

AHRQ Grant Final Progress Report

Title of Project: Improving Population Health through Enhanced Targeted Regional Decision Support

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Structured Abstract

Purpose: We sought to improve public health reporting processes in primary care settings and the quality of information provided to public health authorities for seven routinely reported notifiable diseases.

Scope: Leveraging an existing, robust health information exchange network we implemented a decision support intervention to facilitate awareness that a notifiable disease should be reported to a local public health agency. Clinic staff received pre-populated case reporting forms through an HIE application they already used to receive laboratory results indicating positive cases of the notifiable diseases.

Methods: We employed mixed methods to evaluate the implementation and use of the pre-populated form intervention over an extended period of time. Quantitative measures focused on the change in provider reporting rates, completeness of the information in submitted case reports, and the timeliness with which forms were submitted to local public health authorities. Qualitative interviews with clinic staff examined the burden of case reporting, perceptions of the intervention, and motivations for using the pre-populated forms as compared to the traditional paper-based forms provided by the health department.

Results: Reporting rates in the intervention clinics significantly improved following the intervention when compared to baseline rates as well as concurrent peer clinics. The completeness of information in submitted forms also improved. Timeliness was not affected. Both clinic and public health agency staff positively perceived the intervention, suggesting that workflow was improved as a result of the intervention.

Key Words: Health Information Exchange; Disease Notification; Primary Health Care; Workflow; Epidemiology; Decision Support Systems, Clinical

Purpose (Objectives of Study)

Our long-term goal was to improve population health through innovative informatics strategies that seamlessly integrated and effectively used practice-based population health tools in clinical care. Our objective in this project was to improve the effectiveness of acute and preventative care processes by improving information sharing and data quality among healthcare providers and population health stakeholders using novel decision support tools. These tools delivered reminders to clinical providers using pre-populated reportable condition forms that contained patient demographics and pertinent case management information. Further, this research investigated the process and effects of deploying a framework to integrate HIE data captured from present and previous clinical encounters to improve the identification and reporting of conditions of population health significance. The central hypothesis of this proposal was that automated data capture and enhancements would streamline provider-based population health reporting workflows, lower barriers to reporting and case follow-up, increase data completeness, and capture a greater portion of communicable disease burden in the community.

While this project evaluated novel population health decision support technology, the framework is applicable to a variety of use-cases. Thus, findings from this project will inform future large-scale clinical decision support initiatives in heterogeneous technical settings. We proposed to employ both quantitative and qualitative research methods to determine the data elements and data characteristics vital for clinician case reporting, public health consumption of these reports and bidirectional transmission of case reporting information between public health and healthcare providers through the following Specific Aims.

Specific Aim 1

We evaluated the process and operational outcomes of deploying an advanced technical framework and methodology in the context of a long-standing operational HIE that enhances management of population-level notifiable condition reporting and bidirectional communication among providers and population health stakeholders using decision support tools. To characterize the performance of this intervention we used a variety of metrics, including reporting completeness and timeliness, time-to-treatment, and communication efficiency.

Specific Aim 2

We evaluated the quality of existing healthcare data and the capacity of an advanced technical framework to enhance data quality by measuring baseline, pre-implementation and post-implementation data quality statistics including accuracy, completeness and timeliness for provider and patient demographic information, and additional relevant clinical data. We described methods for improving data quality using HIE components and assess their effectiveness.

Specific Aim 3

We identified and assessed facilitators and barriers – including social, behavioral and environmental – that are associated with the implementation and utilization of an advanced technical framework both within single organizations and across multiple organizations within an HIE.

Scope

Background

Surveillance is the cornerstone of public health practice (1, 2). Traditionally, health departments wait for hospital, laboratory or clinic staff to initiate most case reports (3). However, such passive approaches are known to be burdensome for reporters, producing incomplete and delayed reports, which can hinder assessment of disease in the community and potentially delay recognition of patterns and outbreaks (4-6).

Modern surveillance practice is shifting toward greater use of electronic receipt of disease information. The adoption of electronic health record (EHR) systems and health information exchange (HIE) among clinical organizations and systems (7-9), driven by policies like the ‘meaningful use’ program (10), is creating an information infrastructure that public health organizations can leverage for improving surveillance practice (11-14).

According to the U.S. Office of the National Coordinator for Health Information Technology, health departments currently receive up to 62% of their total laboratory-based reports for notifiable diseases as electronic laboratory reports (ELR) (15). However, provider-based case reporting continues to be largely paper-based via fax machines (16, 17).

EHR systems and HIE networks provide an infrastructure that can support electronic submission of treatment, corollary results, and other details from providers, information that is not available from laboratory information systems. Providers could receive automatically generated electronic case reporting forms through their EHR, which could be completed and sent to local health departments for case investigation. This is what is envisioned by the policymakers who published the latest release of the meaningful use requirements (18).

Context

Our study was performed in the context of the Indiana Health Information Exchange (IHIE), a large HIE network that delivers laboratory results, radiology results, and other clinical messages to providers since 1999 (19-21). Using components within the IHIE information infrastructure, including the Notifiable Condition Detector (22, 23), our intervention pre-populates the official Indiana State Department of

Health communicable disease reporting form with patient demographics, notifiable disease confirmatory test results, and provider information. The pre-populated form was delivered electronically to the provider using the HIE network.

Settings

The intervention was implemented in seven representative primary care clinics in central Indiana. Table 1 summarizes the characteristics of these seven clinics. There were a total of 228 providers practicing across the 7 clinic locations. Among the providers, 215 (94.3%) were medical doctors (MDs) while 11 (4.8%) were nurse practitioners. Four sites provided primary care regardless of age or gender, while one site specialized in primary care for young women, especially sexually active women; one clinic specialized in primary care for individuals 18 years and older; and one clinic specialized in primary care for women. All but one clinic is located in an urban, metropolitan setting. Five of the clinics used electronic lab orders, and all but one clinic faxed communicable disease reports to the local public health agency (PHA).

