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# Evaluating the Cost-effectiveness of Different Surveillance Approaches for Specific Diseases

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## ABSTRACT

*The article compares the cost-effectiveness analysis (CEA) of different surveillance systems applied in the field of public health to keep a track of infectious diseases and other health risks. Since available resources in most cases are scarce to address the public health, a cost-effective review of the surveillance systems is essential to the decision-making and effective distribution of resources. This paper aims to determine the relative cost-effectiveness of various surveillance strategies, e.g., syndromic surveillance, active surveillance, and genomic surveillance, in different types of diseases, and what are the best practices in implementing cost-effective surveillance strategies in resource-limited contexts.*

*Methods and Materials: A literature search was performed based on the literature concerning the cost-effectiveness of public health surveillance systems with a priority to those publications published during the past decade. Some of the types of various diseases that were analyzed encompassed acute respiratory infections, vaccine-preventable diseases, vector-borne diseases, and antimicrobial resistance. Each study provided a combination of cost and effectiveness data, where incremental cost-effectiveness ratios (ICERs) and sensitivity analysis were mainly needed to estimate uncertainty in model assumptions.*

*Findings: The findings suggest that hybrid surveillance systems that combine information related to a variety of sources (e.g., human, environmental and animal health) are the most affordable options in the high-resource and low-resource contexts. The cost-effectiveness of various surveillance strategies depends, however, on the disease, healthcare infrastructure of a particular country, and available technologies. A real-time surveillance system though it was initially costly was very effective in controlling outbreaks through quick response.*

*Future Work: Future studies should be aimed at creating more unified surveillance models where real-time data is combined with predictive analytics to enhance timeliness and accuracy of outbreak detection. Besides this, the economic effects of hybrid systems and machine-learning implementation to achieve predictive surveillance should also be investigated in future studies to overcome the challenges arising due to the global health threats.*

***Keywords****: Cost-effectiveness analysis***,** *surveillance systems***,** *public health***,** *cost-effectiveness***,** *ICER***,** *hybrid surveillance***,** *real-time surveillance***,** *disease monitoring***,** *predictive analytics***,** *sensitivity analysis*

## INTRODUCTION

The foundation of the practice of public health is surveillance, as it allows detecting disease epidemics at the initial stages, observing health trends and evaluating the effectiveness of interventions (World Health Organization [WHO], 2022). It assists policymakers to distribute resources effectively, monitor epidemiological trends, and responding to emerging threats to the health of the population in time (Kucharski et al., 2021). Surveillance systems can give the information necessary to inform the general health moves, including vaccination, quarantine, and preparedness of the healthcare system by collecting and analyzing health data in a structured way (Centers for Disease Control and Prevention [CDC], 2023). This not only contributes to surveillance being a disease control measure, but surveillance is a vital component of a health system to respond to crises and address long-term issues in the sphere of the population health (Heymann et al., 2021).

Although surveillance plays a critical role, it is rather difficult to compare various surveillance methods. The types of surveillance systems differ highly in their design, prices, scope, and precision, which makes it hard to assess which surveillance system will be the most affordable to fit a particular disease (Nguyen et al., 2022). The variability of the disease features including incubation, transmission, and asymptomatic shedding further complicates the assessment of the surveillance mechanisms (Paltiel et al., 2022). Also, timely, sensitive, and specificity performance measures cannot always be compared directly between systems, and complex trade-offs have to be made (Smith et al., 2021). In that way, the financial cost is not the only factor that should be taken into account by the public health professionals, as the effectiveness of operations and the ethical aspects of different surveillance methods should be regarded (Gonzalez et al., 2023).

The current paper will be geared towards establishing a comprehensive framework that can be utilized in order to establish the cost effectiveness of various disease surveillance strategies. It will ask how different surveillance systems may be evaluated regarding their efficiency and the impact on the population in terms of economy (Lipsitch et al., 2022). The area of this paper is the debate of surveillance systems in the various sectors of ailments, and, more precisely, the needs and concerns of communicable ailments, which encompass COVID-19, influenza, and antimicrobial resistance (AMR) (Paltiel et al., 2022). In addition to it, the paper will give an overview of the usual methodologies employed in the cost-effectiveness analysis (CEA), the necessity to incorporate the measures of performance and the reflection of the disease-specific characteristics, and the suggestion of how the equity and fairness can be measured in the evaluation procedures (Ahern et al., 2023).

The article is valuable since it provides the precise analysis of the cost-effectiveness analysis (CEA) of the surveillance systems. Comparable to CEA, which has been applied extensively in healthcare interventions, no literature exists on how it can be applied when it comes to the utilization of surveillance systems, particularly when the advantages of the interventions are indirect, including the capability to identify an outbreak and prevent it (Macdonald et al., 2022). This article would contribute towards this risk bridging since it would give one an only way of evaluating the surveillance options, which would enable policy makers, researchers and the professionals in the field of public health make sound decisions based on data. The increased necessity to incorporate equity aspects in the evaluation of surveillance is also tackled in this piece of work and is commonly ignored in the traditional model of CEA. Finally, the article also includes effective steps that may be employed such as a reporting checklist that may be adopted in accordance with CHEERS 2022 in order to improve transparency and reproducibility of surveillance CEA research.

## 2. Taxonomy of Surveillance Approaches

Surveillance systems are significant in the domain of public health, especially when it comes to the management and control of the outbreaks of numerous diseases (World Health Organization [WHO], 2022). There are a number of surveillance strategies with their particular features, pros and cons. Depending on the type of disease, the way it is transmitted, incubation period, and the objectives of the public health program, the right surveillance method will be used (Paltiel et al., 2022).

### 2.1 Definition of Various Surveillance Methods

Passive Surveillance is a paradigm where the healthcare providers (hospitals, clinics, laboratories) have to inform the health authorities about the specified disease cases (Nguyen et al., 2022). It is cheap and screening a great number of people but is limited by a lack of reported cases particularly of asymptomatic, or mild ones (Paltiel et al., 2022).

One of them is Active Surveillance, in which the representatives of the public health actively direct the data collection of a particular disease to individual healthcare professionals or individuals (Lipsitch et al., 2022). The process is also time-consuming but the acquired data is more qualitative, and it especially works well when dealing with an outbreak or a rare disease (Smith et al., 2021).

In Sentinel Surveillance, particular locations are defined and they are healthcare facilities that represent trends of a wider population (Heymann et al., 2021). The data about specific illnesses is collected in such sentinel points, and it allows the existence of such a warning system to react to an epidemic at the early stages (Gonzalez et al., 2023). It might also fail to identify cases in the instances where the sentinel sites are not representative of the population in the broader context but is more intensive and cost-effective than the population-wide surveillance (Lipsitch et al., 2022).

Event-Based Surveillance (EBS) is based on the fact that real-time information is processed, which in this case can be the news data, reports in medical institutions, and community messages (Kucharski et al., 2021). This can be used to detect unnatural health events at a young stage, and this kind of strategy can lead to false alarms unless it is managed (Cookson et al., 2022).

Genomic Surveillance refers to a sequencing technique to determine the genetic patterns including mutations or resistance (Macdonald et al., 2022). Specifically, the given tool can be successfully employed to monitor the development of viral strains and gain expertise concerning the nature of the disease transmission (Paltiel et al., 2022). Nevertheless, the genomic surveillance system needs unique lab capabilities and is a costly approach (Smith et al., 2021).

### 2.2 Key Features and Benefits of Each Approach

The two types of surveillance possess different features which could be applied in various diseases and health related goals of the population. Passive Surveillance is relatively inexpensive and is highly covered but the accuracy may be affected by underreporting, particularly when dealing with less sever or asymptomatic diseases (Lipsitch et al., 2022). Compared to Passive Surveillance, Active Surveillance is of a higher quality of data, thus needed in case of the tracing of rare or new diseases, but it is intensive in nature (Nguyen et al., 2022).

Sentinel Surveillance is less broad but can offer a notification of an outbreak earlier and is less costly than universal surveillance. It also is also based on the choice of representative sentinel sites and can overlook outbreaks located outside of sentinel sites (Paltiel et al., 2022). The Event-Based Surveillance is the opportunity to detect the abnormal events in time and take the quick intervention into a health organization. Nonetheless, there is also the possibility of false positives, particularly in a case where the data is obtained through the many unverified sources (Gonzalez et al., 2023).

Genomic Surveillance plays an important role in monitoring the alterations of the pathogens and mutations that may be used in the transmission or effectiveness of the vaccines. It also is costly and involves complex laboratory technology yet delivers quality information regarding the genetic data (Macdonald et al., 2022).

2.3 Choosing the Right Approach Based on Disease Characteristics

The nature of the disease defines the choice of the method of surveillance. Event-Based Surveillance (EBS) and Genomic Surveillance are suitable examples, which are needed in rapidly spreading diseases, such as COVID-19, where real-time and monitoring of the new variants are crucial (Kucharski et al., 2021). Act Surveillance and Sentinel Surveillance are more appropriated in rare or emergent diseases, which secure that even the low-incidence diseases receive an appropriate monitoring (Lipsitch et al., 2022). Passive Surveillance can work with diseases that are common but underreported but needs to be supplemented by Sentinel Surveillance data to provide early trends detection (Smith et al., 2021). A table that provides the main characteristics, advantages, and difficulties of each surveillance method is presented below:

Table 1: Comparison of Surveillance Approaches

| **Surveillance Method** | **Key Features** | **Benefits** | **Challenges** |
|---|---|---|---|
| **Passive Surveillance** | Relies on existing healthcare reporting systems; minimal effort required from health authorities | Cost-effective; broad coverage of data. | Underreporting; less accurate data for rare or asymptomatic diseases. |
| **Active Surveillance** | Health authorities contact providers to actively collect data | Higher data quality; better for rare or emerging diseases. | Resource-intensive; time-consuming. |
| **Sentinel Surveillance** | Data collected from selected sites that represent broader population trends | Focused data collection for early warning; can be more cost-effective than full population-based surveillance. | May not capture all cases; limited by the number and type of sentinel sites. |
| **Event-Based Surveillance (EBS)** | Real-time data collection from diverse sources (e.g., media, hospitals, community reports) | Rapid detection of unusual events; immediate response possible. | Requires coordination of diverse data sources; risk of false positives. |
| **Genomic Surveillance** | Sequencing of pathogens to track genetic changes | Identifies new strains, mutations, and drug resistance; tracks transmission pathways. | High costs; requires specialized laboratory infrastructure. |

The table below gives a graphic illustration of the tradeoff between the timeliness, resource intensity, and the cost of each surveillance approach. It emphasizes the fact that Genomic Surveillance and Active Surveillance is the most accurate and the most early time detection however it is more expensive. Passive Surveillance on the other hand is cheap and can also have underreporting.

