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Global Surveillance and the Value of Information: The Case of the Global Polio Laboratory Network

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Effective control and eradication of diseases requires reliable information from surveillance activities, including laboratories, which typically incur real financial costs. This article presents data from a survey we conducted to estimate the costs of the Global Polio Laboratory Network (GPLN), which currently supports aggressive global surveillance for acute flaccid paralysis (AFP) to detect circulating polioviruses. The Global Polio Eradication Initiative (GPEI) of the World Health Organization (WHO) provides resources for some of the laboratory network costs, but the total cost of the network remains relatively poorly characterized given the limited documentation of national contributions. We surveyed network laboratories to quantify AFP surveillance support costs and provide data for cost estimates of potential posteradication surveillance policies related to the laboratories. We estimate that the GPLN currently requires millions (US$ 2002) in total support annually, and that half of the support for national and regional reference laboratories comes from external donors through the WHO or bilateral agreements and half from within nations that host those laboratories. The article also presents the framework for considering the value of information from this global surveillance network and suggests that the expected value of surveillance information from the GPLN currently exceeds its costs. We also provided important insights about how the value of information may change after successful eradication of wild polioviruses.

KEY WORDS: Laboratory network; polio eradication; survellance; value of information

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1. INTRODUCTION

The ability to control and eradicate diseases depends on the ability to detect the specific infectious agents that cause them. Some diseases produce distinct and characteristic clinical outcomes that make surveillance relatively straightforward (e.g., smallpox). In contrast, others may spread silently to some degree with long latency periods between exposure and adverse health outcomes and/or with adverse health outcomes occurring only in a fraction of infected individuals. The literature provides relatively few estimates of the enormous value of laboratory network information in controlling or eradicating disease. We suspect this underappreciation in the

literature may occur due to the obviously large net benefits of the information. For example, in the context of polio eradication the ability to detect polioviruses allows the Global Polio Eradication Initiative (GPEI) and national health leaders to target scarce vaccine resources by identifying areas with circulating polioviruses and an inferred low population immunity (i.e., areas at high risk for an outbreak). Active surveillance with a laboratory network allows the world to certify regions as free of circulating wild polioviruses and assures the true success of regional (and ultimately global) wild poliovirus eradication. In the history of the eradication effort, the existence of the laboratory network in the Pan American Health Organization (PAHO or AMR) region made demonstration of eradication of wild polioviruses in the region possible.[1] This established important precedents for surveillance requirements.

In spite of their importance, the benefits and costs of disease surveillance networks remain relatively poorly characterized. We conducted a survey to estimate the costs of the Global Polio Laboratory Network (GPLN), which currently supports aggressive global surveillance for acute flaccid paralysis (AFP) to detect circulating polioviruses. The GPEI currently provides resources for some of the laboratory network costs, but we were not able to determine the total cost of the network prior to the survey due to limited documentation of national contributions. We surveyed network laboratories to quantify AFP surveillance support costs and to provide data for cost estimates of potential posteradication surveillance policies related to the laboratories, as described in Section 2.

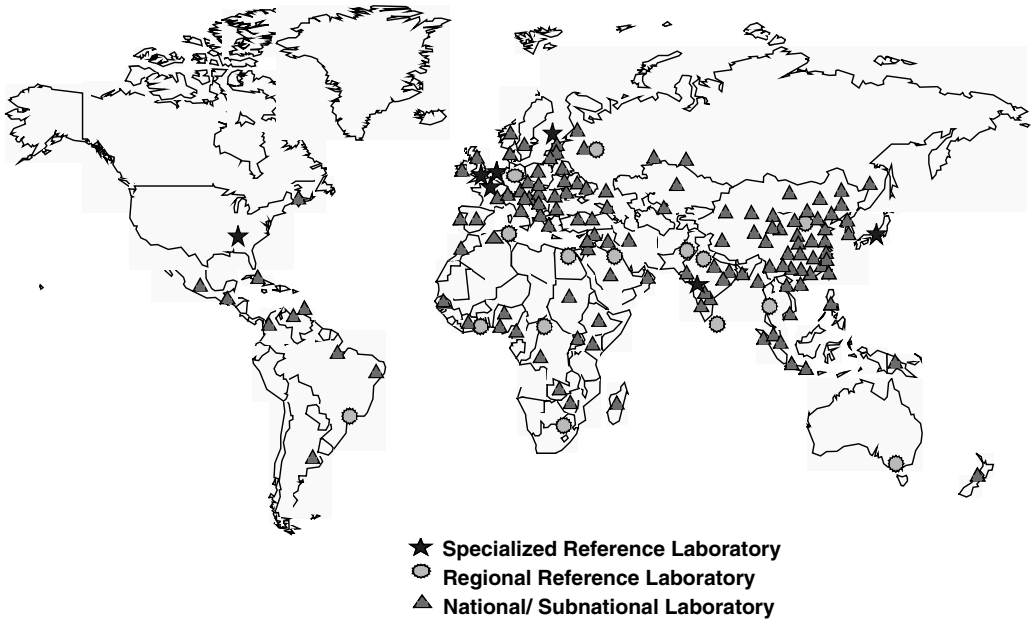
We sought to put the resulting cost estimates in context by exploring the value of the information provided by the GPLN in the context of a decision analytic framework. The role of value of information (VOI) analyses in providing policymakers with quantitative estimates to help inform decisions about investments is well recognized in reviews of the VOI literature,[2,3] with some additional studies conducted since the review demonstrating utility of the method for disease surveillance (e.g., Cox *et al.*).[4] Section 3 provides a simple conceptual model to explore the magnitude of the costs estimated in Section 2 in a VOI context, and Section 4 discusses the results of our analysis with some considerations about how the value of the GPLN might change after eradication.