Clinic	Location	Provider Type: Number	Service	# patients /month	Mode: Lab Orders	Mode: CDR→PHA
1	Urban	MD:9; NP:4	Primary Care	1000	electronic	fax
2	Urban	MD:140; NP:5	Primary Care	6700	electronic	fax out of EMR
3	Urban	MD:8	Teen Clinic	1000	electronic	fax
4	Urban	MD:37; NP:1; PA:2	Adult Medicine	2860	electronic	fax/mail
5	Urban	MD:10; NP:1	Primary Care	2600	electronic	mail
6	Urban	MD:9	Women's Health	1000	paper, fax	fax
7	Rural	MD:2	Primary Care	1200	paper	fax

MD: Medical Doctor; NP: Nurse Practitioner; PA: Physician's Assistant; CDR: Communicable Disease Reporting; PHA: Public Health Agency

Methods

The following methods were detailed in a protocol paper published in *BMC Medical Informatics and Decision Making* in Year 2 of the grant (24). Portions of this paper are included in this report to highlight the methods used to conduct the grant funded research activities. Furthermore, the methods in this report have been updated to reflect changes since the original protocol was published.

Interventions

Two technical interventions were randomized and staggered at participating clinics:

- 1) "standard" pre-populated forms, and
- 2) "enhanced" pre-populated forms.

The "standard" forms intervention used EHR (patient demographics and clinic information) and ELR (notifiable disease test results) data available in the HIE to pre-populate and deliver an electronic version of the existing state notifiable condition reporting form to the provider. Providers were able to review the pre-populated form, add any additional information, and fax completed forms to their local health department.

The "enhanced" forms intervention pre-populated an alternative reporting form with an expanded set of data available in the HIE. For example, the "enhanced" form not only included test results data for a case of hepatitis B but also corollary results on the patient's liver enzymes, information the health department typically requested from the provider in a follow-up phone call when investigating the reported case of hepatitis. Providers were still able to review the pre-populated "enhanced" form, add any additional information, and fax completed forms to their local health department.

Due to the projected deployment schedule, some clinics changed from using the "standard" to the "enhanced" forms while other clinics shifted from routine processes to using the "enhanced" forms. Since deployment was randomized, at any point in time the non-intervention sites acted as natural controls for the intervention sites without the selection bias that is generally present in non-randomized experiments. Therefore, the study protocol was theoretically equivalent in its ability to generate causal evidence to a traditional randomized controlled experiment.

Given the deployment schedule and natural controls, for analysis we grouped the standard and enhanced form interventions together to compare between two states: non-intervention (or pre-intervention) and intervention. This enabled us to utilize a traditional generalized linear model (GLM) to statistically assess whether the interventions (as a group) had an impact on reporting rates, completeness, and timeliness. Interrupted time-series analysis, the originally planned analysis method, could not be used because the clinics were staggered in their "go live" dates and variable lengths of being "on" versus "off," the analysis assumes all clinics went "live" on the same date for the same period of time.

Research Questions

Mixed methods studies require that research questions be linked to and drive the data collection and analysis methods, as well as inform the study design, sample size, sampling, instruments developed and administered, and data analysis techniques (25). Our primary research questions are:

1. What individual, organizational and data quality factors may act as barriers or facilitators to the successful adoption and utilization of pre-populated reporting forms and enhanced data transaction processing to public health; and
2. What is the relationship of these barriers and facilitators to fostering improvements in provider-based population health reporting workflows, lowering barriers to reporting and case follow-up, increasing data completeness, and enabling greater capture of communicable disease burden in the community?

Data Collection

Using a concurrent mixed methods design, data collection was conducted during the three project phases—Baseline/Pre-Implementation, Post-Implementation/Standard Form, and Post-Implementation/Enhanced Form—with qualitative methods embedded within the quantitative methods. In each phase, qualitative and quantitative data were collected in tandem as coordinated but independent studies. This design allowed us to triangulate the quantitative results from surveys, time-series, and data quality measures with qualitative interview and open-ended survey results to understand experiences with public health reporting before and after the forms implementations. The main components of the evaluation strategy are described in Table 1.

Table 1. Evaluation Strategy

Evaluation Construct	Data Collected	Tool/ Method	Data Collection			Analysis
			Pre	Post-S	Post-E	
Reporting rates	Provider reports to public health	C	X	X	X	GLM
Completeness	Completed/missing provider report data fields	C	X	X	X	GLM
	Comparison of completeness between S & E forms	C	X	X	X	PPC
	Provider perceptions of completeness of pre-populated forms	S/I	X	X	X	QUAL/DESC
Timeliness	Time between lab-confirmed diagnosis & report to public health	C	X	X	X	GLM
	Comparison of timeliness between S & E forms	C	X	X	X	PPC
	Provider perceptions of timeliness of intervention	S/I	X	X	X	QUAL/DESC
Burden	Provider perceptions regarding reporting burden	S/I	X	X	X	QUAL/DESC
Data Quality	Provider perceptions regarding quality of data in pre-populated reporting forms	S/I	X	X	X	QUAL/DESC
Form Enhancement	Supplementary data & fields of value to public health	FG	X			QUAL/DESC
Benefits & Utility	Provider perceived benefits & utility of intervention	S/I	X	X	X	QUAL/DESC
Adoption & Use	Provider perceived barriers & facilitators to adopting & using pre-populated report forms	S/I	X	X	X	QUAL/DESC
	Level of acceptance & satisfaction with intervention	S/I	X	X	X	QUAL/DESC
	Provider perceived ease of operations	S/I	X	X	X	QUAL/DESC
Workflow	Public health workflow observations	O	X	X	X	DESC
	Provider reported impact of intervention on work & information flows	S/I	X	X	X	QUAL/DESC
Context	Clinic demographics	S/I	X	X	X	DESC

C: Census of public health report forms & data fields; DESC: Descriptive Statistics; GLM: Generalized Linear Model; FG: Focus Groups; I: Semi-Structured Interviews; PPC: Pre-Post Comparison; O: Observations; Post-E: Post-Enhanced Pre-populated Report Form Implementation; Post-S: Post-Standard Pre-populated Report Form Implementation; QUAL: Qualitative Data Analysis; S: Clinician Surveys

Quantitative Data Collection

The following data were collected at baseline (retrospective to 12 months prior to introduction of the intervention) and at 6-, 9-, and 12-months after implementation of standard or enhanced forms: reporting rates (the number of reports for individual conditions and in aggregate submitted to public health daily); report data completeness (completeness of fields); and reporting timeliness (length of time between the laboratory test date and receipt of report at the health department).