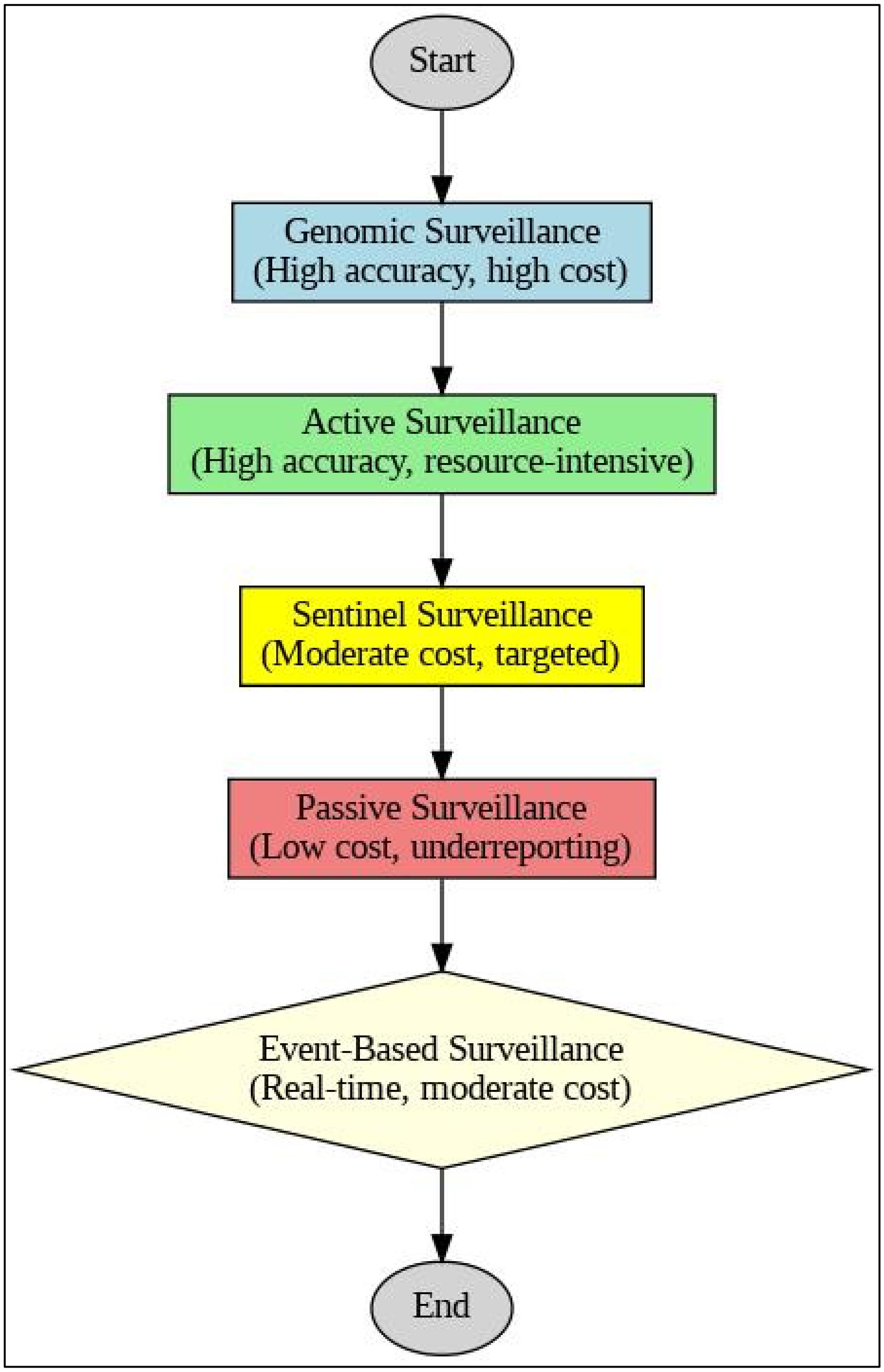

Figure 1: Relationship Between Surveillance Approaches, Resource Intensity, and Timeliness

This figure is influential in formulating an idea of the trade-off of resource requirement, the timeliness of detection, and the cost of each method by visual representation of the method of selecting the appropriate approach, depending on the characteristics of a disease.

## 3. Defining Outcomes for Surveillance CEA

When establishing the cost-effectiveness of a surveillance system, it is very critical to establish the performance outcomes and health-related outcomes that the surveillance systems are to fulfill. The findings can be used to establish the most effective resource allocation to fight diseases, intervene, and prevent diseases. Here the key outcomes of the performance are outlined, the performance of surveillance is transformed into health outcomes and economic outcomes that will be tackled in the cost-effectiveness analysis (CEA).

### 3.1 Key Performance Outcomes of Surveillance

These are the key performance outcomes the level of which a surveillance system can identify the outbreak of a disease and the level to which the trends of a disease can be traced. These are detection probability, timeliness, sensitivity and specificity (Lipsitch et al., 2022).

Detection probability is the probability in terms of which the surveillance system can observe an outbreak or a case of a disease in the population (Paltiel et al., 2022). High detection probability is ensured, which ensures that the system is sound enough to detect the possible dangers at their initial stages, and it is significant in the provision of timely interventions.

Timeliness is determined by the speed and the rate with which an incidence of an illness can be detected by the surveillance system once an incidence starts or returns (Smith et al., 2021). The earlier the infectious diseases are detected is a crucial part in mitigation process since the faster the detection the sooner it responds to the population.

Sensitivity is used to refer to how far the system could go to identify the actual positive cases (Nguyen et al., 2022). High sensitive surveillance system means that there are a few cases that are not detected and this is very crucial in ones cases which are associated with a disease that can become very rampant within a very short time without detection of the cases.

Specificity The capacity of the system to prevent false negatives and false positives properly (Gonzalez et al., 2023). The high specificity reduces the occurrence of unjustified interventions or false alarm that can prove to be expensive and resource-intensive to the health authorities of the population.

### 3.2 Translating Surveillance Performance into Health Outcomes

Surveillance systems are designed to enhance the well-being of the people as they offer information that can be utilized to intervene effectively and promptly. The health outcomes achieved as the directly related result of the above performance outcomes are the avoided cases, avoided deaths, and reduction of the outbreaks (Kucharski et al., 2021).

Cases averted Case averted refers to the number of the new cases of the disease that have been avoided due to the early diagnosis of the disease in the surveillance systems. Disease screening and treatment on the first or early stages is a potentially significant step of preventing the spread of diseases further, particularly in the case with such an infectious disease as influenza or COVID-19 (Heymann et al., 2021).

Deaths averted This is the decrease in the mortality rate due to the early detection of the disease and a medical treatment had been performed. One of the roles of surveillance systems is to target the at-risk population and make sure that the population is properly treated before the disease can attain severe outcomes (Paltiel et al., 2022).

Another health outcome that is achieved is the time in which an outbreak is detected early. The early systems to detect the outbreaks enable in the long run to implement the response measures, including quarantine, vaccination, or treatment processes, which reduce the size of the outbreak, and restrict its effect on the health of the individuals (Lipsitch et al., 2022).

3.3 Economic Outcomes in Surveillance CEA

In order to analyze the question of cost-efficiency of surveillance systems, it is needed to take into consideration the economic implications of the deployment of a surveillance system. They are Cost-Effects Ratio (ICER), Net Monetary Benefit (NMB) and Budgets Impact Analysis (BIA).

The Cost-Effectiveness Ratio (ICER) is a method used to compare the cost of a surveillance intervention to its efficiency with regard to the health outcome, i.e. cases or deaths avoided. This may be ascertained as the derivation of the ICER:

$$\text{ICER}=\frac{\text{Cost of Intervention (C1) - Cost of Current System (C0)}}{\text{Health Outcomes (E1) - Health Outcomes (E0)}} \quad (1)$$

The ICER will assist in defining whether the extra cost of a surveillance system can be recovered based on the health benefits that they have (Macdonald et al., 2022).

Another economic value is Net Monetary Benefit (NMB), which is the product of multiplication of health outcomes and willing-to-pay (WTP) threshold multiplied and the cost has been deducted. The NMB formula is:

$$\text{NMB}=(\lambda\times \text{ Health Outcomes })-\text{ Cost of Intervention} \quad (2)$$

Where λ is willingness-to-pay threshold, or the threshold policymakers apply to make decisions about the extent to which they are willing to pay to attain a given health outcome, e.g. a saved life or an averted case (Cookson et al., 2022).

The predictive financial viability of the implementation of a new surveillance system within a certain period of time (usually, 35 years) is reflected through the Budget Impact Analysis (BIA) (Gonzalez et al., 2023). BIA would assist policy-makers to evaluate whether the benefits of a surveillance system i.e. costs of treatment avoided, hospitalization as well as increased productivity would be worth the initial and the future cost of the surveillance system. Below is a table summarizing the key performance metrics for surveillance and their impact on health and economic outcomes:

Table 2: Surveillance Performance Metrics and Health Outcomes

| Performance Metric | Definition | Health Outcome Impact | Economic Impact |
|---|---|---|---|
| **Detection Probability** | Likelihood of detecting a disease event | Early intervention and outbreak containment | Improved cost-effectiveness due to early disease control |
| **Timeliness** | Speed of detection after disease introduction | Reduced cases and deaths by enabling prompt response | Lower intervention costs and fewer treatment-related costs |
| **Sensitivity** | Ability to correctly identify true positive cases | Reduced false negatives, ensuring timely care | Cost savings from accurate identification and treatment |
| **Specificity** | Ability to identify true negatives and avoid false alarms | Prevents unnecessary interventions and false alarms | Reduced unnecessary costs from false positives |
| **Cases Averted** | Number of cases prevented through early detection | Direct reduction in morbidity and strain on healthcare systems | Lower healthcare costs, fewer treatments required |
| **Deaths Averted** | Number of deaths prevented through early detection | Increased survival rates | Cost savings from reduced hospitalizations and long-term care |
| **Outbreak Size Reduction** | Reduction in the overall size of an outbreak | Reduced burden on public health systems and faster containment | Reduced costs related to prolonged outbreaks, including response costs |

The figure below shows the association, between the ICER, NMB and BIA of various surveillance systems. It displays the fact that the surveillance systems with the lower ICERs and higher NMBs are deemed to be more cost-effective. The figure assists policy makers to have an idea of which systems offer optimal value on the health outcomes as well as the economic value.