2. ESTIMATING THE COSTS OF THE GPLN

Efforts to eradicate wild polioviruses depend on aggressive global surveillance for AFP cases and detection of circulating polioviruses from fecal samples using the extensive GPLN established in 1988.[5] Fig. 1 shows the locations of the seven global specialized reference laboratories (SRLs), 15 regional reference laboratories (RRLs), and 123 national laboratories (NLs) that comprise the GPLN.[6] The hierarchical structure of the network reflects the different responsibilities at each level.[7] NLs generally isolate and determine the serotype of polioviruses, RRLs assess the vaccine or wild origin of the viruses, and SRLs use molecular biology methods to determine the genetic relationships among isolates to investigate their transmission linkages.[8] Using the network structure (in which a few NLs and all RRLs and SRLs serve multiple countries), every country can access even the most sophisticated technologies through mechanisms established by the World Health Organization (WHO) for collaboration and sample referral. The WHO sets standards for surveillance quality to detect nonpolio AFP cases at an annual rate of at least 1 per 100,000 children younger than 15 years of age, and to collect stool specimens from at least 80% of these cases. It administers an accreditation program to assure high-quality laboratory performance. By testing stool samples of AFP patients by at least this rate, the GPLN reliably identifies circulating polioviruses.

The GPEI Strategic Plan for 2004–2008 defines the objectives and key milestones for polio eradication and certification and the GPLN's key role in implementation.[6] In 2003, WHO estimated that over the five-year time period 2004–2008 approximately 27.8 million (US$ 2002) of external financing would be required for the operational costs of the GPLN and that 12.5 million (US$ 2002) would be needed for personnel costs.[9] Unfortunately, since these estimates include only the external resource needs, additional efforts are required to capture the significant national contributions made to the GPLN.

Consequently, we developed and conducted a survey of the existing GPLN to collect data that would validate estimated external costs and document the true global costs of laboratory support of polio surveillance from all funding sources. This analysis takes a global perspective that aims to estimate all of the major costs of the laboratory network from any funding source, although we did not estimate currently unbudgeted costs (e.g., buildings or volunteers). Table I provides the survey instrument that we used to request information about the role of the laboratory and the countries/regions it serves, estimated workloads for 2001–2003, the costs of its AFP surveillance-related and other polio activities in 2002 by funding source (i.e., from external donors through WHO, from



Type of laboratory	AFR	AMR	EMR	EUR	SEAR	WPR	World
Specialized reference	0	1	0	4	1	1	7
Regional reference	3	1	4	3	3	2	16
National	13	6	8	32	13	10	82
Subnational	0	0	0	9	0	31	40
Total	**16**	**8**	**12**	**48**	**17**	**44**	**145**

AFR = African region; AMR = American region; EMR = Eastern Mediterranean region; EUR = European region; SEAR = South-East Asian region; WPR = Western Pacific region

Fig. 1. The Global Polio Laboratory Network—2002.[6]

bilateral agreements, or from national funds), details about any nonpolio activities, and the percent utilization of staff and equipment for nonpolio activities. In October 2003, we sent the survey electronically to the directors of all 145 laboratories in the GPLN and to polio laboratory coordinators in the six WHO regional offices. We continued to follow up by email with nonresponders until August 2004. We received survey responses from 85 of the 145 (59%) laboratories in the GPLN, including 5 of the 7 SRLs, and 1 incomplete response from an SRL. Table I summarizes the number of responses (and percentages) that we received for each question.

Responding laboratories characterized themselves as exclusively public health (54%), academic (5%), research (10%), and other (31%), which usually indicated multiple roles within one facility for public health, academic, research, and/or diagnostic services. Globally, considering all funding sources, 63 of the 84 responding laboratories (75%) reported nonzero costs for personnel, 63 laboratories (75%) for supplies and equipment, and 48 (57%) for operations. A total of 33 laboratories (39% of responders) reported "other" costs, which they noted included communication, sample shipment, and other miscellaneous costs. Overall, 24 laboratories (29%) reported training costs. Finally, 35 (42%) reported costs for non-AFP activities for poliovirus detection, including testing of sewage waters, stool samples from healthy children, samples from meningitis cases, or characterization of enteroviruses.

Table II shows the number of AFP sample analyses that responding RRLs and NLs reported performing in 2001, 2002, and 2003 by type of analysis and region, with the data for 2003 covering only January to September. Laboratories most frequently performed virus isolation and serotyping analyses, as expected given the hierarchical structure, and fewer laboratories reported intra-typic differentiation (ITD) or sequencing of viruses since only a few RRLs and SRLs

Table I. Survey Questions with Number (and Percentage) of Laboratories Responding to Each Question Among the 145 Network Laboratories[a]

1. What is the role of your laboratory in the global polio laboratory network (i.e., subnational, national, regional reference, or specialized laboratory) and what provinces, countries, or regions does it serve? (Please list roles and geographic area served — provinces, countries, or regions.) 85 (59%)
2. Please characterize the type of your laboratory (public health, academic, research, other (specify)). 82 (57%)
3. Is your laboratory designated for polio surveillance activities only (yes/no)? 81 (56%)
4. If your laboratory conducts non-polio activities, please specify in the table below what percentages of polio staff time and equipment you would estimate are spent on those other activities.

Laboratory Activity Other Than Polio-Related Activities	Percentage of Staff Time Spent on Activity	Percentage of Equipment Use Attributable to Activity
59 (41%)	53 (37%)	53 (37%)

5. How many AFP sample procedures did you perform yearly?

	Number of Samples Tested		
Type of Procedure	2001	2002	2003 (up to September 30)
Virus isolation	83 (57%)	84 (58%)	84 (58%)
Serotyping	75 (52%)	75 (52%)	76 (52%)
Intratypic differentiation	52 (36%)	43 (30%)	44 (30%)
Sequencing	38 (26%)	33 (23%)	32 (22%)

6. How much did your laboratory budget for analysis of samples from AFP cases in 2002?

	External Contributions (i.e., Through WHO or UNICEF)[b]	Contributions from Bilateral Agreements (Specify Source)	Total National Contributions
Personnel	54 (37%)	31 (21%)	69 (48%)
Training	43 (30%)	30 (21%)	29 (20%)
Supplies and equipment	68 (47%)	31 (21%)	51 (35%)
Operational costs	53 (37%)	27 (19%)	46 (32%)
Other (specify)	33 (23%)	27 (19%)	38 (26%)

7. Did your laboratory directly receive supplies, equipment and/or funds that are not counted toward the budget in question 6? If so please estimate the value of these in US$ and describe.