Qualitative Data Collection

Semi-structured interviews and open-ended survey items were used to collect qualitative data regarding provider perceptions of completeness, timeliness and burden associated with notifiable condition reporting prior to and after the intervention. In addition, perceptions regarding data quality, benefits,

utility, adoption, utilization and impact on workflow of reporting prior to and after the intervention were collected during baseline and at 12-months after implementation of the intervention. Interviews (minimum n=12) were audiotaped and transcribed. Survey data (minimum n=20) was uploaded into spreadsheets. Public health practitioner input regarding enhancements and supplemental data preferences for the enhanced report form were captured by convening focus groups (n=2) to establish a collective understanding of desirable data elements.

Data Analysis

Quantitative analysis provides measurable evidence of the impacts of the intervention and enables us to establish likely cause and effect while qualitative analysis will provide in-depth context regarding facilitators and barriers to implementation, adoption, benefits and use of the intervention; identify and describe their impacts on HIE individual and organizational processes; and look at the broad range of interconnected processes or causes at play regarding data quality.

Data Analysis (Quantitative)

We evaluated the effects of the interventions in aggregate and across covariates on reporting rates, data completeness, and reporting timeliness using a generalized linear model (GLM). Data from non-intervention periods were compared to those post-intervention, regardless of whether the intervention was a standard or enhanced pre-populated form. Furthermore, sites within the Indiana Network for Patient Care (INPC) that could be future sites for the intervention were included as “non-intervention” controls.

Data Analysis (Qualitative)

Qualitative analyses were conducted using qualitative software by experienced coders using the constant comparative method of analysis (26) and utilizing standard approaches to ensure credibility, consistency and robustness of the findings. Transcribed interviews and open-ended survey items were loaded into qualitative data analysis software (NVivo 9.0, QSR Int. USA) and underwent a series of well-established steps to identify emerging themes and trends and, ultimately, build a model to describe the intervention phenomenon in a conceptual form (27). The process developed a coding scheme from combining concepts derived *a priori* from the conceptual frameworks driving the study and inductively as the analysis proceeded. Content was grouped into nodes, a codebook built, and codes or code combinations summarized and stratified by contextual factors such as demographics, respondent role, etc. These summaries were entered into appropriate data displays that specify interactions between the intervention, its context and its effects as preparation for triangulation.

Triangulation of Quantitative and Qualitative Data

Data were triangulated to find convergence or agreement by cross-validating results to produce a contextualized portrayal of the facilitators and barriers to implementation and use of the intervention. Quantitative data were reduced via descriptive statistics that were used to generate relevant tables and graphs. The next step, data transformation, involved either conversion of quantitative data into narrative data ("qualitized") or conversion of qualitative data into numerical codes ("quantitized") that can be represented statistically.

Limitations

There are several limitations to our proposed work. First, some clinical sites may be more open to recruitment and enrollment in the study and thus introduce a bias in our sample. For example, some sites may serve patient populations that are more likely to require notifiable condition reporting (for example, a women's clinic with a high Chlamydia reporting history) and thus be more incentivized to participate. Introduction and adoption of the intervention may be more rapid in some settings (small ambulatory clinic) than others (large hospital) as the workplace may accommodate or adjust to the intervention more

easily or require administrative protocols to support the intervention. It is also possible that the staggered implementation of the intervention may complicate quality control of data collection. Also, given data collection covers only one baseline year and a maximum of two years post-intervention, depending on site, this short time frame may limit ability for analysis to account for seasonal trends in reporting. Our findings may also be limited by the context in which this study is conducted. The INPC is one of the most advanced HIEs in the country; therefore, our results may have limited generalizability. However, we believe our emphasis on context and by clearly documenting the characteristics of the sites in which the intervention, our findings could inform implementation other HIE settings. Given current mandates to build systems and infrastructures for ELR and HIE in communities where it is absent, expand efforts in communities where ELR is already occurring, and requirement for eligible hospitals to routinely transmit reportable laboratory results to a public health agency, our findings may provide insights and inform roadmaps for more nascent HIEs to move forward towards better notifiable disease surveillance.

Ethics

The project received approval by the Institutional Review Board of Indiana University with a concurrent Institutional Review Board deferral from the University of Washington to Indiana University.

Results (Principal Findings, Outcomes, Discussion, Conclusions, Significance, Implications)

We summarize the results in three sections. First, we summarize the reporting rates, data completeness, and timeliness for the pre-intervention period. Second, we summarize reporting rates, data completeness, and timeliness for the intervention period. Finally, we present a comparison of the two time periods to demonstrate the effect of the intervention on reporting rates, completeness, and timeliness. Throughout these sections we provide qualitative feedback gathered from the clinic and public health staff.

Please note that the pre-intervention findings have been published in two separate articles (28, 29) appearing in *BMC Medical Informatics and Decision-Making* and *BMC Public Health*. The comparison of pre- and post-intervention periods will be submitted for publication in the future.

Principal Findings

Pre-Intervention Findings

A total of 12,304 reports representing 9,034 unique cases for 8,353 unique patients were gathered from health department records. The dataset represents everything reported to the health department during the respective baseline time periods for the seven diseases.

Reporting Rates

Providers submitted 2,740 reports representing 2,496 cases for 2,314 patients; labs submitted 1,447 reports representing 1,188 cases for 1,134 patients; and the HIE submitted 7,906 reports representing 6,777 cases for 6,294 patients. These figures translate into the following reporting rates: 27.6% for providers; 13.2% for laboratories; and 75% for the HIE. Examining cases with at least one fax-based laboratory report or HIE-based ELR (N=7,624) results in an overall laboratory reporting rate of 84.4%.