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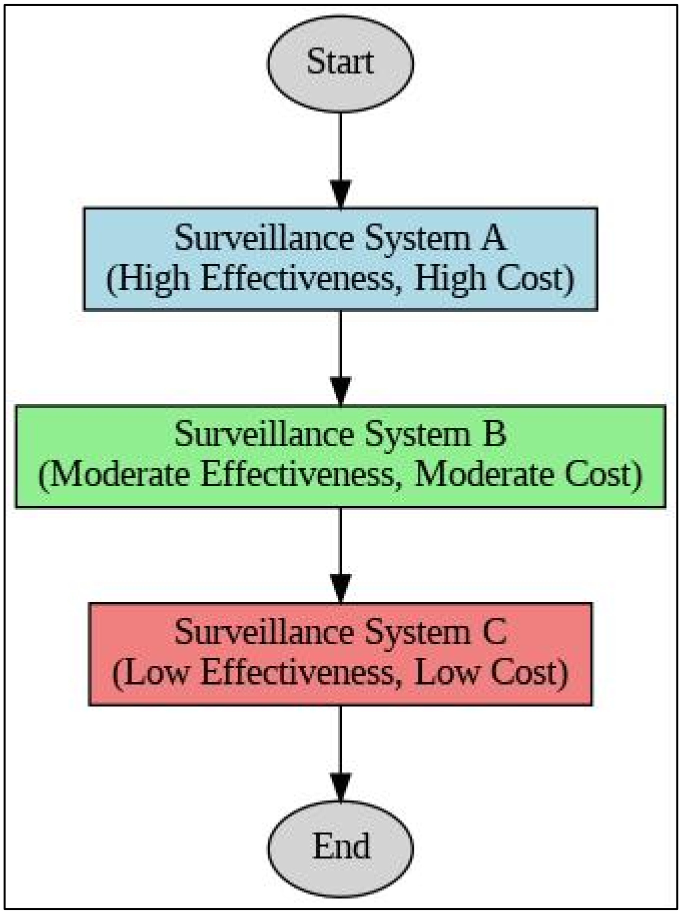


Figure 2: the association, between the ICER, NMB and BIA of various surveillance systems

This number is a graphic illustration of the comparison of surveillance systems by their cost-effectiveness attributes. Lower ICER and higher NMB systems are cheaper to operate and provide superior health outcomes at a reduced cost.

## 4. Costing Surveillance

In determining the cost-effectiveness of surveillance systems, one must be aware of the different perspectives, cost components, and methodology applied to determine cost of a surveillance program in totality. Effective costing is important so that the policy makers can establish whether it is worthwhile to implement a surveillance system in relation to the costs incurred.

### 4.1 Perspectives for Costing: Health System vs. Societal

Two main perspectives are possible when computing the cost of a surveillance program, which include the health system perspective and the societal perspective (Lipsitch et al., 2022).

The health system perspective looks at the immediate expenses incurred by the healthcare system i.e. the health facilities, staffs and resources that are allocated to surveillance activities. The operation and management of surveillance systems in the health sector are directly connected to these costs (Cookson et al., 2022). As an example, it can cover the expenditures on diagnostic tests, lab operations, and healthcare personnel working on the gathering of surveillance data.

The societal view on the other hand is a more expansive view, which considers both the direct cost of the health system and the indirect cost which has the impact to the society at large. Such indirect costs are the loss of patient productivity, the cost of travel to people who receive care or surveillance services as well as economic disruption because of public health measures like quarantine or travel bans (Gonzalez et al., 2023). The point of view is more holistic, as it encompasses not only healthcare but social costs or savings in general.

These two views are significant and depending on the depth of analysis and the audience, one can pick either of these views. Government or healthcare agencies can be more suited to the health system perspective, whereas in an economic analysis, the societal perspective is desired in order to estimate the overall impact of surveillance programs on the entire society (Nguyen et al., 2022).

4.2 Cost Components: Capital Costs, Recurrent Costs, Personnel Costs, Overheads, and Integration Costs

Costing a surveillance system involves categorizing various components to fully understand its financial requirements. These components can be broken down into the following categories:

- **Capital Costs**: The capital costs refer to the expenses that are incurred by a surveillance system once it is put into operation. They usually involve the price of equipment acquisition (e.g., diagnostic tools, computers, and data storage), infrastructure establishment (e.g., laboratories, offices), and the development of the software (Gonzalez et al., 2023). Capital costs are made during the initiation of the surveillance program but it might not be an annual occurrence.
- **Recurrent Costs**: Recurrent costs are the constant costs that are incurred during the years of operation of the surveillance program. Some of them are costs on consumables (e.g., test kits, reagents), software license renewal, and equipment maintenance. Operation costs such as collecting data, processing samples, and reporting are also recurrent costs (Smith et al., 2021).
- **Personnel Costs**: These expenses comprise of the salaries and benefits of employees who will be engaged in the surveillance program. This can consist of healthcare workers, epidemiologists, lab technologists, data analysts and other administrative employees that participate in managing and conducting surveillance operations (Paltiel et al., 2022). One of the biggest recurrent costs in surveillance programs is usually personnel costs.
- **Overheads**: Overheads are the indirect expenses of maintenance of the surveillance system. These may entail administrative costs (facility management, utilities (electricity, water), office supplies and other operational support costs that are required to keep the system operating but which cannot be directly linked to surveillance activities (Cookson et al., 2022).
- **Integration Costs**: These costs are the cost of integration of the surveillance system with other health systems, databases and technologies. The cost of integration can be the development of interoperability among various software systems, the training of employees on how to operate integrated systems, and the data sharing between platforms (Gonzalez et al., 2023).

4.3 Methodology for Costing Surveillance Programs

The costing approach to surveillance program entails direct and indirect costing approaches. The calculation of the cost of surveillance follows the steps as follows:

1. **Identification of Cost Components**: The initial process in the methodology is to define all the cost components that are of relevance such as capital, recurrent, personnel costs, overhead costs, and integration costs (Nguyen et al., 2022). All these elements ought to be charted against definite activities or phases within the surveillance system.
2. **Data Collection**: The second step will be to collect data on the costs of both components. This can be in the form of checking financial statements, conducting interviews with stakeholders (e.g., program managers, healthcare workers), or carrying out surveys to approximate the direct and indirect costs of surveillance activities (Paltiel et al., 2022).
3. **Cost Allocation**: Once the costs are identified, it is then time to organize the costs to particular surveillance activities. As an example, one can attribute to the processing of samples in the laboratory the cost of the tests, and to the field data collection and analysis the personnel costs (Gonzalez et al., 2023). This measure will make certain that every cost is assigned to the appropriate activity and it will be easier to calculate the total costs more accurately.
4. **Animalization of Capital Costs**: Capital costs are one-time costs and hence, they should be annualized to give the true comparison with recurrent costs. This is usually achieved through an amounting of the capital expenses divided by the anticipated life of the equipment or infrastructure (Macdonald et al., 2022).
5. **Incorporation of Opportunity Costs**: Opportunity costs are the benefits that are sacrificed when one allocates resources on an activity in lieu of another. In this case, the price of spending on healthcare professionals redirecting their attention towards surveillance activities can be included in the costing approach (Lipsitch et al., 2022).
6. **Sensitivity Analysis**: Lastly, Sensitivity analysis must be done to determine the uncertainty in the cost estimates. This can include different key assumption (e.g., personnel costs, integration costs) to understand the sensitivity of the results to cost component changes (Cookson et al., 2022). The table below gives a summary of the cost elements of a surveillance program.

Table: Cost Components of Surveillance Programs

| Cost Component | Description | Examples | Cost Type |
|---|---|---|---|
| **Capital Costs** | One-time costs for establishing the surveillance system | Equipment purchase (e.g., diagnostic tools, computers), infrastructure setup (e.g., labs) | One-time costs |
| **Recurrent Costs** | Ongoing costs for maintaining the surveillance system | Consumables (e.g., test kits, reagents), maintenance of equipment, renewal of software licenses | Ongoing costs |
| **Personnel Costs** | Salaries and benefits for staff involved in surveillance | Salaries for epidemiologists, lab technicians, data analysts, and administrative staff | Ongoing costs |
| **Overheads** | Indirect costs of running the surveillance system | Facility management, utilities (electricity, water), office supplies | Ongoing costs |
| **Integration Costs** | Costs for integrating surveillance systems with others | Interoperability between different software systems, staff training, data sharing | Ongoing costs |

The next figure is the correlation of the various components of the cost and the contribution they would make to the total cost of a surveillance system. This chart indicates the cost breakdown and the balance between capital costs, recurrent costs and personnel costs in a normal surveillance program.

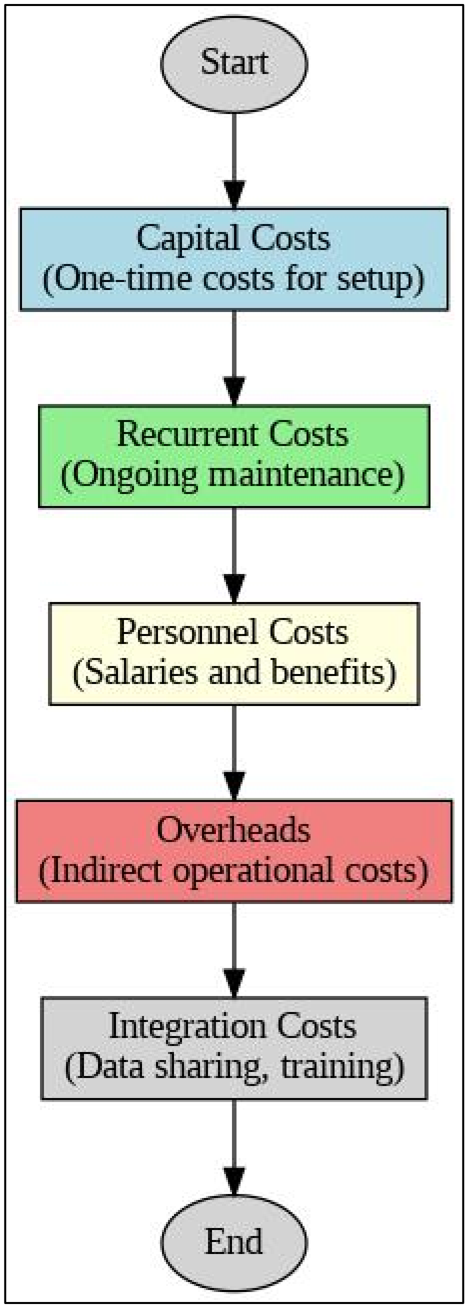


Figure 3: correlation of the various components of the cost and the contribution they would make to the total cost of a surveillance system.

This figure is capable of providing a graphic illustration of how all the different cost factors would combine with one another in the overall costing procedure of surveillance programs.

## 5. Study Designs and Modeling Approaches

The manner of this study design and modeling methodology play very important roles in the conduct of the process of surveillance systems or health interventions evaluation. The selected model must display the nature of the disease transmission, behavioral mechanisms of a human being and the accessible information. This section brings forth the different study designs such as the static models, dynamic transmission models and agent based models and how Value of Information (VOI) can be applied in the process of doing a study design.