	Estimated Value in US$	Description and Comments
Supplies	25 (17%)	
Equipment	26 (18%)	
Grants/funds	24 (17%)	
Other (specify)	20 (14%)	

(*continued*)

within the GPLN conduct these tests. We estimate that the annual number of samples for virus isolation exceeds 80,000 based on direct extrapolation of the reported workload from 80 responding labs to all 138 NLs and RRLs. As noted in the footnote in Table II, the survey response rate among RRLs and NLs varied across the six WHO regions, ranging from 26% in the Western Pacific region (WPR) to 100% in the African region (AFR). In the WPR, the low response rate reflects the absence of any response from China,

Table I. (*Continued*)

8. How much did your country budget for any other polio surveillance activities (i.e., other than AFP surveillance) in 2002?

	External Contributions (i.e., Through WHO or UNICEF)	Contributions from Bilateral Agreements	Total National Contributions
Analysis of environmental samples			
Personnel	28 (19%)	24 (17%)	30 (21%)
Training	28 (19%)	24 (17%)	27 (19%)
Supplies and equipment	32 (22%)	24 (17%)	32 (22%)
Operational costs	30 (21%)	24 (17%)	28 (19%)
Other	29 (20%)	24 (17%)	24 (17%)
Analysis of samples from healthy children			
Personnel	30 (21%)	24 (17%)	33 (23%)
Training	27 (19%)	24 (17%)	28 (19%)
Supplies and equipment	31 (21%)	25 (17%)	32 (22%)
Operational costs	29 (20%)	24 (17%)	30 (21%)
Other	27 (19%)	23 (16%)	26 (18%)
Other (specify)			
Personnel	27 (19%)	24 (17%)	29 (20%)
Training	26 (18%)	22 (15%)	25 (17%)
Supplies and equipment	27 (19%)	22 (15%)	28 (19%)
Operational costs	26 (18%)	22 (15%)	27 (19%)
Other	24 (17%)	22 (15%)	25 (17%)

9. Are there any other costs or issues related to the laboratories that you think we should consider?

[a]That the numbers in the tables do not represent responses to the questions, they represent the number and percentages of respondents.
[b] "External contributions" refers to contributions that you receive from WHO, UNICEF, bilateral agreements with other countries or from other sources (i.e., from external sources as opposed to funding, staff, or provisions paid by the government).

which accounts for 70% of laboratories that operate in the region.

We requested cost estimates for 2002 and we report all costs in year 2002 U.S. dollars using mid-year 2002 exchange rates to convert estimates given in non-U.S. currencies into U.S. dollars.[10] We analyzed cost estimates for AFP-related activities (obtained by Question 6) for the RRLs and NLs, separating out the SRLs because industrialized nations provide direct financial support for these. We focused on estimating the costs of all 138 of the RRLs and NLs and extrapolated to account for missing survey responses. We considered a missing response or a response of zero costs (i.e., from any funding source) as a nonresponse for personnel, supplies and equipment, and operational costs, based on our knowledge that each laboratory must incur some amount of costs for these components (i.e., the laboratory cannot function without these). However, we considered absence of an estimate or a response of zero costs for training or "other" as true zeros, since laboratories may incur no costs for training or "other" activities. We extrapolated costs for component j (j = personnel, supplies and equipment, operational costs, training, or "other") as $O_j = rc_j \times n/n_j$, where rc_j = total reported costs for component j, $n = 138$ = number of RRLs and NLs in the GPLN, and n_j = number of laboratories reporting nonzero costs (j = personnel, supplies and equipment, or operational costs) or number of responding laboratories (j = training or "other").

The 80 RRLs and NLs that responded reported total costs of US$ 6.4 million, with US$ 5.3 million (83%) for AFP activities (Question 6), US$ 0.5 million (7%) for unspecified activities from other sources such as grants (Question 7), and US$ 0.6 million (10%) for non-AFP activities (Question 8). On Question 8, the survey allowed respondents to represent their estimates as percentages of the total costs instead of the budget numbers, which in some cases unfortunately resulted in ambiguity about whether "total cost" referred to the total laboratory budget or polio activities. Consequently, we excluded five responses expressed as a percentage of total costs from the analysis.

Table II. Number of AFP Sample Tests Performed by Responding Regional Reference and (Sub)national Laboratories ($n = 80$ in 2001, 2002, and 2003), by WHO Region, and Estimated Total Workloads for All 138 Regional Reference and (Sub)national Laboratories

								Extrapolated Total*	
	AFR	EMR	EUR	AMR	SEAR	WPR	Total	By Region	Globally
2001									
Virus isolation	16,500	5,943	4,786	2,944	13,252	3,119	46,544	65,061	80,288
Serology	2,252	765	1,179	248	691	710	5,845	9,222	10,083
Intra-typic differentiation	1,550	431	247	170	155	336	2,889	4,257	4,984
Sequencing	76	0	99	20	0	19	214	360	369
2002									
Virus isolation	16,460	7,789	5,073	2,420	14,232	3,538	49,512	69,467	85,408
Serology	1,871	894	4,036	95	897	630	8,423	13,683	14,530
Intra-typic differentiation	1,677	407	220	117	171	207	2,799	3,733	4,828
Sequencing	116	54	103	30	0	28	331	518	571
2003 (up to September)									
Virus isolation	12,592	6,626	3,274	1,915	10,747	2,658	37,812	70,068	85,408
Serology	2,036	536	720	89	706	280	4,367	8,010	14,530
Intra-typic differentiation	1,529	382	146	142	93	101	2,393	3,947	4,828
Sequencing	351	162	82	40	0	2	637	1,000	571

*Multiplied by 12/9 for 2003 (to account for the months October to December) after extrapolating for missing responses.
AFR = African region, 16/16 (100%) response rate; AMR = American region, 4/7 (57%) response rate; EMR = Eastern Mediterranean region, 11/12 (91%) response rate; EUR = European region, 25/44 (57%) response rate; SEAR = South-East Asian region, 13/16 (81%) response rate; WPR = Western Pacific region, 11/43 (26%) response rate.