Fifteen percent of cases (N=1,340) included multiple reports from the same source type. For example, in some cases both the infection control staff at a hospital and the patient's primary care physician submitted a provider report. In other cases, the laboratory submitted a fax directly to the health department and an ELR was delivered via HIE.

Reporting rates varied greatly by disease. Provider reporting rates ranged from 0.5% to 61.7% with providers reporting more than half of known cases of common sexually transmitted infections like chlamydia while reporting only one-third of known cases of conditions like salmonella. When laboratory and HIE results were combined, representing the union of cases that contained at least one laboratory report, reporting rates were generally high, ranging from 63% to 99.9%.

Completeness

Completeness is summarized in **Table 2**. Lab and HIE reports were generally more complete than provider reports with a few notable exceptions, such as ethnicity and provider phone number. For cases in which both HIE and provider reports were captured by the health department, the synthesis of information across reports was more complete than cases in which only a provider or HIE report was available.

Table 2: Completeness of key informational fields contained within notifiable disease reports submitted to a county health department between 2010-2012 for seven commonly reported conditions. Completeness is measured for cases in which only one data source (e.g., providers, laboratory) submitted a report indicating positive diagnosis of a notifiable disease.

Data Element	% Complete for Cases with Only Provider Reports	% Complete for Cases with Only Laboratory Reports	% Complete for Cases with Only HIE Reports
Patient's First Name	99.9%	100.0%	100.0%
Patient's Last Name	100.0%	100.0%	100.0%
Patient's Street Address	43.9%	64.5%	72.5%
Patient's Zip Code	41.8%	66.3%	71.1%
Patient's Phone Number	37.2%	74.1%	71.7%
Patient's Date of Birth	97.4%	99.6%	96.3%
Patient's Sex	97.0%	97.5%	100.0%
Patient's Race	43.5%	12.4%	70.4%
Patient's Ethnicity	34.4%	12.7%	0.0%
Physician's First Name	38.1%	81.9%	80.4%
Physician's Last Name	39.0%	85.9%	99.2%
Physician's Address	42.5%	95.5%	37.7%
Physician's Zip Code	31.6%	95.2%	24.1%
Physician's Phone	38.6%	91.6%	34.5%
Lab Test Performed	76.5%	99.1%	100.0%

HIE = Health information exchange

Timeliness

The timeliness with which reports were submitted to the health department varied by source as summarized in **Table 3**. The most timely data source was the HIE with an average of 2.1 days (median 1 day) between when the test was performed and receipt of the case report by the health department. Laboratory reports faxed to the health department, or sent electronically via manual upload to an online reporting system operated by the state health department, were the next most timely with an average of 4.1 days (median 2 days). Provider reports were submitted an average of 9.5 days after diagnosis with a median of 4 days.

Table 3: Timeliness of notifiable disease reports submitted to a health department between 2010-2012 for seven common conditions.

Report Source	Total N	Mean # days	Median # days	Max # days
HIE	7943	2.1	1	320
Laboratory	1605	4.1	2	379
Provider	3016	9.5	4	375

HIE = health information exchange

Interviews with Clinic Reporters and Public Health Staff

Clinic reporter and public health staff interviews, respectively, captured in-depth information regarding the experiences of those responsible for completing notifiable disease forms and those processing notifiable disease form information. **Communicable disease form completion is typically the responsibility of clinic reporters, not providers.** Provider involvement with reporting primarily revolves around ordering medications to treat a condition confirmed by the lab result. Providers were unfamiliar with reporting workflow, reporting requirements or how to report. Providers overall report uncertainty regarding notifiable condition reporting rules, responsibilities, and protocols—which could be expected given their lower responsibility for reporting compared to other clinical team members. They are also perceived as less knowledgeable by both clinic reporters and public health workers.

Principal responsibility for reporting rests on clinic reporters, who vary in frequency of reporting. We found an **association between frequency of reporting, reporting knowledge and perceptions of reporting burden.** Providers, who rarely report, are not familiar with the list of legally reportable conditions or the timeframes for reporting. We found that regular reporters had a more efficient reporting workflow, greater comfort and familiarity with reporting protocols, spent minimal time on reporting activities, and associated little burden with reporting. Infrequent clinic reporters found reporting more burdensome and time-consuming, an unwelcome diversion from regular workflow, and expressed a lack of clarity about processes for form completion and submission to public health agencies.

While a **positive laboratory report initiates the case reporting process in both clinic and public health settings,** for providers lab results primarily serve as a trigger to order treatment while clinic reporters are tasked to initiate the reporting process. In public health agencies, workers often do not wait for forms from clinics, but rather begin case investigation activities based on lab results they receive, regardless of limited information provided on lab reports. Both settings encounter **interruptions and delays in reporting workflow due to inaccurate or missing information.** Issues of reporting timeliness, data quality and completeness impact both clinic reporters and public health workers who spend **significant time and effort searching for information.** Particularly for public health workers, the overwhelming amount of time spent on information seeking could be significantly reduced if forms were completed on time and contained accurate information.

Both providers surveyed (52%) and clinic reporters (72.7%) **lack clarity regarding how communicable disease reports or their data are used by public health agencies.** It is possible that the value and importance of reporting may be diminished when those responsible for reporting do not perceive receiving benefit from submitting notifiable condition data to public health agencies or perceive a lack of information reciprocity with public health authorities. This may account for the seemingly low awareness of or recollection of communications from public health agencies or with public health workers, as well

as low levels of public health information distribution within clinics. Despite the high likelihood that advisories and guidance disseminated by public health agencies are based, in part, on data submitted by clinics, a direct concordance may not be recognized.

