamic decision-making infrastructures capable of responding rapidly to complex and uncertain health emergencies.

Furthermore, the effectiveness of smart health policies depends not only on technological sophistication but also on the maturity of digital governance structures, including data sovereignty, algorithmic transparency, cybersecurity, ethical AI principles, and institutional readiness. The findings highlight the necessity of developing human-centered AI governance models in which citizens, healthcare professionals, technology providers, and policymakers collaboratively participate in designing and implementing digital health solutions. Building digital trust, improving health data literacy, ensuring equitable access to intelligent healthcare services, and strengthening organizational agility are identified as critical prerequisites for sustainable digital transformation in public health systems.

Ultimately, the future of pandemic management lies in the convergence of artificial intelligence, smart governance, and participatory health ecosystems. A resilient health system in the era of AI is not defined merely by its capacity to deploy advanced technologies, but by its ability to transform data into actionable knowledge, integrate human intelligence with machine intelligence, and create adaptive policy frameworks capable of anticipating, preventing, and managing emerging health threats. Therefore, the transition toward AI-powered smart health governance represents a fundamental paradigm shift from traditional public health administration toward a proactive, predictive, and continuously learning healthcare ecosystem.

Practical Recommendations for Policy and Practice

To facilitate the transition toward a Metaverse-ready Public Health System, the following strategic actions are proposed for health authorities and policymakers:

Integrated Metaverse Health Framework: The Ministry of Health should develop a comprehensive “Digital-First” policy roadmap that integrates Generative AI, Big Data analytics, the Internet of Medical Things (IoMT), and Healthcare Metaverse protocols into a single unified surveillance ecosystem.

Sovereign Data Governance: Establish national standards for health data interoperability and “Spatial Data Privacy.” This includes developing secure, unified platforms for real-time data exchange that protect individual confidentiality while enabling large-scale epidemiological modeling.

Digital and Virtual Literacy Programs: Launch specialized training initiatives to enhance “Immersive Health Literacy” among healthcare professionals, administrators, and the general public to reduce the digital divide and increase the adoption of virtual health services.

Multi-Stakeholder Virtual Co-creation: Strengthen mechanisms for public-private partnerships (PPP), involving knowledge-based firms, startups, and academic institutions in the design and auditing of virtual health policies and immersive interfaces.

Investment in Digital Twins and Predictive AI: Prioritize the development of Digital Twins of the National Health System and AI-driven spatial dashboards to simulate pandemic scenarios and optimize resource allocation before crises escalate.

Real-time Policy Auditing: Implement dynamic, data-driven evaluation systems to continuously assess the socio-technical impact of digital health policies, allowing for iterative “Agile Policy-making.”

Recommendations for Future Research

Given the rapid evolution of virtual and immersive technologies, the following areas are recommended for future academic inquiry:

Generative AI and Crisis Leadership: Investigate the impact of Large Language Models (LLMs) and Multi-modal AI on the quality of decision-making among health managers during acute public health crises.

Decentralized Governance Models: Explore the role of Blockchain and decentralized data governance in enhancing the transparency and security of health policy implementation in the metaverse.

Behavioral Dynamics in Virtual Health: Conduct longitudinal studies on “Spatial Presence” and user acceptance of immersive health platforms using extended Technology Acceptance Models (TAM) or UTAUT.

Digital Maturity Benchmarking: Evaluate the “Metaverse Readiness” of medical universities and hospitals, identifying the technical and cultural barriers to adopting digital twin technologies.

Cross-National Policy Synthesis: Perform comparative analyses between Iran and leading nations in digital health governance to identify best practices for trans-national health crisis management.

Cyber-Psychological Impacts: Utilize advanced SEM or mixed-methods approaches to analyze how variables such as Cybersecurity Trust, Algorithmic Transparency, and Digital Wellbeing influence the long-term success of digital health transformations.

Declaration of Competing Interest

The author declares that he has no competing financial interests or known personal relationships that would influence the report presented in this article.

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