Table III shows the average reported cost (and range) per responding laboratory and the average reported cost (and range) per sample for virus isolation for 2002 by region and overall. The table also shows that removal of the personnel costs changes the relative differences among regions. Aggregating these costs to account for the total number of laboratories in a region, we found that national contributions paid for approximately 53% (range 24–89%) of the total costs in 2002 and for the largest proportion of total costs in the EUR and WPR regions. Nonnational resources paid for 47% (range 11–76%) of the costs, including 34% (range 11–73%) from external resources through WHO and 13% (range 0–49%) from bilateral agreements.

Fig. 2 shows estimates of the major cost components related to AFP surveillance for the RRLs and NLs, including personnel, supplies and equipment, operations, training, and other costs. Laboratories generally spend the highest proportion of their budget on personnel costs, followed by supplies and equipment and operational costs. The Western Pacific and European WHO regions (WPR and EUR) reported the highest personnel costs, and we found overall generally low or no support from national authorities for training of laboratory personnel. Several laboratories also mentioned the use of or need for resources to maintain equipment. We extrapolated from the 80 responding RRLs and NLs laboratories to the full 138 to estimate the total costs for all laboratories of approximately US$ 12.3 million globally. Using the alternative method of extrapolation of AFP cost components by region and then taking the sum we obtain a similar total of US$ 11.7 million.

The costs of the SRLs vary widely because of differing sizes and responsibilities. The largest SRL provided an overall estimate of approximately US$ 4.4 million for all poliovirus eradication activities. The other four SRLs that responded to the survey reported aggregate costs for AFP surveillance activities of approximately US$ 610,000 and an additional approximately US$ 670,000 in aggregate costs for other activities, including testing of sewage waters (environmental surveillance) and samples from healthy children. Based on the known activities and workload of the nonresponding SRLs and their underlying cost structures, we estimate total costs of the SRLs of approximately US$ 6 million per year. In addition, the annual costs of coordinating the GPLN amount to approximately US$ 3 million. Combining this $9 million estimate with the estimate of approximately $12 million provided above for SRLs, we estimate total annual costs of the GPLN of approximately US$ 21 million.

Table III. AFP-Related Costs (US$) per Laboratory and Cost per AFP Sample for Virus Isolation in 2002 for the 80 Responding Regional Reference and (Sub)national Laboratories

	Reported AFP-Activities Costs per Responding Laboratory			Reported Nonpersonnel AFP-Activities Costs per Responding Laboratory			Reported AFP-Activities Costs per Virus Isolation			Reported Nonpersonnel AFP-Activities Costs per Virus Isolation		
	Mean	Range	Diff.[a]	Mean	Range	Diff.	Mean	Range	Diff.	Mean	Range	Diff.
AFR	111599	0–287164	2.02*	68134	0–190376	2.73*	108	0–1198	0.48	66	0–637	0.72
AMR	35925	22900–63000	0.53*	12750	8000–21000	0.37*	59	13–356	0.38*	21	6–75	0.15*
EMR	82479	0–509774	1.29	58551	0–509774	1.98	116	0–1520	0.51	83	0–520	0.49
EUR[b]	29955	0–186474	0.36*	14175	0–73258	0.33*	148	0–3474	3.00	70	0–3333	2.71
SEAR	64538	7369–220820	0.97	26074	4325–45500	0.74	59	25–318	0.18*	24	3–250	0.22*
WPR	81144	1050–424079	1.27	18928	0–96500	0.53	252	24–2017	1.44	59	0–551	1.31
World	66463	0–509774	–	33584	0–509774	–	107	0–3474	–	54	0–3333	–

[a]Diff. = mean of given region divided by mean of the other regions. An asterisk denotes significantly different means between given region and other regions based on a two-tailed *t*-test assuming unequal variance with a significance level of 5%.
[b]In computing the cost per virus isolation, we considered the cost per virus isolation for one laboratory that reported zero costs and zero virus isolations as zero to avoid dividing by zero.
AFR = African region; AMR = American region; EMR = Eastern Mediterranean region; EUR = European region; SEAR = South-East Asian region; WPR = Western Pacific region.

Approximately one-fifth of network laboratories (Question 8 in Table I) also incurred costs (US$ 0.6 million, as stated previously) for non-AFP surveillance activities undertaken to supplement AFP surveillance for detection of polioviruses. However, we did not include activities other than AFP surveillance in our cost estimates because (1) AFP surveillance remains the "gold standard" for certification of polio eradication, (2) other activities generally did not utilize external resources, (3) we did not request workload estimates for other activities in our survey, and (4) WHO does not normally incorporate them into routine reporting of the GPLN.