Intervention Condition (Standard and Enhanced Pre-Populated Forms)

A total of 25,513 unique cases were gathered from health department records from clinics under the intervention condition (i.e., during periods when some providers received pre-populated forms). Of these cases, 15,809 were gathered during the “standard” pre-populated intervention period, and 9,704 were gathered during the “enhanced” pre-populated intervention period. The dataset represents everything reported to the health department during all intervention time periods for the seven diseases at clinics who receive electronic reports from IHIE. In other words, the total population represents all cases at clinics that could be affected by the intervention if it was scaled across the HIE network.

Reporting Rates

Reporting rates for the intervention period are summarized in **Table 4**. Provider reporting rates for the intervention sites were higher than the non-intervention clinics. Lab reporting rates were highest with nearly all cases including a laboratory report.

Table 4: Reporting rates for cases of notifiable disease submitted between 2014-2016 post-intervention for seven commonly reported conditions.

Population of Cases	N	Reporting Rate
Provider Reports from Intervention Clinics/Sites	522	50%
Provider Reports from Non-Intervention Clinics/Sites	1,759	11%
Lab Reports	14,985	97%

Completeness

Completeness is summarized in **Table 5**. A total of 838 cases were submitted by providers to the health department during the standard pre-populated form period. Of these cases, 450 came from the seven pilot clinics used for the trial. Of the cases from pilot clinics, 188 (45%) contained a pre-populated identifier, meaning the intervention generated a provider report, routed it to the intervention site, and the intervention clinic completed the form then faxed it to the health department. When the pre-populated report completeness is compared to that of all provider reports (at intervention and non-intervention sites) during the standard pre-populated form period, the pre-populated forms appear to more complete for 10 of 15 key information fields. When compared to the standard electronic laboratory reports collected by the HIE network for the health department, the pre-populated provider reports are more complete for 7 of the 15 fields; and they are equivalent for 5 of the 15 fields. Patient race is the only field which is less complete than reports from other providers as well as the electronic lab reports.

Table 5: Completeness of key informational fields contained within notifiable disease reports submitted to a county health department between 2014-2016 post-intervention for seven commonly reported conditions. Completeness is measured for cases in which a given data source (e.g., providers, laboratory) submitted a report indicating positive diagnosis of a notifiable disease.

Data Element	% Complete for Reports from Providers	% Complete for Pre-Populated Reports from Providers	% Complete for Reports from Laboratories via the HIE
Patient's First Name	100%	100%	88.1%
Patient's Last Name	100%	100%	100%
Patient's Street Address	96.9%	100%	77.1%
Patient's Zip Code	92.6%	100%	70.9%
Patient's Phone Number	85.1%	97.3%	79.0%
Patient's Date of Birth	98.5%	100%	100%
Patient's Sex	97.1%	100%	100%
Patient's Race	79.2%	66.0%	74.6%
Patient's Ethnicity	67.4%	67.0%	3.6%
Physician's First Name	100%	100%	100%
Physician's Last Name	99.6%	100%	100%
Physician's Address	69.1%	68.1%	0.3%
Physician's Zip Code	73.4%	93.1%	69.8%
Physician's Phone	45.5%	80.9%	66.0%
Lab Test Performed	84.5%	99.5%	100%

Timeliness

Timeliness is summarized in **Table 6**. The most timely data source is the HIE, which sends electronic lab reports within 2-3 days (although some reports can take up to 320 days to be reported). Timeliness at the intervention sites is slightly less than that of non-intervention sites (average 8.1 versus 7.5 days). However, reports were not delayed more than 120 days (4 months) at the intervention clinics when compared to non-intervention sites, where some reports can take more than a year to be submitted. When compared to the pre-intervention period, timeliness for all providers improved (9.5 days average) and timeliness for the HIE network worsened (2.1 days average).

Table 6: Timeliness of notifiable disease reports submitted to a health department post-intervention between 2014-2015 for seven common conditions.

Report Source	Total N	Mean # days	Median # days	Max # days
Intervention Sites	727	8.1	5	120
Other Providers	3665	7.5	4	371
Laboratories via the HIE	29345	3.8	2	320

HIE = health information exchange

Comparison of Pre- and Post-Intervention Conditions

In this section we summarize the output of the GLM quantitative comparison between cases received by the health department from non-intervention sites and those received from intervention sites. The non-intervention sites included reports sent from the pilot clinics prior to deployment of the intervention.

Reporting Rates

Reporting rate comparisons are provided in **Table 7**. At the intervention sites, the proportion of lab reports submitted dropped significantly while the proportion of provider reports increased significantly following the introduction of the intervention.

The higher rates within the intervention sites appears to be driven primarily by increased provider reports for chlamydia and gonorrhea. These are high volume tests performed by clinics. The intervention increases these rates within the intervention clinics from around 50% in the pre-intervention period to around 70% post-intervention. Rates for the other five conditions were similar as indicated by p-values from the GLM that ranged from 0.067 to 0.83. The p-value for syphilis was 0.047 which is on the cusp of statistical significance. For this condition, reporting increased from 4% prior to the intervention to 13% following the intervention at those sites implementing the pre-populated case reports.

Table 7: Reporting rates for cases of notifiable disease submitted for seven commonly reported conditions at non-intervention and intervention sites.

Source of Report	% Reports Submitted from Non-Intervention Providers	% Reports Submitted from Intervention Providers	p-value
Lab via HIE	97%	78%	< 0.001
Clinic / Provider	11%	50%	< 0.001

Completeness

The comparison of completeness across key information fields for provider reports is summarized in **Table 8**. Completeness is higher for 11 of 15 fields when the intervention was active. The non-intervention provider reports includes reports from pilot clinics when the intervention was inactive (turned off) as well as reports from non-pilot clinics during the same timeframe as when the intervention was active.

Table 8: Comparison of completeness for key informational fields contained in notifiable disease reports submitted to a county health department between 2014-2016 post-intervention for seven commonly reported conditions from ambulatory clinics. Completeness is measured for cases in which a given data source (e.g., providers, laboratory) submitted a report indicating positive diagnosis of a notifiable disease.