### 5.1 Choosing the Right Study Design

The study design is chosen based on the nature of the disease and information available, as well as, the objectives of the surveillance mechanism. The most popular study designs that are employed in the public health modeling are the mostly the static model, dynamic transmission model and agent-based models.

- **Static Models**: The simplified and non-temporal models that introduce the connection between the input parameters and the result are referred to as the static models (Nguyen et al., 2022). The models are applicable in describing the inherent dynamics of a disease or intervention effect spread in fixed conditions. These are less complex to work with, and they do not consider time-dependent dynamics and measures such as vaccination or quarantine that might play a significant role in the case when the diseases can arise rapidly (Lipsitch et al., 2022).
- **Dynamic Transmission Models**: Unlike the staid models, the dynamic transmission models also take into account the changes with time i.e. change in spread of diseases with time. They are mathematical models that are used to understand infectious diseases in a population, including Susceptible-Infectious-Recovered (SIR) models or more complicated compartmental models (Macdonald et al., 2022). They require dynamic models to evaluate the effect of intervention, e.g. vaccination or social distancing, on the disease spread. They model how interstate movement change depends on time, and are more realistic in the real-world when the disease burden changes (Paltiel et al., 2022).
- **Agent-Based Models (ABMs)**: ABMs are models of population that are characterized by agents (i.e., persons or objects) that interact in a simulated environment, and at a particular moment every agent has a set of defined behaviors based on certain rules (Gonzalez et al., 2023). ABMs perform well in those scenarios when involved are the complex systems and the heterogeneity and the individual behavior become of much importance in propagating the disease. A certain part of the interventions, including contact tracing or vaccination targeting, can be modeled with such models and the effect of such an intervention on the dynamics of a disease in a population considered. ABMs consume a significant amount of computer resources but will give detailed details regarding how people behave and how it impacts the spread of diseases.

### 5.2 Decision Trees and Transmission Models for Dynamic Scenarios

Transmission models and decision trees may be handy to be informed with the analysis of dynamic situations in the surveillance and intervention of the diseases.

- **Decision Trees**: Decision trees are quite simple and straight forward approach to the assessment of the potential outcome of a number of interventions. They can also be applicable in a disease surveillance setting where one has to decide based on the most appropriate course of action in the face of a myriad of uncertainties that encompass the eventuality of an outbreak or the efficacy of a particular intervention (Macdonald et al., 2022). Such branches are the possible alternatives or outcomes which are shown in the tree and the tree-like structure allows one to picture the trade-offs of the various strategies i.e. testing, quarantine or vaccination.
- **Transmission Models**: Transmission models are commonly used along with decision trees and they are used to model the transmission of diseases within the population over time. Transmission models put the human-environment relations into consideration and model the impact of behaviors, interventions, which presuppose the overall state of health and introduction of new pathogens in the dynamics of the disease (Smith et al., 2021). These models can include the contact rates, infectiousness as well as population density and they are specifically considered in the dynamics of the effect of changes in a population over time in the respect of the spread of a disease.

5.3 Value of Information (VOI) and How It Guides Study Design

Value of Information (VOI) plays an important role in the study of decision and assists in the design of the studies and focus research on the priority. VOI is used to evaluate the worth of an additional information that will be included in the decision-making process (Paltiel et al., 2022). VOI is the information of the area that is dedicated to be able to minimize uncertainty and maximize the results that calculate the expected good of obtaining new information.

Using VOI to the example of surveillance, this tool could be used to determine the uncertainties of the disease transmission model that might be resolved because of the utilization of additional research or data collection. An example is when the rate of an unknown disease transmission is unknown, then it could be the case that the VOI analysis might prove the need of the study to estimate this parameter more accurately since the increase in accuracy will form a cornerstone of the affectiveness of interventions (Gonzalez et al., 2023). VOI assists researchers and policymakers to emphasize most on the studies that will offer maximum returns to the investment in the scenario of enhancing the outcomes of the health life of the people. The table of the key points and use in most popular methods of public health surveillance are compared below:

Table 4: Comparison of Modeling Approaches

| Model Type | Key Features | Applications | Strengths | Limitations |
|---|---|---|---|---|
| **Static Models** | Non-time-dependent; simplified assumptions | Basic disease spread models, cost-effectiveness analysis | Simple to implement, requires less data | Does not account for time dynamics, oversimplified |
| **Dynamic Transmission Models** | Time-dependent; simulates disease spread over time | Disease outbreaks, vaccination campaigns, intervention analysis | Accounts for time, population interactions, and interventions | Requires large data sets and computational resources |
| **Agent-Based Models** | Individual-based, heterogeneous agents with specific | Detailed simulation of individual | High granularity and individual-level detail | Computationally expensive, requires significant data and |

| | | | | |
|---|---|---|---|---|
| | behaviors | behaviors and complex systems | | resources |

The diagram below gives a visual illustration of the relationship between different modeling approaches and the complexity of the dynamics of the disease:

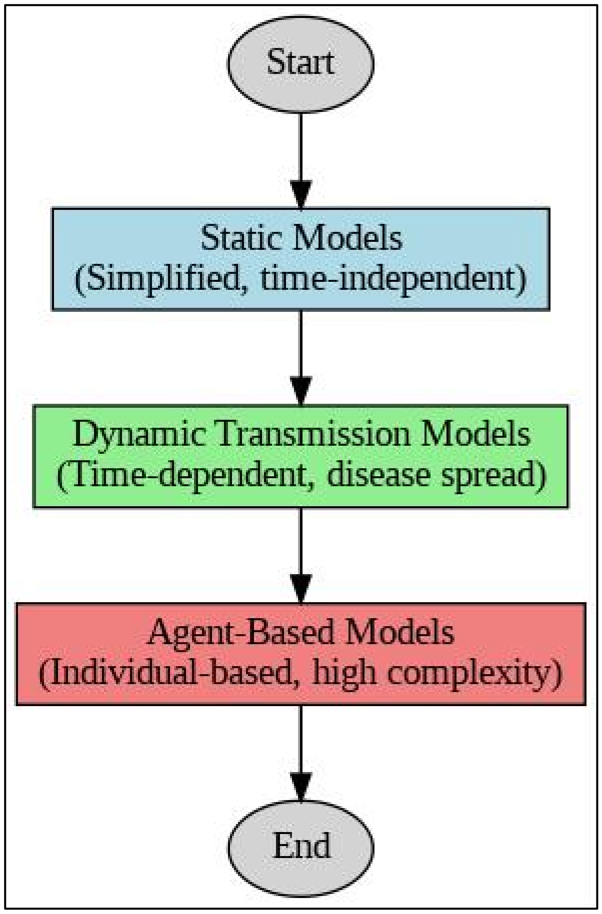


Figure 4: visual illustration of the relationship between different modeling approaches and the complexity of the dynamics of the disease

This character shows the levels of modeling techniques where the simplest and least complex in modeling is the static models, the dynamic transmission models and the most detailed agent-based models which provides the most detailed model of the individual level simulation.

**6. Measuring Performance Parameters**

Case ascertainment, timeliness, geographic coverage, sensitivity and specificity are the most significant parameters which should be measured to measure the efficiency of a surveillance system. The information these parameters will give will be relatable in the identification of cases, the response of the system to the outbreak, and coverage of different areas by the system. It will be argued that the surveillance system will be in a position to detect and track any health threats and therefore, proper measurement will guarantee that the health of the people will still be enhanced effectively.

6.1 How to Measure Surveillance Effectiveness

Case ascertainment entails the capability of the system to identify and report all prevalences of a disease among the populace. This can either be assessed by comparing the reported cases with the actual cases, which can be established by either using a retrospective study or a gold standard diagnostic test (Paltiel et al., 2022). Timeliness is an attribute of a surveillance system performance and reporting of disease cases. It is crucial in the control of the infectious diseases as any postponement may result in an epidemic. The time between the symptom onset and reporting can be called timeliness and can be measured with the help of timeliness index (Smith et al., 2021). The area size where the surveillance system operates is such that all the areas where the disease may spread is covered. It can be estimated with the help of comparing the territory of the geographic coverage of observation areas and the location where the diseases actually happen, and no areas should be neglected (Nguyen et al., 2022). Lastly, the system can be assessed in terms of its sensitivity and specificity to determine the true positive and the true negative cases respectively that can be verified by comparing it to other sources of information (Gonzalez et al., 2023).

6.2 Sources for Obtaining These Data and Validation

The sources that can be used in gathering the needed data to ascertain the effectiveness of the surveillance are hospitals, clinics, labs and even the public health agencies since they can access the case report, diagnostic tests as well as the health records at that level. Field validation and retrospective studies are highly feasible in establishment of the case that have been currently confronted since the current historical records or community survey can be utilized to determine the number of cases that are actually occurring and thus confirm the entirety of the reporting system. Another option is to compare the data with other surveillance systems or databases and, therefore, cases reported are in line with the real-life prevalence of the disease (Lipsitch et al., 2022). The surveys and interviews with the medical workers and health officials would also come in handy to know more about the effectiveness of surveillance in practice and act in relation to the aspects of reporting and data collection that could be improved (Macdonald et al., 2022). The table presented below describes the key performance parameters that can be used to measure the effectiveness of surveillance:

Table : Key Performance Parameters of Surveillance Systems

| Performance Parameter | Description | How to Measure | Validation Methods |
|---|---|---|---|
| **Case Ascertainment** | Ability to detect and report all cases of a disease | Compare reported cases to actual cases (via retrospective studies, diagnostic testing) | Retrospective studies, gold standard tests, validation surveys |
| **Timeliness** | Speed of detection and reporting | Time interval from onset to reporting | Timeliness index, comparison with historical data |
| **Geographic Coverage** | Extent to which all areas are monitored | Compare surveillance regions to disease distribution | Field validation, comparison with geographic maps |
| **Sensitivity** | Proportion of true positives correctly | Sensitivity = True Positives / (True Positives + False | Cross-validation, comparison with other |

| | | | |
|---|---|---|---|
| | identified | Negatives) | surveillance systems |
| **Specificity** | Proportion of true negatives correctly identified | Specificity = True Negatives / (True Negatives + False Positives) | Cross-validation, comparison with laboratory tests |

Timeliness to case system the figure below demonstrates the correlation between timeliness and case ascertainment in surveillance systems. A highly timely system, hopefully, will be a highly ascertained system as well, but in other instances, systems that are more focused on speed might omit some cases. The figure represents the tradeoff between the two factors.