We note that AFP surveillance involves other costs than the cost of the GPLN (i.e., surveillance personnel, transportation, cold chain equipment, data management, and other nonlaboratory costs). WHO estimated that the external resource needs of the

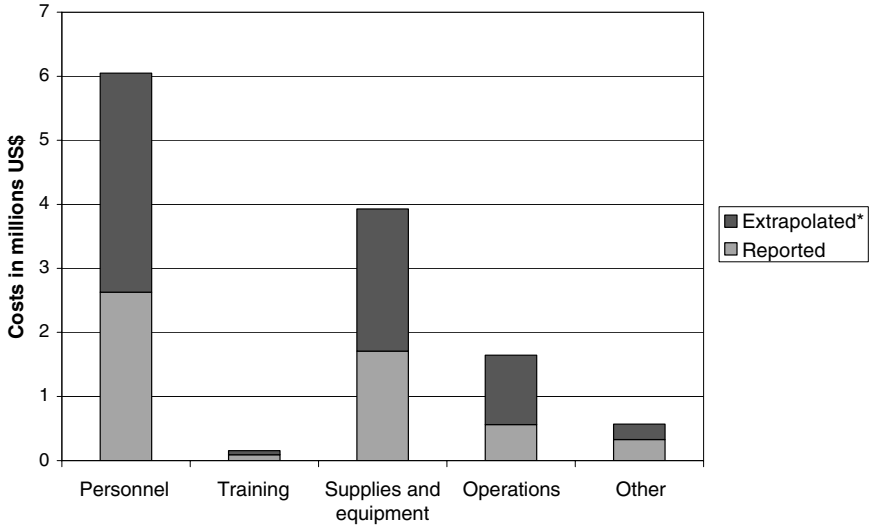


Fig. 2. Global aggregates of reported and extrapolated AFP surveillance-related costs for the 138 regional reference and national/subnational laboratories, by component.

*For personnel, supplies and equipment, and operations, we view a response of zero costs as a lack of response (i.e., we multiply by the number of laboratories/number of nonzero responses). For training and "other" costs (e.g., communication, sample shipment, and other miscellaneous costs) we extrapolate assuming that a lack of a cost estimate represents zero costs (i.e., we multiplied by number of laboratories/number of responders).

GPLN account for 17% of the external resources needed for AFP surveillance.[11] Assuming that this implies that the GPLN accounts for 17% of the total costs for AFP surveillance, we assume total costs for AFP surveillance of approximately US $125 million annually.

3. VOI FRAMEWORK

Since US $125 million per year represents a significant investment of resources, we believe that it is useful to explore the value of this investment. We begin by presenting the basic concepts of VOI analysis in the simplest terms, and then turn to the many ways that analyses could be performed in the context of valuing the information obtained by the GPLN and its components.

3.1. Simple VOI Concepts

Fig. 3 shows a simple decision tree for deciding whether to use a test with cost T to obtain additional information about a disease. We assume the simplest possible system, with two states (disease or no disease) where p indicates the probability of disease and $1 - p$ indicates the probability of no disease. We also assume two possible actions (Y and N) and would like to minimize the total societal costs denoted C. For example, we could imagine that action Y refers to investing in control efforts and action N refers to no control efforts. Fig. 3 shows the symbols of the costs for each outcome (i.e., each combination of state and action), which in this framework include the societal financial costs of the action and health costs associated with the burden of disease. We constrain the costs such that $C3 > C1$ and $C4 > C2$. This constraint ensures that the lines that describe the expected value of the costs of the actions (noted as $E(\text{Action})$) intersect. Thus, $E(Y) = pC4 + (1-p)C1$ and $E(N) = pC2 + (1-p)C3$, intersect at $p^* = (C3 - C1)/(C4 + C3 - C1 - C2)$ with $0 < p^* < 1$. Without this constraint one action dominates, which means that either action Y or N would always yield the lowest possible cost independent of p and any uncertainty about p would be irrelevant to the decision. Fig. 4 shows the cost functions for Y and N as a function of p and shows that the lines cross at the breakpoint, p^*, indicating that Y and N yield equal values at that point. For $p < p^*$ the decisionmaker would prefer N since this minimizes costs, but for $p > p^*$ the decisionmaker will prefer Y. In contrast to decision making

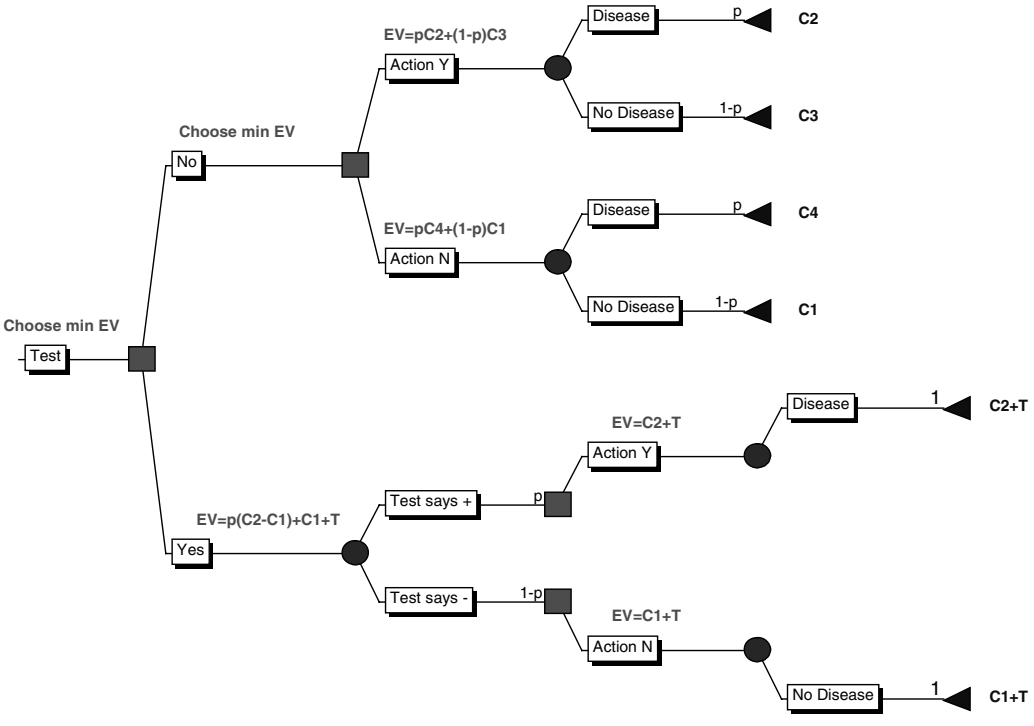


Fig. 3. Decision tree for deciding whether to invest in a test that provides perfect information about disease at cost T.