Data Element	% Complete for Non-Intervention Provider Reports	% Complete for Intervention Provider Reports	p-value
Patient's First Name	100%	100%	0.371
Patient's Last Name	100%	100%	0.371
Patient's Street Address	89.9%	99.2%	<0.001
Patient's Zip Code	86.5%	98.5%	<0.001
Patient's Phone Number	83.2%	92.0%	<0.001
Patient's Date of Birth	98.0%	100%	<0.001
Patient's Sex	91.1%	98.9%	<0.001
Patient's Race	75.5%	76.3%	0.0571
Patient's Ethnicity	58.4%	72.8%	<0.001
Physician's Last Name	99.0%	100%	<0.001
Physician's First Name	98.3%	99.2%	<0.001
Physician's Phone	69.0%	75.1%	<0.001
Physician's Address	65.5%	87.4%	<0.001
Physician's Zip Code	43.3%	65.5%	0.231
Lab Test Performed	86.6%	95.8%	<0.001

Timeliness

Although provider timeliness increased and the HIE-based laboratory report timeliness decreased between the pre- and post-intervention time periods, the negative binomial GLM reveals these changes are non-significant. The comparison of the time periods is presented in **Table 9**. All p-values are well above 0.05, which requires we accept the null hypothesis that the timeliness is equivalent across time periods.

Table 9: Comparison of timeliness between non-intervention and intervention sites for providers and the HIE-based lab reports.

Source	Chi Square	p-value
Provider	0.04	0.8435
Lab via HIE	1.77	0.1828

Discussion

The results from the introduction of pre-populated electronic case reporting forms to routine primary care settings in an effort to provide decision support for notifiable disease reporting processes are encouraging. The intervention appears to have had a positive impact on reporting rates as well as the completeness of data submitted to public health authorities for the intervention clinics. Timeliness did not seem to be impacted by the intervention. Feedback from both clinic staff and public health workers were also highly positive, suggesting that decision support tools can facilitate improvements in case reporting without placing additional burden on workflow.

Implications

This project has several implications for the implementation and adoption of HIE-based methods for improving case reporting processes:

1. There exists a temptation to conclude that, given the strength of completeness with respect to laboratory reports, public health agencies might abandon provider reports as a source of data for surveillance. However, provider reports often contain information not available from the lab, including documentation of whether or not the patient is receiving treatment. Furthermore, we found that completeness can sometimes be greater in certain fields with respect to forms completed by providers when compared to the lab. While the increases are modest, they represent key information required for case management at the health department. Therefore, dual-reporting continues to be important for accurate surveillance of notifiable diseases.
2. Reporting rates, completeness and timeliness of case reporting have much room for improvement, even after the implementation of electronic enhancements. Baseline reporting rates were far from ideal. Yet while the implementation of pre-populated forms routed electronically to clinics did remind clinic staff to complete the forms and submit them to public health authorities, reporting rates did not achieve 100% compliance. Furthermore, for conditions such as Hepatitis B and Hepatitis C reporting rates remained virtually unchanged. Therefore while electronically-enhanced reporting methods leveraging HIE will boost reporting rates, some clinics will continue to underreport notifiable disease cases. Furthermore, some fields on ELR and provider-based case submissions will continue to be missing or null. A continued awareness and bidirectional communication between public health and their clinical partners will be necessary to monitor and improve data quality over time.

3. Interventions like this one need to involve and target clinic reporters, who are most often not MDs. There is a tendency for public health authorities to criticize or shame physicians for underreporting disease as many states have laws that require physicians to report case information. Our findings highlight that physicians task others in the clinic with the responsibility for reporting, and these individuals can be engaged in productive conversations about the burden of reporting and how to improve reporting processes. Therefore as electronically-enhanced case reporting initiatives are implemented, these individuals should be engaged; and EHR-based interfaces/interventions should target these individuals (and not physicians).
4. Public health authorities often conceive of a positive, confirmatory lab test as the initial signal to begin work on a notifiable disease case. Yet providers view the test as a signal to initiate treatment. Only then does the clinic have enough information to submit a complete case report to public health. As information flows and interventions for case reporting evolve, these disparate views of case reporting need to be factored in to prevent the development of onerous alerts or forms from being introduced into the clinical environment. The fact that our intervention did not improve timeliness for provider reports is telling as it signals there may be few ways to speed up provider reporting even though completeness can be improved. Interventions that allow flexibility in when clinic reporters are alerted, perhaps in parallel with clinical decisions like treatment, would likely improve compliance with reporting requirements while concomitantly supporting clinic workflows and processes.

Challenges

We encountered several challenges, some of which delayed the implementation of our intervention. While delays and challenges are inevitable, they have lessons for others who seek to implement electronically-enhanced case reporting.

1. A major challenge with the underlying infrastructure supporting our intervention delayed the implementation and disrupted the intervention time period. The intervention relies on the INPC and its Notifiable Condition Detector, which detects positive cases of notifiable disease for ELR within the HIE network. The server on which the NCD operates began to experience significant throughput issues requiring a transfer to another server – and eventually a new data center. The technical issues initially delayed deployment. Then, when the situation worsened, the intervention had to be suspended until the NCD found a new home. This challenge impacted the project timeline, and it may have impacted the timeliness results for the “standard” pre-populated form intervention phase (analysis in progress). While these kinds of infrastructure issues are expected in health IT, this challenge underscores the fragility of the public health infrastructure which lags behind the infrastructure used by clinical organizations. For interventions that rely on networked applications (or even application programming interfaces APIs), network level disruptions or challenges can significantly impact downstream health IT applications.
2. Clinic staff turnover is another challenge for a project like ours in which the investigators rely upon case reporters to respond to an intervention over a sustained period of time. Some clinics experienced significant turnover, which impacted awareness of the intervention as well as the investigators’ ability to perform follow-up interviews with clinic staff. Our project manager spent significant time keeping up-to-date records on each clinic and performing just-in-time trainings with clinic staff so they were aware of the intervention and whom to contact with questions.