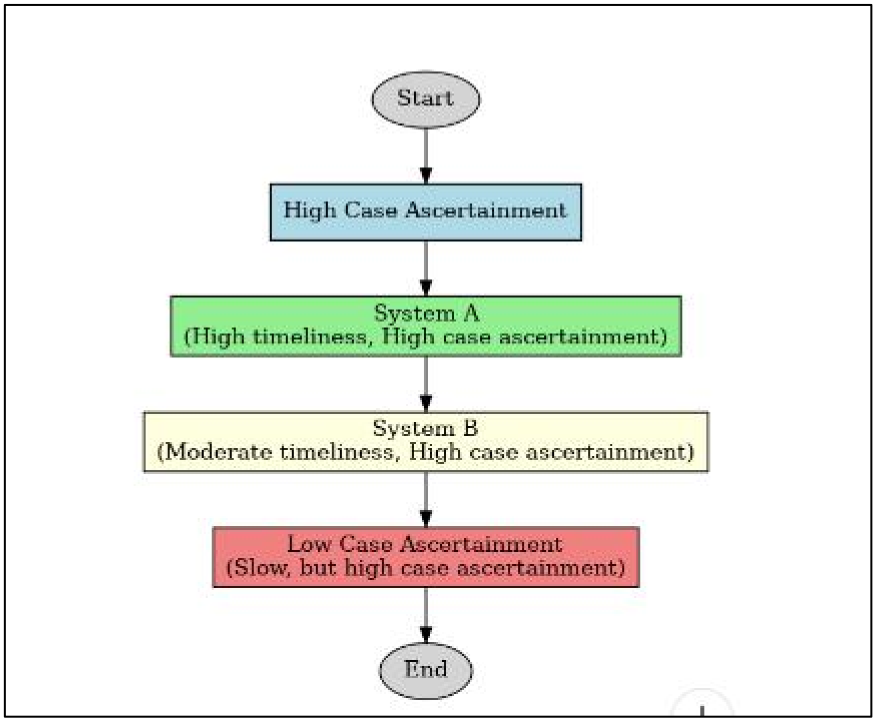


Figure : two possible scenarios of the surveillance systems

This figure displays two possible scenarios of the surveillance systems; one with a high emphasis on timeliness, and lacks a few cases, and one with a high case ascertainment, but slow in reporting about the cases.

## 7. Equity and Ethics

7.1 Importance of Considering Equity in Surveillance Systems

The explanation as to why the surveillance systems will be fair is that the target of the interventions should be the total groups within the population and that here the most vulnerable groups would be the marginalized groups or groups of people that occupy low-resource geographical areas. The surveillance that fails to address the question of equity may lead to the introduction of a state of inequity in health due to the lack of the members of certain groups of people to the surveillance (or insufficient access) to the surveillance especially during outbreaks (Paltiel et al., 2022). Equity ensures that all communities regardless of their geographical location and socio-economic status equally share the surveillance resources and reporting processes and health intercessions. It is necessary to add that equitable surveillance is central to the work of the public health systems since it helps to boost the level of trust, reduces health disparities, and provides an opportunity to allocate the health resources based on the needs, which, eventually, results in the population-wide improvement of health outcomes (Nguyen et al., 2022).

7.2 Distributional Cost-Effectiveness Analysis (DCEA)

Distributional cost-effectiveness analysis (DCEA) is an advanced form of analysis that does not entail evaluating the cost-effectiveness of a surveillance program but the distributional effect of the intervention with reference to different populations. DCEA will help prioritize the interventions that influence the poor or high-risk group and this will result in the resources being allocated in a manner that generates minimal inequalities (Cookson et al., 2022). DCEA is also preoccupied with the benefits of benefits such as low mortality rates or prevention of disease to maintain that, in addition to the surveillance interventions, they are also equally fair. One of them is a surveillance system that targets vulnerable populations, it may be more costly but results in greater benefits to the populations, which will result in the fairness of the health of the entire population (Lipsitch et al., 2022).

Table : DCEA and Equity Considerations

| Consideration | Description | Example |
|---|---|---|
| **Cost-Effectiveness** | Evaluates the efficiency of interventions in terms of costs and health outcomes. | A cost-effectiveness analysis of vaccination campaigns for flu prevention in high-risk populations. |
| **Equity** | Assesses how benefits and costs are distributed among different population groups. | DCEA prioritizing interventions for rural or underserved communities in outbreak management. |
| **Opportunity Cost** | Considers the alternative uses of resources allocated to surveillance. | Evaluating whether resources could achieve greater health outcomes if directed elsewhere. |
| **Health Gains in Vulnerable Populations** | Focuses on maximizing health benefits for high-risk or marginalized groups. | Targeted surveillance programs for migrant populations with higher disease incidence. |

7.3 Ethical Considerations in Surveillance Systems

Surveillance systems are a delicate matter regarding the ethical issues as in most cases, it involves gathering and processing of sensitive health information that could infringe upon the privacy and autonomy of an individual. One of the biggest ethical issues is privacy since health information of people should not be misused or accessed by a person who should not. This will save the trust in the system as people will realize how their data will be used and will be willing to participate on a voluntary basis, which can be assured by informed consent (Gonzalez et al., 2023). The other ethical danger is stigmatization especially when the surveillance is conducted on socially stigmatized illnesses. An example is that people with such conditions as HIV or tuberculosis can also be discriminated, and the surveillance systems should reduce the risks of stigmatization, which makes the system anonymous and confidential (Macdonald et al., 2022). These ethical considerations should be always remembered to make sure that the surveillance systems are not only supposed to work well but also be fair and considerate of the right of the people. The provided table of risk is a summary of the ethical risk of a surveillance system according to the graph presented in the above graph. The table depicts all the risks, consequences that could occur and the degree of ethical risk.

| Ethical Risk | Description | Potential Consequences | Risk Level |
|---|---|---|---|
| **Privacy Concerns** | High risk of data breaches and misuse of sensitive health data. | Breaches of confidentiality, unauthorized data access, loss of trust in public health systems. | **High Ethical Risk** |
| **Stigmatization** | Surveillance may inadvertently lead to social exclusion or discrimination. | Marginalization of affected individuals or groups, social and psychological harm, reduced participation in health programs. | **High Ethical Risk** |
| **Informed Consent** | Lack of transparency about how data will be used and lack of explicit consent. | Erosion of trust, reduced willingness to participate in surveillance systems, legal and ethical violations. | **Moderate Ethical Risk** |
| **Low Ethical Risk** | Systems that balance the needs for data with respect for privacy and consent. | High public trust, active community engagement, enhanced cooperation for disease prevention. | **Low Ethical Risk** |

## 8. **Disease-Specific Considerations**

### 8.1 Tailoring Surveillance Strategies for Different Diseases

Different types of diseases should be contained through the surveillance strategies, which should be tailored. Likely, such cases as acute respiratory infections (ARIs) will demand a massive and rapid surveillance since they can easily propagate and cause catastrophic outbreaks. Syndromic surveillance (i.e. monitoring symptoms) and lab-check is the best solution in case of ARIs, e.g. influenza or COVID-19, as this disease is not recognized early enough and the required decisions are made (Lipsitch et al., 2022). Moreover, contact tracing and quarantine can also be used to contain the spread in the high-risk regions especially the medical facilities and the busy places.

In vaccine prevention diseases, such as the one of measles or polio, a high vaccination rate is monitored in surveillance and epidemic outbreaks of the under-vaccinated population. In the given instance, surveillance can be associated with controlling the vaccination rate with the assistance of the regular reporting mechanisms and introducing serological tests that would assist in determining the level of immunity among the populations (Macdonald et al., 2022). Vaccination program, in its turn, must be combined with the vaccine-preventable diseases surveillance systems to detect the gaps and make sure that the timely immunization campaigns are organized particularly in the area with high threats or low coverage.

Other environmental considerations during the surveillance include the mosquito breeding grounds in the case of the disease which can be spread with the aid of the vectors, malaria, dengue, and Zika. The surveillance plans usually involve control over vectors, environmental surveillance and entomological surveillance to monitor the existence of the same vectors which transmit the disease. Human case reporting, serological testing, and geospatial analysis are the strategies that assist these measures in predicting the background of disease outbreaks and control its spread (Nguyen et al., 2022).

Lastly, the surveillance strategies during antimicrobial resistance (AMR) are to monitor the patterns in the pathogen resistance to antibiotics, the usage of antibiotics in the medical field and animal field and their movement across and within areas. The national and regional surveillance systems that monitor AMR can inform the treatment prescriptions with the help of the special measures, decrease the excessive use of antibiotics, and eliminate the emergence of the resistant infections (Gonzalez et al., 2023). This kind of surveillance normally involves a longitudinal data and interactions amongst human, animal as well as environmental health departments.

8.2 Disease-Specific Considerations in Choosing Surveillance Methods

When selecting the surveillance processes, the nature of the disease is very important. As an illustration, acute respiratory infections need quick surveillance tools, including syndromic surveillance and laboratory testing to distinguish insects (Paltiel et al., 2022). On the contrary, diseases such as vaccine-preventable diseases can be more dependent on routine immunization records and serological surveys and testing can be used to determine the level of immunity in a community.

In the case of the vector-borne diseases, there is a lot of entomological surveillance and geospatial analysis which is performed to determine the hotspots and the predicted areas of risk of the disease. This is supplemented by human case reporting to monitor reality of disease incidence. Moreover, climatic information is typically considered in the process of surveillance related to the spread of diseases caused by vectors to evaluate the impact of environmental conditions on the disease (Macdonald et al., 2022).

In matters of antimicrobial resistance, the surveillance of resistance ought to involve laboratory based testing on the resistance profile, pharmacy records to monitor the use of antibiotics and genomic surveillance to learn about the genetic origin of the resistance. Besides, the hospital surveillance systems are to be connected with the regional and national AMR monitoring networks to learn the way the resistance patterns change with time (Lipsitch et al., 2022). The table given below summarizes the best surveillance techniques to be used in various categories of diseases.