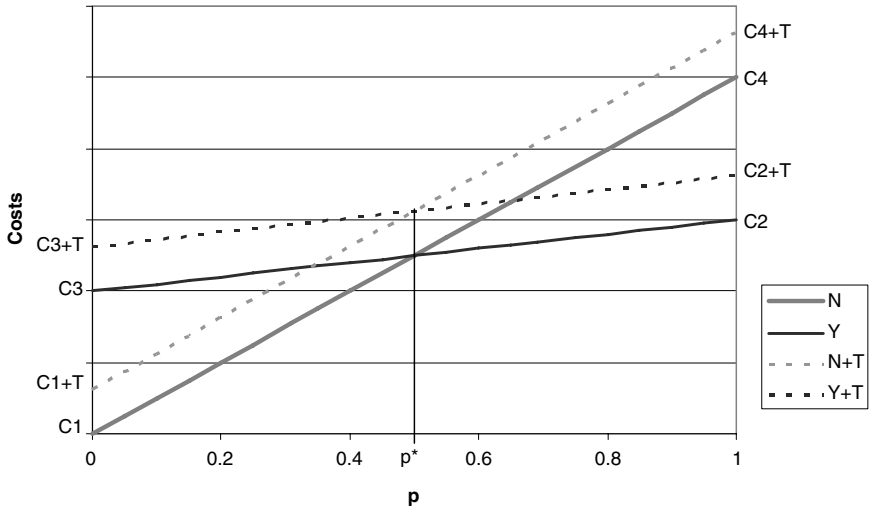


Fig. 4. Graphical representation of the cost functions for Y and N as a function of p (solid lines show costs assuming $T = 0$, dashed lines show costs including $T = T$) (see text).

with no additional information, which simply means choosing the Y or N that yields the minimum expected value

$$E(Y) = pC4 + (1 - p)C1 \quad \text{(choose } Y \text{ if } p < p^*\text{)}$$

$$E(N) = pC2 + (1 - p)C3 \quad \text{(choose } N \text{ if } p > p^*\text{)},$$

access to free perfect information (i.e., $T = 0$) allows the decisionmaker to always stay on the lowest line such that the expected value with perfect information (PI) is

$$E(\text{Action with } PI) = pC2 + (1 - p)C1.$$

Thus, the expected value of perfect information (EVPI) represents the difference between the expected value with perfect information and the expected value with no information:

$$\text{if } p < p^*\text{:} \quad \text{EVPI} = p(C4 - C2)$$

$$\text{if } p \geq p^*\text{:} \quad \text{EVPI} = (1 - p)(C3 - C1).$$

Note that if the decisionmaker expresses certainty about p and thus assigns p a value of 0 or 1 then the EVPI becomes 0. A plot of the EVPI shows that the value peaks at p^*. Thus, the cost (T) that the decisionmaker would be willing to pay for perfect information is a function of p and is bounded by the EVPI. We can include the cost of the test directly in the analysis by recognizing that deciding to test adds T to every C and effectively shifts the lines up as shown in Fig. 4. This leads to an expected value with perfect information of

$$E(\text{Action with } PI) = pC2 + (1 - p)C1 + T.$$

Thus, the EVPI at cost T represents the difference between the expected value with perfect information and the expected value with no information, with the additional constraint that the EVPI must be greater than 0 (i.e., if it becomes negative then this implies that the test costs more than it is worth and the decisionmaker will not buy the test):