Bibliography

1. Lee LM, Thacker SB. The cornerstone of public health practice: public health surveillance, 1961-2011. *MMWR Surveill Summ*. 2011 Oct 7;60 Suppl 4:15-21. PubMed PMID: 21976162. Epub 2011/10/07. eng.
2. Thacker SB, Qualters JR, Lee LM. Public health surveillance in the United States: evolution and challenges. *MMWR Surveill Summ*. 2012 Jul 27;61:3-9. PubMed PMID: 22832990. Epub 2012/07/27. eng.
3. Progress in improving state and local disease surveillance--United States, 2000-2005. *MMWR Morb Mortal Wkly Rep*. 2005 Aug 26;54(33):822-5. PubMed PMID: 16121122. Epub 2005/08/27. eng.
4. Silk BJ, Berkelman RL. A review of strategies for enhancing the completeness of notifiable disease reporting. *J Public Health Manag Pract*. 2005 May-Jun;11(3):191-200. PubMed PMID: 15829831. Epub 2005/04/15. eng.
5. Jajosky RA, Groseclose SL. Evaluation of reporting timeliness of public health surveillance systems for infectious diseases. *BMC Public Health*. 2004 Jul 26;4:29. PubMed PMID: 15274746. PMCID: 509250. Epub 2004/07/28. eng.
6. Doyle TJ, Glynn MK, Groseclose SL. Completeness of notifiable infectious disease reporting in the United States: an analytical literature review. *Am J Epidemiol*. 2002 May 1;155(9):866-74. PubMed PMID: 11978592. Epub 2002/04/30. eng.
7. Adler-Milstein J, DesRoches CM, Kralovec P, Foster G, Worzala C, Charles D, et al. Electronic Health Record Adoption In US Hospitals: Progress Continues, But Challenges Persist. *Health affairs (Project Hope)*. 2015 Dec 1;34(12):2174-80. PubMed PMID: 26561387. Epub 2015/11/13. eng.
8. Adler-Milstein J, Bates DW, Jha AK. Operational health information exchanges show substantial growth, but long-term funding remains a concern. *Health affairs (Project Hope)*. 2013 Aug;32(8):1486-92. PubMed PMID: 23840051. Epub 2013/07/11. eng.
9. Furukawa MF, Patel V, Charles D, Swain M, Mostashari F. Hospital electronic health information exchange grew substantially in 2008-12. *Health affairs (Project Hope)*. 2013 Aug;32(8):1346-54. PubMed PMID: 23918477. Epub 2013/08/07. eng.
10. Centers for Medicare and Medicaid Services. Meaningful Use Baltimore, MD: Centers for Medicare & Medicaid Services; 2013 [updated Aug 23. Available from: <https://www.cms.gov/Regulations-and-Guidance/Legislation/EHRIncentivePrograms/index.html>.
11. Dixon BE, Gibson PJ, Grannis SJ. Estimating increased electronic laboratory reporting volumes for meaningful use: implications for the public health workforce. *Online J Public Health Inform*. 2014;5(3):225. PubMed PMID: 24678378. PMCID: 3959912. Epub 2014/03/29. eng.
12. Dixon B, Grannis S. Public Health Informatics Infrastructure. In: Magnuson JA, Fu JPC, editors. *Public Health Informatics and Information Systems*. Health Informatics: Springer London; 2014. p. 69-88.
13. Lamb E, Satre J, Hurd-Kundet G, Liscek B, Hall CJ, Pinner RW, et al. Update on progress in electronic reporting of laboratory results to public health agencies - United States, 2014. *MMWR Morb Mortal Wkly Rep*. 2015 Apr 3;64(12):328-30. PubMed PMID: 25837244. Epub 2015/04/04. eng.
14. Dixon BE, Pina J, Kharrazi H, Gharghabi F, Richards J. What's Past is Prologue: A Scoping Review of Recent Public Health and Global Health Informatics Literature. *Online J Public Health Inform*. 2015;7(2):e216. PubMed PMID: 26392846. PMCID: Pmc4576440. Epub 2015/09/24. eng.
15. Wu L, Abbey R, Daniel J, Daniel J, Heisey-Grove D, Murray M, et al. *ONC Issue Brief: Health IT for Public Health Reporting and Information Systems* Washington, DC: Office of the National