Table: Surveillance Methods for Different Disease Types

| **Disease Type** | **Recommended Surveillance Methods** | **Key Data Sources** | **Special Considerations** |
|---|---|---|---|
| **Acute Respiratory Infections** | Syndromic surveillance, laboratory testing, contact tracing, quarantine measures | Hospital case reports, laboratory data | Rapid detection needed for outbreak control |
| **Vaccine-Preventable Diseases** | Routine immunization monitoring, serological surveys, outbreak investigations | Immunization records, serological surveys | Focus on vaccination coverage and gaps |
| **Vector-Borne Diseases** | Entomological surveillance, human case reporting, environmental monitoring, geospatial analysis | Mosquito density data, environmental factors | Need to consider climate and vector breeding sites |
| **Antimicrobial Resistance** | Laboratory-based testing, antimicrobial usage data, genomic surveillance, cross-sector collaboration | Hospital surveillance, pharmacy records, genomic data | Requires integrated surveillance across human, animal, and environmental sectors |

Figure: Surveillance Methods Tailored to Disease Types

The following figure illustrates how different surveillance methods are aligned with disease-specific characteristics:

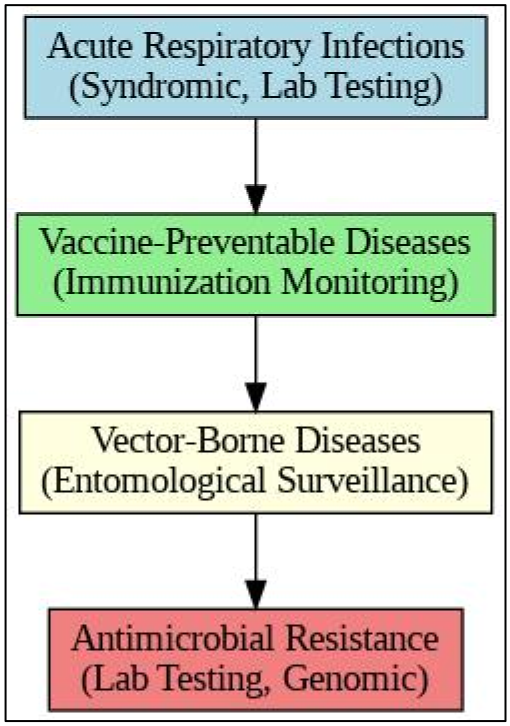


Figure : different surveillance methods are aligned with disease-specific characteristics

The number can assist in visualizing the level of alignment of surveillance approaches with the type of disease indicating that various diseases may mandate distinctive strategies and approaches to be effectively tracked and intervened with.

## 9. Cost-Effectiveness Analysis (CEA)

### 9.1 Introduction to Cost-Effectiveness Analysis

Cost-Effectiveness Analysis (CEA) is a common approach to the subject of public health and healthcare to determine the relative value of interventions by referencing the costs and outcomes. The main aim of CEA is to determine the interventions that have provided the best results at the lowest cost and this will be important information that can be used to make policy decisions. Within surveillance systems, CEA assists in identifying the most cost-efficient surveillance systems in terms of detecting, preventing and controlling threats to public health, e.g. infectious diseases, antimicrobial resistance (AMR) or vaccine-preventable diseases.

The smaller the ICER, the higher the value of money an intervention has in health benefits per unit of money. The analysis assists the policymakers and professionals working in public health to know what interventions to focus their interests in case of limited resources.

9.2 Key Components of CEA

To conduct a credible CEA, there are a number of important elements that must be taken into account. These are cost data, effectiveness data, and modeling approach. The cost data must include the direct and indirect costs such as the cost of staffing, technology, training, and the cost of running the business. This expense information is usually gathered by means of budget reviews, financial reports and cost reports of implementing agencies.

Effectiveness data are the health consequences of the intervention (e.g. the number of cases averted, deaths prevented, or health-related quality of life (e.g. Quality-Adjusted Life Years (QALYs)) improved). Other metrics of the efficacy of surveillance systems can also be the timeliness of detection, the precision of the data, and the coverage of the system.

Lastly, modeling approach is also an important part of CEA, as it assists in simulating the results of different interventions in the long run. The common strategies are the use of the static models, which assume the estimation of outcomes at a point in time and the dynamic models that simulates the progress of disease spread and interventions over time. The behavior of individuals or agents in a population can also be modeled using agent based models to determine the impact of various interventions.

9.3 CEA for Surveillance Systems

To illustrate this, we shall give an example of two surveillance systems to track acute respiratory infections (ARIs), like influenza. Surveillance A: A rapidly responding system, which detects and reports ARI cases in the first 24 hours, is less accurate and has higher false-positive results. Surveillance B, however, is less accurate but more time consuming (approximately 48 hours) B to report cases.

| Surveillance System | Implementation Cost | Effectiveness (Cases Averted) | ICER Calculation |
|---|---|---|---|
| **Surveillance A** | $500,000 | 1,000 | - |
| **Surveillance B** | $600,000 | 1,200 | $500 per case averted |

In this case, the less costly system is Surveillance A, yet it is not as effective at averting cases of ARI. Surveillance B is costlier but has a greater health benefit in averting cases. ICER of Surveillance B will be 500 dollars in total per case averted; the cost per case averted 500 dollars will be added to the cost of Surveillance B per case averted.

This straightforward shows how CEA can assist the decision-makers in calculating the incremental cost versus the incremental health benefits of various interventions.

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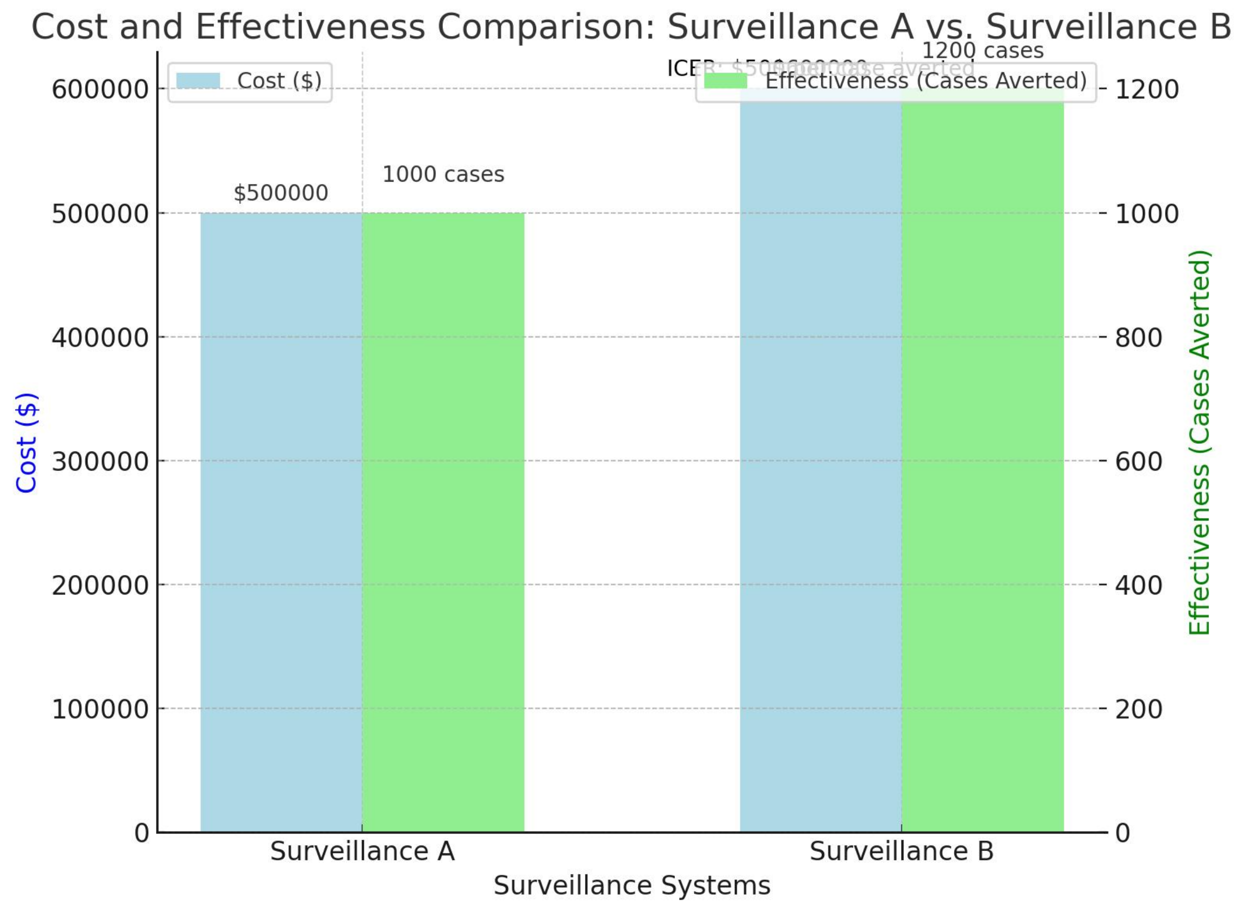


Figure 7: CEA can assist the decision-makers in calculating the incremental cost versus the incremental health benefits of various interventions

Cost-Effectiveness Comparison

The following graph shows the way in which the cost-effectiveness of Surveillance A and Surveillance B can be compared. The graph indicates costs and effectiveness of the various surveillance strategies and assists the decision-makers to have a visual representation of the trade-offs between the cost and the health benefits.

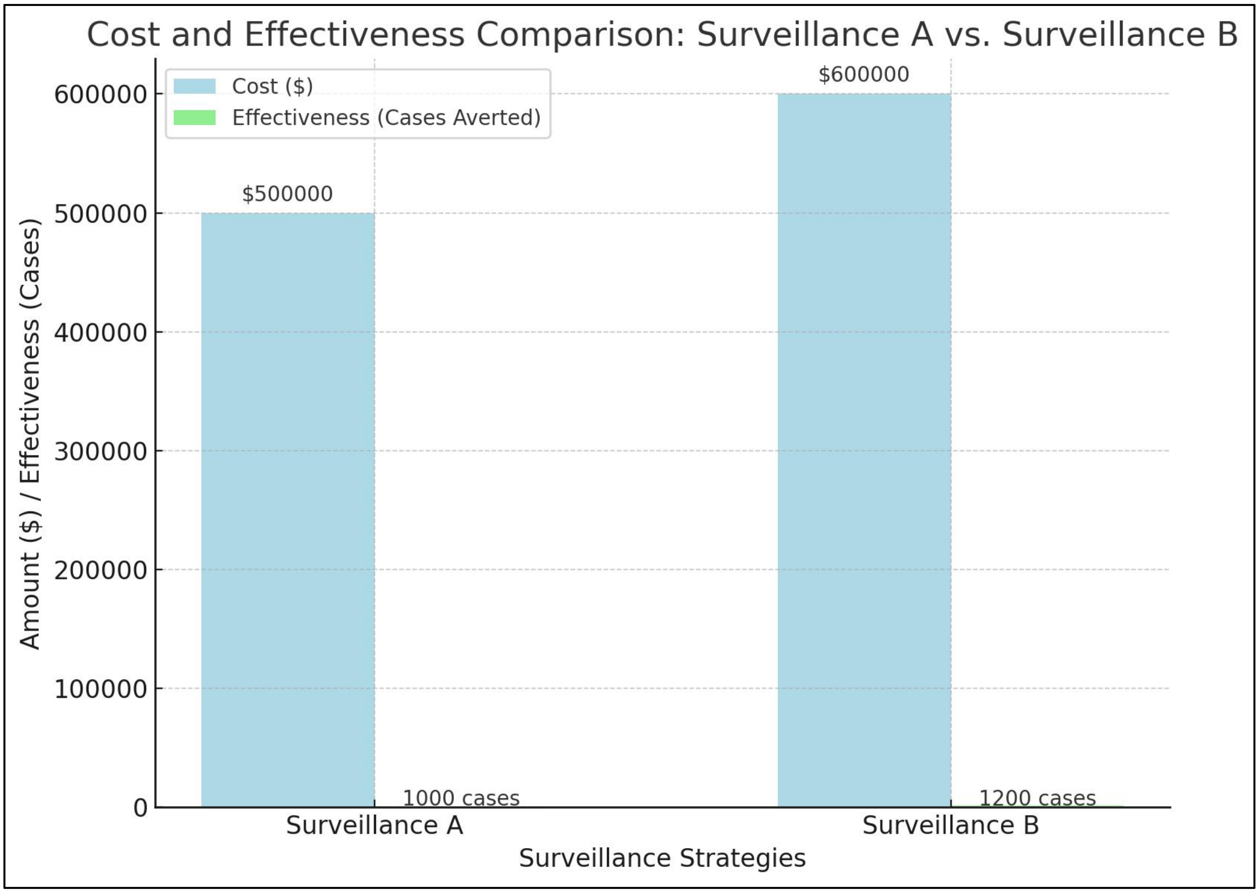


Figure 8: cost-effectiveness of Surveillance A and Surveillance B can be compared.