$$\text{if } p < p^*\text{:} \quad \text{EVPI} = p(C4 - C2) - T$$

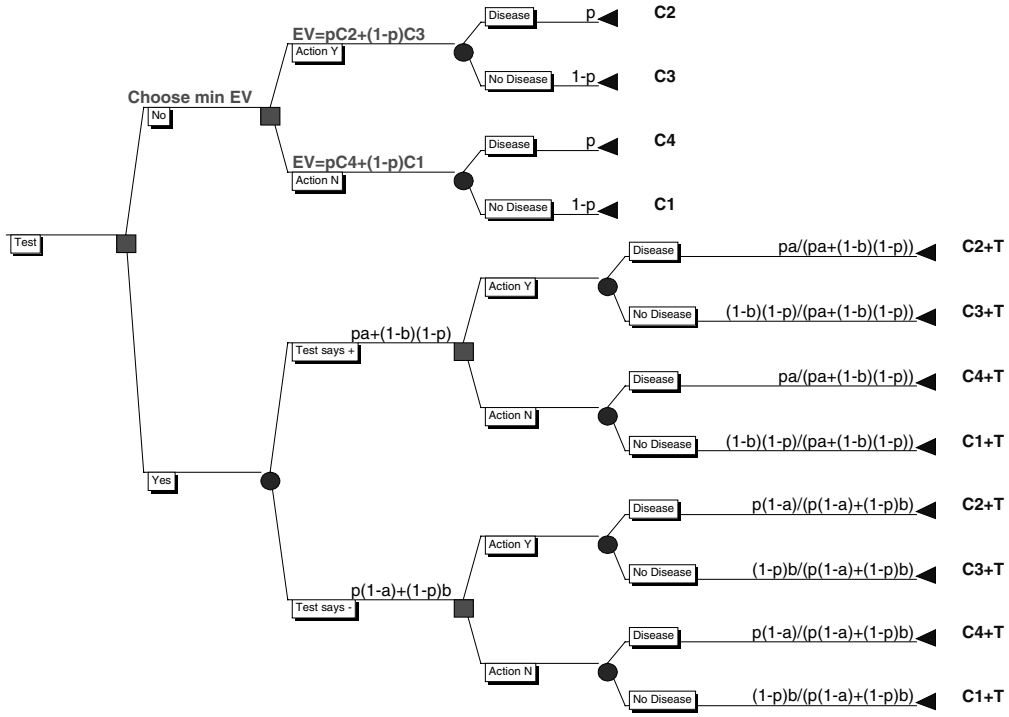
$$\text{for } T < p(C4 - C2)$$

$$\text{if } p \geq p^*\text{:} \quad \text{EVPI} = (1 - p)(C3 - C1) - T$$

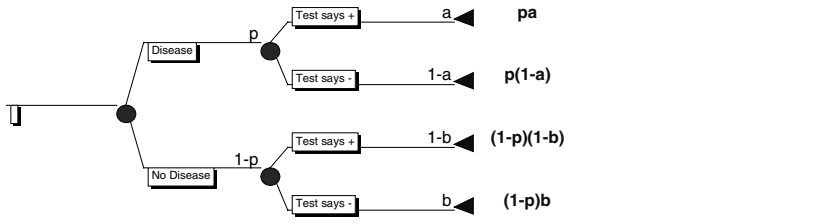
$$\text{for } T < (1 - p)(C3 - C1).$$

Clearly, in the evaluation of real tests, T represents an important consideration.

If the test does not provide perfect information, then this implies that the analysis must focus on assessing the value of imperfect information. In this context, we must consider the sensitivity of the test (a), which represents the probability that the test says positive when disease is present (i.e., true positives) and the probability that the test says negative when disease is present (i.e., false negatives), given by $1 - a$. Similarly, we must also consider the specificity of the test (b), which represents the probability that the test says negative when no disease is present (i.e., true negatives) and recognizes that the probability of false positives is given by $1 - b$. Fig. 5 provides the equations required to solve for the expected value of imperfect information (EVII) in the context of this simple framework. These concepts can readily be extended to situations that involve multiple actions and uncertainties.



Tree used to determine probabilities related to the interpretaton of the test results above:



	Disease	No Disease	Sum
Test says +	pa	(1-p)(1-b)	pa+(1-p)(1-b)
Test says -	p(1-a)	(1-p)b	p(1-a)+(1-p)b

Fig. 5. Decision tree for deciding whether to invest in a test that provides imperfect information about disease at cost T with sensitivity of the test = probability of true positive = a and specificity of the test = probability of true negative = b.

3.2. Conceptual Application of VOI Concepts to the GPLN

Given the framework described above, if we assume that the GPLN provides essentially perfect information about the presence of disease then support of the GPLN as part of AFP surveillance would be justified in the context of a VOI framework as long as \$125 million $< \min\{p(C4 - C2), (1 - p)(C3 - C1)\}$. Thus, the challenge lies in estimating p and the costs ($C1, C2, C3$, and $C4$). In the simplest possible framing, we assume that in the absence of the disease the best strategy would represent very limited action (N) and that circulating disease necessitates action (Y), where action would include prevention efforts (e.g., vaccination campaigns) and treatment (e.g., care for polio victims). In the context of eradication, the GPLN provides critical information for targeting resources and it helps distinguish between areas with and without circulating disease. Thus, it provides global information about p at the level of local areas, and in this context we might consider p as a composite representing the probability of disease circulating in any part of the area covered by the surveillance program. We could assume in the absence of disease that limited

action (i.e., N = poor or no control) would mean essentially no costs (i.e., $C1 = 0$) and aggressive action (i.e., Y = control) would require real costs (e.g., ongoing maintenance of response capacities, etc.) for which we assume a placeholder of US$50 million (i.e., $C3$ = US$50 million). In contrast, in the presence of circulating disease, we assume that limited action (N) leads to large outbreaks and uncoordinated vaccination efforts with resultant huge costs (i.e., $C4$ = $huge, and for purposes of demonstration we assume the $C4 >$ US$1 billion). In contrast, the cost of action in the presence of circulating disease includes incurring the costs of the GPEI and any health costs of the small number of cases that occur (i.e., for purposes of demonstration we assume that $C2$ = US$600 million). Given these hypothetical assumptions, we find that $p^* = 0.5$ and that investing in AFP surveillance represents an optimal strategy as long as $0.31 < p < 0.69$. Interpreting p as the probability of disease circulating in those parts of the world that represent at-risk or high-risk areas (i.e., believed to be endemic or recently endemic areas), a p of approximately 0.5 seems reasonable and it implies a large VOI. However, we caution that future studies will need to develop better estimates of the costs and reconsider the interpretation of p, and we note that this article focuses on presenting the approach to support consideration of its use in further studies.

We suggest that given the assumption of successful eradication, however, analysts might more appropriately focus on characterizing how the costs and p might change after eradication and how close the information actually comes to perfect information. We emphasize that this type of analysis should consider the impacts of changes over time (i.e., not simply the costs in one year as simplistically done above) and the importance of the timing of information. Because of the possibility of outbreaks from vaccine-derived polioviruses (VDPVs)[12] and the key role that surveillance plays in the rapid response to potential outbreaks,[13,14] we suggest that maintaining high-level polio surveillance in the posteradication era will continue to depend on sustained GPLN and AFP surveillance activities, at least during the time immediately following the global disruption of transmission of wild polioviruses. We suggest that particularly in the time period immediately after the disruption of circulating wild polioviruses (for the last known reservoirs) ongoing surveillance will remain essential to ensure success, and in the context of OPV cessation ongoing surveillance will provide the best means for early detection and management of any outbreaks from circulating VDPVs. After OPV cessation, action Y might represent restarting global vaccination and action N might represent continued OPV cessation. In addition, the VOI approach might prove useful in the context of future efforts to prioritize spending of limited resources for surveillance by helping policymakers identify areas in which the combinations of probabilities and costs lead to high VOI associated with continued collection of surveillance information.