- Coordinator for Health Information Technology; 2014 [Available from: <http://www.healthit.gov/sites/default/files/phissuebrief04-24-14.pdf>.
16. Downs SM, Anand V, Sheley M, Grannis SJ. The last mile: Using fax machines to exchange data between clinicians and public health. *Online Journal of Public Health Informatics*. 2011;3(3):1-14.
 17. Dixon BE, Jones JF, Grannis SJ. Infection preventionists' awareness of and engagement in health information exchange to improve public health surveillance. *American journal of infection control*. 2013 Sep;41(9):787-92. PubMed PMID: 23415767. Epub 2013/02/19. eng.
 18. Medicare and Medicaid Programs; Electronic Health Record Incentive Program--Stage 3 and Modifications to Meaningful Use in 2015 Through 2017. Final rules with comment period. *Fed Regist*. 2015 Oct 16;80(200):62761-955. PubMed PMID: 26477064. Epub 2015/10/20. eng.
 19. Gamache R, Stevens KC, Merriwether R, Dixon BE, Grannis S. Development and Assessment of a Public Health Alert Delivered through a Community Health Information Exchange. *Online J Public Health Inform*. 2010;2(2). PubMed PMID: 23569583. PMCID: 3615760. Epub 2010/01/01. eng.
 20. Biondich PG, Grannis SJ. The Indiana network for patient care: an integrated clinical information system informed by over thirty years of experience. *J Public Health Manag Pract*. 2004 Nov;Suppl:S81-6. PubMed PMID: 15643364. Epub 2005/01/12. eng.
 21. Overhage JM. The Indiana Health Information Exchange. In: Dixon BE, editor. *Health Information Exchange: Navigating and Managing a Network of Health Information Systems*. 1 ed. Waltham, MA: Academic Press; 2016. p. 267-79.
 22. Fidahussein M, Friedlin J, Grannis S. Practical Challenges in the Secondary Use of Real-World Data: The Notifiable Condition Detector. *AMIA Annu Symp Proc*. 2011:402-8.
 23. Grannis SJ, Stevens K, Merriwether R. Leveraging Health Information Exchange to Support Public Health Situational Awareness: The Indiana Experience. *Online Journal of Public Health Informatics* [Internet]. 2010; 2(2). Available from: <http://ojphi.org/htbin/cgiwrap/bin/ojs/index.php/ojphi/article/view/3213>.
 24. Dixon BE, Grannis SJ, Revere D. Measuring the impact of a health information exchange intervention on provider-based notifiable disease reporting using mixed methods: a study protocol. *BMC Med Inform Decis Mak*. 2013 Oct 30;13(1):121. PubMed PMID: 24171799. PMCID: 3819468. Epub 2013/11/01. Eng.
 25. Onwuegbuzie AJ, Leech NL. Linking research questions to mixed methods data analysis procedures 1. *The Qualitative Report*. 2006;11(3):474-98.
 26. Strauss A, Corbin J. *Basics of Qualitative Research*. London: Sage; 1998.
 27. Reeder B, Revere D, Hills RA, Baseman JG, Lober WB. Public health practice within a health information exchange: Information needs and barriers to disease surveillance. *Online Journal of Public Health Informatics*. 2012;4(3).
 28. Revere D, Hills RH, Dixon BE, Gibson PJ, Grannis SJ. Notifiable condition reporting practices: implications for public health agency participation in a health information exchange. *BMC Public Health*. 2017 Mar 11;17(1):247. PubMed PMID: 28284190. PMCID: PMC5346201.
 29. Dixon BE, Zhang Z, Lai PTS, Kirbiyik U, Williams J, Hills R, et al. Completeness and timeliness of notifiable disease reporting: a comparison of laboratory and provider reports submitted to a large county health department. *BMC Medical Informatics and Decision Making*. 2017 Jun 23;17(1):87. PubMed PMID: 28645285. PMCID: PMC5481902.

List of Publications and Products

1. Dixon BE, Zhang Z, Lai PTS, Kirbiyik U, Williams J, Hills R, et al. Completeness and timeliness of notifiable disease reporting: a comparison of laboratory and provider reports submitted to a large county health department. *BMC Medical Informatics and Decision Making*. 2017;17(1):87. PMID: PMC5481902
2. Revere D, Hills RH, Dixon BE, Gibson PJ, Grannis SJ. Notifiable condition reporting practices: implications for public health agency participation in a health information exchange. *BMC Public Health*. 2017;17(1):247. PMID: PMC5346201
3. Lai PT, Johns JE, Kirbiyik U, Dixon BE. Timeliness of Chlamydia Laboratory and Provider Reports: A Modern Perspective. *Online Journal of Public Health Informatics*. 2015 02/26;7(1):e141. PMID: PMC4512351
4. Revere D, Dixon BE, Hills R, Williams JL, Grannis SJ. Leveraging health information exchange to improve population health reporting processes: lessons in using a collaborative-participatory design process. *eGems (Generating Evidence & Methods to Improve Patient Outcomes)* 2014; 2(3): 1082. PMID: PMC4371487
5. Dixon BE, Gibson PJ, Grannis SJ. Estimating increased electronic laboratory reporting volumes for meaningful use: implications for the public health workforce. *Online Journal Public Health Informatics* 2014; 5(3): 225. PMID: PMC3959912
6. Revere D, Hills R, Grannis SJ, Dixon BE. Clinical Versus Public Health Perceptions of Notifiable Disease Reporting Burden. *Online Journal of Public Health Informatics*. 2014 04/29;6(1):e24. PMID: PMC4050821
7. Dixon BE, Vreeman, DJ, Grannis, SJ. The long road to semantic interoperability in support of public health: experiences from two states. *Journal of Biomedical Informatics* 2014; 49: 3-8. PMID: PMC4083703
8. Dixon BE, Grannis SJ, Revere D. Measuring the impact of a health information exchange intervention on provider-based notifiable disease reporting using mixed methods: a study protocol. *BMC Medical Informatics & Decision Making* 2013; 13(121): 1-8. PMID: PMC3819468
9. Dixon BE, Lai PT, Grannis SJ. Variation in information needs and quality: implications for public health surveillance and biomedical informatics. *AMIA Annual Symposia Proceedings* 2013; 2013: 670-9 (Nov. 16). PMID: PMC3900209
10. Duke JD, Morea J, Mamlin B, Martin DK, Simonaitis L, Takesue BY, Dixon BE, Dexter PR. Regenstrief Institute's Medical Gopher: a next-generation homegrown electronic medical record system. *International Journal of Medical Informatics* 2014; 83(3): 170-9.
11. Dixon BE, Gamache RE, Grannis SJ. Towards public health decision support: a systematic review of bidirectional communication approaches. *Journal of the American Medical Informatics Association* 2013; 20(3): 577-83. PMID: PMC3628068

12. Dixon BE, Siegel JA, Oemig TV, Grannis SJ. Electronic health information quality challenges and interventions to improve public health surveillance data and practice. *Public Health Reports (a Journal of the US Public Health Service)* 2013; 128(6): 546-53. PMID: PMC3804098
13. Gamache RE, Dixon BE, Grannis S, Vreeman DJ. Impact of selective mapping strategies on automated laboratory result notification to public health authorities. *AMIA Annual Symposium Proceedings* 2012; 2012: 228-36. Nov 3. PMID: PMC3540490
14. Gichoya J, Gamache RE, Vreeman DJ, Dixon BE, Finnell JT, Grannis S. An evaluation of the rates of repeat notifiable disease reporting and patient crossover using a health information exchange-based automated electronic laboratory reporting system. *AMIA Annual Symposium Proceedings* 2012; 2012: 1229-36. Nov 3. PMID: PMC3540527