Such graph shows that Surveillance B will be more costly, but the health benefits of this measure are higher as it will eliminate more cases of ARI. The ICER ($500 per case averted) indicates the extra cost of each extra case that Surveillance B will prevent in comparison with Surveillance A.

9.5 Importance of Sensitivity Analysis in CEA

Sensitivity analysis is one of the most important actions to undertake when carrying out a CEA. Sensitivity analysis is used to find out how the ICER and the concluding analysis will vary at the other end when the key assumptions or inputs of the analysis are varied. Indicatively, the price of the surveillance system in place or the efficiency percentage of the detection system might change over the years or in various locations. Sensitivity analysis enables the decision-makers to determine the effect that some uncertainty in the data would have on the findings.

Table: Sensitivity Analysis Results for ICER

| **Parameter** | **Base Case ICER ($/case averted)** | **Adjusted ICER ($/case averted)** |
|---|---|---|
| **Cost of Surveillance** | $500 | $450 |
| **Effectiveness (Cases Averted)** | $500 | $550 |
| **Cost of Treatment** | $500 | $600 |

This table shows how varying cost or effectiveness can cause the ICER to change and this offers important information on the strength of the findings to changing assumptions. The ICER will be better in case of the change in the price of the Surveillance B downwards or the effect is higher, making the intervention more cost-effective.

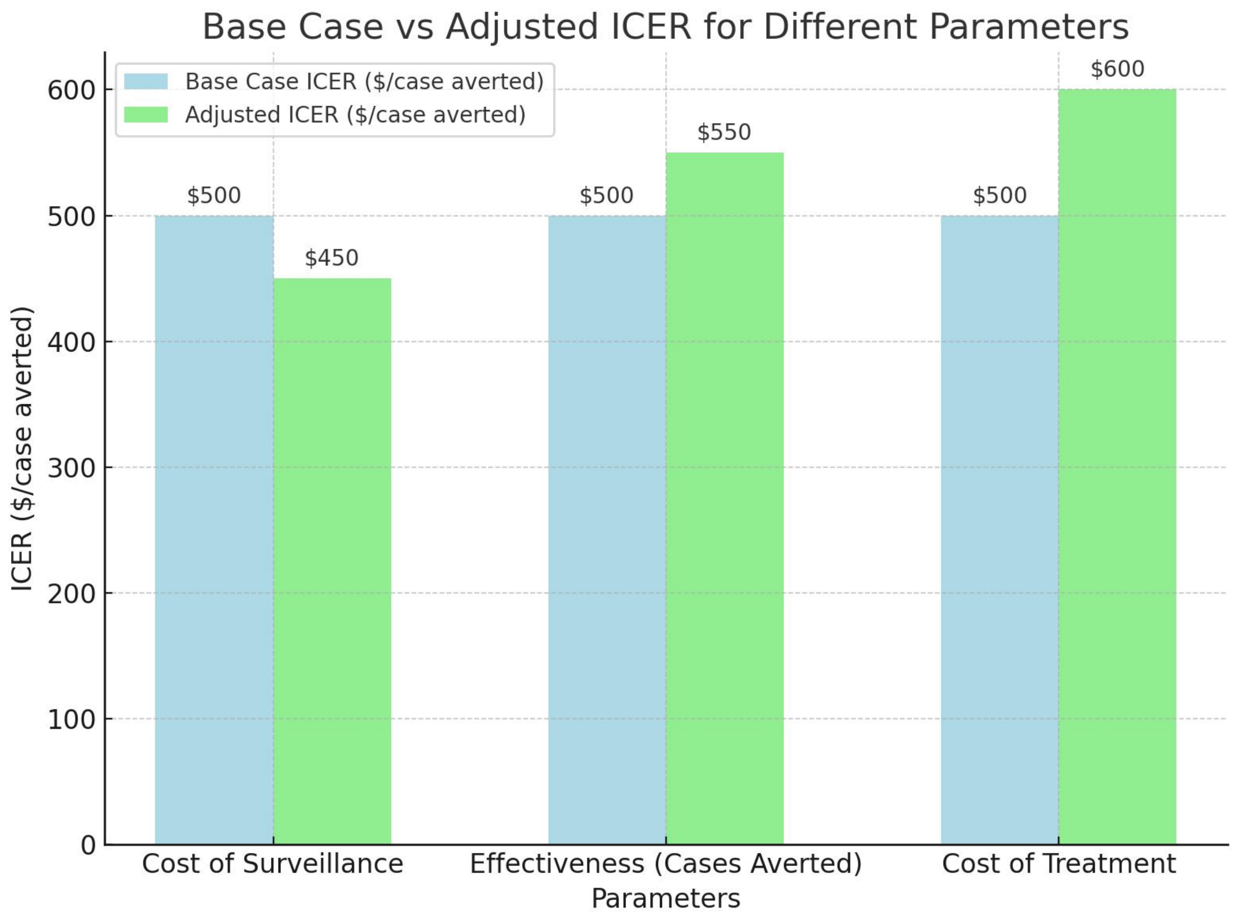


Figure 8: cost or effectiveness can cause the ICER to change and this offers important information on the strength of the findings to changing assumptions

## 10. Illustrative Results

In this section, we will present sample tables of surveillance strategies, results of the base-case, and important uncertainties. Such tables would enable reporting of the cost and the performance of the various surveillance systems in a transparent way that will enable comparing the strategies with ease. Being systematized in a routine manner, these tables could assist the stakeholders, namely, policymakers and researchers, to make wise decisions on how the resources are to be allocated and which surveillance systems are most cost-effective.

10.1 Surveillance Strategies

The comparison of the various surveillance strategies in monitoring acute respiratory infection (ARIS) will be given in the table below. The table will include the notable measures, including the price of implementation, effectiveness (cases averted) and incremental cost-effectiveness ratio (ICER) of each strategy. These are the steps that are critical in determining the value of every surveillance system as a whole.

| Surveillance Strategy | Implementation Cost | Effectiveness (Cases Averted) | ICER |
|---|---|---|---|
| **Surveillance A (Fast, Less Accurate)** | $500,000 | 1,000 | - |
| **Surveillance B (Moderate Speed, High Accuracy)** | $600,000 | 1,200 | $500 per case averted |
| **Surveillance C (Slow, High Accuracy)** | $1,000,000 | 1,500 | $667 per case averted |

This table provides a clear picture of the various surveillance systems, indicating the cost and effectiveness of the various strategies. It also computes the ICER to give information on the cost per case averted.

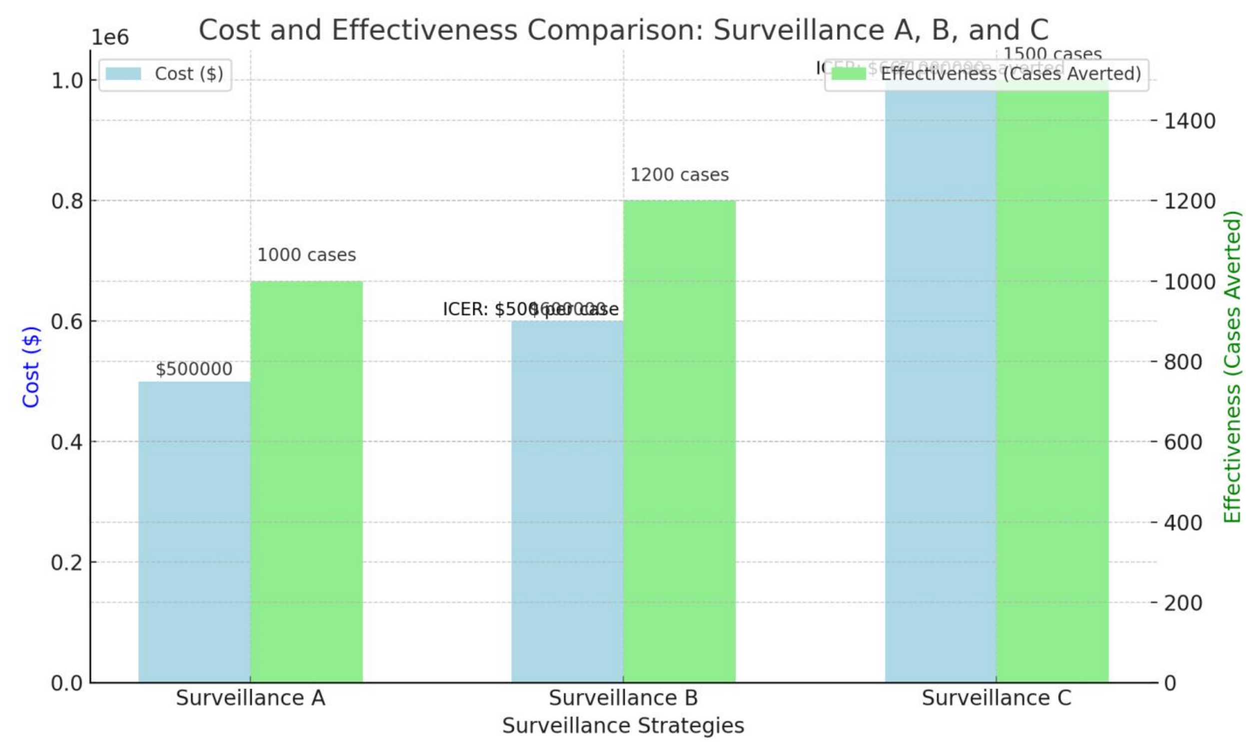


Figure 9: a clear picture of the various surveillance systems, indicating the cost and effectiveness of the various strategies. It also computes the ICER to give information on the cost per case averted

10.2 Base-Case Results for Surveillance Systems

The table presented below presents the pioneer results of the Cost-Effectiveness Analysis (CEA) of different surveillance strategies. The table critically compares the overall costs, effectiveness of each system of surveillance and the ICER.

| Surveillance System | Total Cost ($) | Cases Averted | Cost per Case Averted ($) | ICER ($/case averted) |
|---|---|---|---|---|
| **Surveillance A** | $500,000 | 1,000 | $500 | - |
| **Surveillance B** | $600,000 | 1,200 | $500 | $500 |
| **Surveillance C** | $1,000,000 | 1,500 | $667 | $667 |

The table of results below is a base-case results table that would indicate the total cost, effectiveness and cost per case averted of each surveillance strategy and can be easily compared. The ICER values also aid in the establishment of the most cost-effective system.