4. DISCUSSION

The GPLN represents a unique and highly valuable partnership between national governments and a number of funding and technical partners established to support a high priority public health program. National governments provide approximately half of the operating costs of the RRLs and NLs, although their relative contribution varies by country and WHO region. In addition, national contributions pay for most of the SRLs, but external contributions pay for the coordination costs. Thus, the overall contribution of national governments to the GPLN could be as high as 60%. We expect that following successful eradication some of the resources that currently support the GPLN may move to other priorities and we emphasize that the VOI framework might help provide important context about the value of the GPLN to decisionmakers and the potential need for some future support.

Currently, countries in the WHO regions of the Western Pacific and Europe make the largest contributions to laboratory operating costs, while laboratories in the regions of Africa and South East Asia are most dependent on external resources. The extent of an individual laboratory's reliance on external resources depends on its national budget and workload, including the number of countries it serves. While the concept of networking ensures global laboratory capacity, it presents several logistical and financial challenges to those laboratories that serve more than one country.

Interpretation of the cost estimates from the survey has several limitations. First, we assumed that the cost per laboratory for the nonresponders equals that of the responders. Similarly, we assumed equivalent workloads of the nonresponding laboratories and the responding laboratories, which appears reasonable based on the surveillance report for the WPR.[15] The 31 nonresponding Chinese laboratories tested 79% of the specimens in the WPR in 1999 and at the same time constituted 72% (31/43) of laboratories in this re-

gion, thus supporting the assumption of comparability of workload to the responding laboratories. Our overall estimate of the extrapolated total costs might not fully capture all of the costs, even though it provides the best estimate available to date. Notably, we did not consider the US$ 0.6 million of costs reported by laboratories for supplementary, non-AFP surveillance activities such as testing of sewage samples or fecal samples from healthy children. Some countries undertake these types of surveillance activities as forms of additional polio surveillance, usually at their own expense. We also did not consider "other" funding sources in our cost estimates, although 33 laboratories (39% of responders) reported receipt of "other" funding totaling US$ 0.5 million occasionally for more than one purpose (e.g., special grants for time-limited projects, training funds, donations of equipment or reagents, and salary support). If we include the costs incurred under "other" funding even though they do not represent regular resources available to the laboratory, this increases the overall cost estimate of US$21 million by approximately US$1 million to $22 million, which does not represent a large difference in the context of the VOI discussion. The survey also revealed the need to improve monitoring of costs in individual laboratories that may contribute some uncertainty to the cost estimates. Some responders expressed difficulty in estimating their costs, particularly those that operate within multilaboratory institutions where equipment and supplies may come from a common stock procured and managed centrally and in some cases shared. In such settings, the laboratories also expressed uncertainty about operational costs (e.g., cost of electricity, water, and communication services).

In the future, the achievement of a polio-free world may lead to changes in surveillance approaches, decline in AFP surveillance quality, and reduction in funding support. These factors will impact the structure of the GPLN, and a reduction in support may necessitate a reduction in the number of laboratories. Our results suggest significant variability in the laboratories, and we assume that laboratories with a low workload, a high dependence on external resources, and good travel connections for rerouting samples would represent obvious candidates for reduction in external support. Thus, applying a VOI approach for each laboratory within regions and/or individually might help to support decisions about transitions in the structure relative to the information that the GPLN provides and we hope that presenting the concepts this article motivates future work in this area. In the context of applying a VOI approach, we emphasize that the approach focuses on characterizing the benefits of reducing the uncertainty that policymakers face and that the variability in the laboratories implies that two-dimensional models may prove useful in future discussions. For example, quantitatively modeling the variability in the population of laboratories using a distribution instead of integrating all of the laboratories to assess the VOI of the entire network may prove particularly useful in the context of evaluating individual laboratories. Overall, the GPLN should recognize opportunities to utilize personnel and laboratory infrastructure to support other public health activities and maximize the benefits of the investment made to date through the GPEI, and in this regard a more narrowly constructed VOI approach that focuses solely on the benefits of the information obtained by the laboratories related to polio may underestimate the overall value of the laboratories (e.g., if they provide information that improves nonpolio decisions). The fact that only 25% of responding laboratories reported exclusive dedication to polio activities suggests that achievement of polio eradication will not lead to a significant deterioration of the global network. In the past, the GPLN infrastructure provided cost-effective information to support decisions related to other diseases, thus effectively subsidizing programs for other diseases. With eradication, programs to support surveillance of other diseases may need to subsidize some ongoing efforts for polio surveillance. The existing infrastructure, including laboratories currently dedicated to only polio activities, represents an important consideration in planning for laboratory support for other public health initiatives. However, estimating the true costs and benefits of such a transition requires caution given the finite lifespan of equipment and technology that needs replacement and requires retraining.

This study validates previous WHO estimates of external resources needed for supporting the GPLN, provides new estimates for its national support, and offers a simple analysis to explore the value of the information currently provided by AFP surveillance. We believe that the cost estimates of laboratory surveillance from this study may prove useful for planning other public health laboratory networks that require global capacity. Recognizing that as the probability of disease (p) approaches 0 the apparent value of the surveillance information declines, we anticipate that after eradication the GPLN and AFP surveillance may not emerge as priorities as they compete with other public health interventions for scarce resources.

However, we recognize that $C2$ and $C4$ will increase with time since OPV cessation,[14] implying a lower threshold of p for a positive VOI of surveillance. We note that one objective in the strategic plan focuses on transitioning the polio eradication infrastructure, including the GPLN, to other public health activities.[6] We emphasize that changes to the process for AFP surveillance and to the GPLN may impact the sensitivity and specificity of the information provided, and in this context future analyses should appropriately consider the more complex Expected Value of Imperfect Information framework. This study provides the first quantitative estimates of the costs of the GPLN in its current configuration and explores the concepts associated with considering a VOI framework for evaluating the value of the information obtained.

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