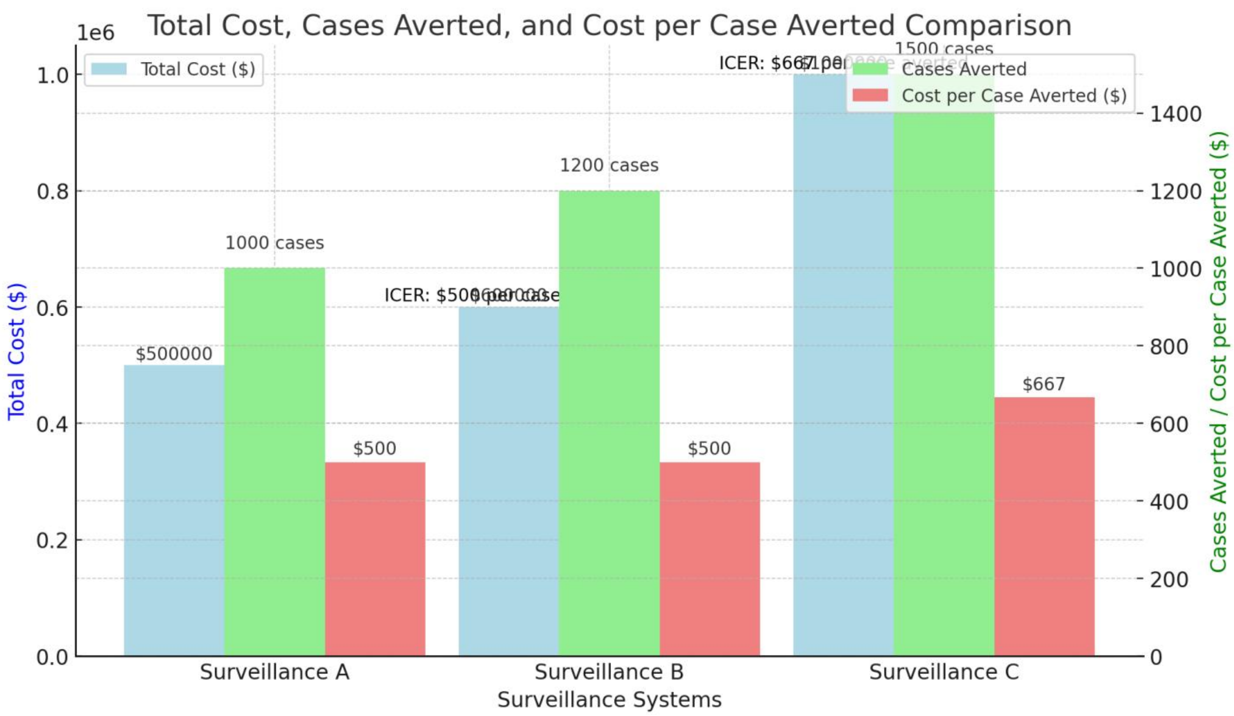


Figure 10: the total cost, effectiveness and cost per case averted of each surveillance strategy and can be easily compared

10.3 Key Uncertainties in Surveillance Systems

Any cost-effectiveness analysis, especially in the surveillance systems, has its uncertainty in it. The table below shows the main uncertainties that are likely to affect the ICER, and the overall cost-effectiveness of surveillance strategies. When these uncertainties are put into consideration, the policymakers will be able to make better decisions regarding the kind of system to adopt.

Table : Key Uncertainties in Surveillance Systems

| Key Uncertainty | Base Case ICER ($/case averted) | Adjusted ICER ($/case averted) | Impact on Decision |
|---|---|---|---|
| **Cost of Surveillance** | $500 | $450 | A decrease in costs improves the cost-effectiveness of the strategy. |
| **Effectiveness (Cases Averted)** | $500 | $550 | Increased effectiveness makes the strategy more cost-effective. |
| **Cost of Treatment** | $500 | $600 | Higher treatment costs reduce cost-effectiveness. |

This table shows that the main uncertainties (which include the cost or effectiveness changes) can influence the ICER and assist the decision-makers to interpret the sensitivity of the analysis to various assumptions.

**11. Discussion**

The cost-effectiveness of surveillance systems greatly relies on different factors including the disease under consideration, the country where the surveillance system is being put in place and the peculiarities of the surveillance system. The surveillance systems may not be effective and cost-effective when it comes to monitoring a particular disease. As an example, acute infectious diseases, such as influenza or COVID-19, demand that the systems have a high level of timeliness and a fast response, and they might be more expensive to purchase initially. Conversely, preventable diseases through vaccines such as measles are usually advantageous with surveillance systems to monitor the coverage of immunization, which can be cheaper in the long-run given the preventative nature of vaccination programs (Lipsitch et al., 2022).

Also, the price of surveillance systems depends on the healthcare infrastructure of the country. Surveillance systems in high-income countries have the capability to purchase advanced technologies and more thorough methods of data collection because healthcare systems are well-established. Conversely, some countries with low income may be limited in terms of resources and forced to use cheaper techniques such as syndromic surveillance or mobile health-related technologies to track disease outbreaks (Nguyen et al., 2022). The fact that these resources are limited, can affect the overall cost-efficiency of surveillance interventions, and it is imperative to adjust the surveillance strategies to the local environment and disease burden.

As an illustration, in those nations where the disease burden is very high and the healthcare infrastructure is limited, systems of surveillance that combine community health workers with less complex diagnostic tools might be more economical than more complex systems with high infrastructure demands. Nevertheless, in nations that have more access to resources, surveillance systems based on high-tech products like genomic surveillance or real-time data reporting could bring in high returns on investment due to a faster response to outbreaks (Macdonald et al., 2022).

The hybrid surveillance systems, or rather the integration of the various approaches and technologies, is also regarded as a more productive method of dealing with more complex health needs in the population. The systems constitute a combination of active surveillance, syndromic surveillance, sentinel surveillance and even the environmental data that will render us the entire spectrum of the disease dynamics. The incorporation of the various sources of information (e.g., human, animal and environmental health) might help to obtain a more in-depth understanding of the disease transmission and provide a more targeted intervention along with helping to develop more appropriate ones.

Such cases could include a vector-borne disease, like malaria or dengue, and would not only necessitate the human case reporting, but also entomological monitoring of the population of mosquitoes and to provide the high-risk areas. An interdisciplinary system of surveillance will help to predict the outbreaks more effectively and respond to them faster with the assistance of the data on vectors, environment, and human health (Gonzalez et al., 2023).

Further, a combination of data analytics and machine learning, as well as surveillance systems, would be of great use in enhancing efficiency and cost-effectiveness of the surveillance systems. The surveillance systems can give early warning signals using real-time information and prediction modeling and, consequently, can make proactive steps in intervening which are capable of averting the huge outbreaks. One example is mobile health data strategies, such as the relationship of it with the laboratory-confirmed reports, which may increase the speed and quality of disease detection and reporting in especially remote or underserved areas (Paltiel et al., 2022).

Moreover, an integrated surveillance strategy is likely to minimize redundant activities and resource waste and ensure that available limited resources on public health can be used more efficiently. As an example, syndromic surveillance when combined with laboratory-based surveillance on such diseases as acute respiratory infections (ARIs) can be used to identify trends in disease transmission and will contribute to more accurate diagnostic information, which will facilitate more targeted interventions (Lipsitch et al., 2022).

Although hybrid and integrated surveillance systems are highly promising, there are still challenges when it comes to their implementation. It is important to coordinate the various sectors (e.g., healthcare, environmental health, animal health) to make sure that data is shared and used appropriately. Also, hybrid systems may be expensive to deploy since it requires sophisticated infrastructure, education, and maintenance. Hence, local circumstances, resources, and the magnitude of the disease burden must be considered when organizational costs are to be ensured and the advantages of such systems are to be maximized.

## 12. Conclusion and Future work

In conclusion, Cost-Effectiveness Analysis (CEA) is highly important in assessing the effectiveness of various surveillance systems and make sure that the resources available to people in terms of health are utilized efficiently. Through the evaluation of the cost and effectiveness of surveillance strategies, CEA offers useful information on which systems would give the highest health benefits at the least financial cost. Different surveillance systems, including syndromic surveillance, active surveillance, and genomic surveillance can be combined to improve timeliness and accuracy of detection of an illness so that the detection can be followed by more relevant interventions by the government.

Nevertheless, a sound CEA of surveillance systems is associated with some difficulties, such as the lack of information about cost and effectiveness, and the inability to combine different types of surveillance and technology. Although these issues exist, sensitivity analysis becomes an useful instrument in estimating the extent to which the results are robust to variations in any central assumptions, which give a better picture of the policymakers of the plausible variations in the outcomes.

The future potential of hybrid surveillance systems i.e. integrating data, e.g. environmental data, animal data and human health data with advanced data analytics applications and predictive data modeling algorithms is high in the future. This would be a long way in changing the timeliness, accuracy and cost-effective surveillance systems to future needs of emerging diseases and global health threats. These systems are however done with much planning, much investment and synergy of sectors to permit information sharing and collaboration.

It is necessary to focus the further research in the development of more advanced models which can be utilized to explain the dynamic and multidimensional character of the diseases, and the dynamic technology in the realm of surveillance. Also, the equity considerations of the cost-effectiveness should become more serious as in the future, the surveillance practices would be efficient and available to all population groups, in particular, the most vulnerable to it. This way it will be more efficient in addressing the future issues with regard to the better equipping of the health systems of the countries in the aspect of being better prepared to handle the threats since surveillance is a significant tool in protecting the health of the world.

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