

3-30-2015

Creating Value: Unifying Silos into Public Health Business Intelligence

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Recommended Citation

Davidson, Arthur J. (2014) "Creating Value: Unifying Silos into Public Health Business Intelligence," *eGEMs (Generating Evidence & Methods to improve patient outcomes)*: Vol. 2: Iss. 4, Article 8.

DOI: <http://dx.doi.org/10.13063/2327-9214.1172>

Available at: <http://repository.academyhealth.org/egems/vol2/iss4/8>

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The Electronic Data Methods (EDM) Forum is supported by the Agency for Healthcare Research and Quality (AHRQ), Grant 1U18HS022789-01. eGEMs publications do not reflect the official views of AHRQ or the United States Department of Health and Human Services.

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Technology: Certified EHR technology could create new public health (PH) value through novel and rapidly evolving data-use opportunities, never before experienced by PH. The long-standing “silo” approach to funding has fragmented PH programs and departments,² but the components for integrated business intelligence (i.e., tools and applications to help users make informed decisions) and maximally reuse data are available now.

Systems: Challenges faced by PH agencies on the road to integration are plentiful, but an emphasis on PH systems and services research (PHSSR) may identify gaps and solutions for the PH community to address.

Conclusion: Technology and system approaches to leverage this information explosion to support a transformed health care system and population health are proposed. By optimizing this information opportunity, PH can play a greater role in the learning health system.

Acknowledgements

The paper was made possible through the funding of the Robert Wood Johnson Foundation and the leadership of AcademyHealth in organizing and supporting this author and others. The author would like to thank the many thoughtful individuals who commented on various earlier drafts of this paper: anonymous manuscript reviewers, as well as Scott Afzal, Linda Bilheimer, PhD, James W. Buehler, MD, Elizabeth Cole, Erin Holve, PhD, MPH, MPP, Barbara Ferrer, PhD, MPH, Med, Seth Foldy, MD, MPH, J.P. Leider, PhD, Remle Newton-Dame, MPH, Marguerite J. Ro, DrPH, Charles J. Rothwell, MBA, MS, Paula Soper, MS, MPH, PMP, and Matthew C. Stiefel, MPA.

Keywords

Public Health, PHSSR, business intelligence

Disciplines

Health Services Research | Public Health

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Arthur J. Davidson, MD, MSPHⁱ

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Introduction

The American health care system is a high-cost, low-yield investment. Despite spending nearly 50 percent more per capita than most developed countries, the United States ranks 30th in many comparisons of health status.³ Health care reform seeks improved population health as an outcome and anticipates greater value through information technology investments that help transform health care. In 2004,⁴ President Bush declared a national goal of an electronic medical record (EMR) for every American by 2014. By late 2014, more than 88 percent of all eligible hospitals and more than 60 percent of Medicare and Medicaid outpatient providers used an EMR to care for patients.⁵ The next generation of EMRs, which allow for capture of data that extends to sources outside of clinical settings, are referred to as electronic health records (EHR),⁴ and use of certified EHR technology in American health care has been accelerated by more than 25 billion dollars in incentive funds distributed to eligible hospitals and providers through the Health Information Technology for Economic and Clinical Health (HITECH) Act.¹ Meaningful Use payments encourage eligible providers and hospitals to adopt, implement, and upgrade certified EHR technology.

Nationally, there is great hope for adapting these technology investments to a learning health system⁶ capable of comparative effectiveness research⁷ and patient-centered oriented research.⁸ Given the barriers to interoperability, however, many EMRs are still in the process to achieve the vision of the EHR. For this reason, “EMR” and “EHR” will be used interchangeably through this manuscript.

EMR and certified EHR technology are tools implemented to qualify for incentive payments and increase opportunities to access standardized process and outcome measures of patient care. Local public health (PH) agencies should promote the concept of a local learning health system that benefits from these national EHR investments. Among the opportunities presented by these new sources of data is the ability for well-governed county, regional, or state jurisdiction data sharing efforts to benefit from federal investments to drive educated local decision-making. When combined with routinely collected data (e.g., census, population surveys, socioeconomic and built environment), EHR-based analyses can inform governmental planning, guide program

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development, evaluate policies and programs, support community health assessment, and identify health disparities.⁹ Beyond passive receipt of data, as community leaders PH agencies should convene stakeholders and encourage alignment efforts (e.g., nonprofit hospital IRS obligation for community health needs assessments,¹⁰ accountable care organization quality measures,¹¹ and PH accreditation community health assessments¹²) to mutually benefit from federal investments and potentially improve population health.¹³

With local, interoperable data exchange, even more opportunities emerge for PH agencies to develop new ways of monitoring essential PH service delivery. Using EMR data, service delivery systems (e.g., hospitals, integrated networks, and Accountable Care Organizations) have been able to measure and improve the quality of care delivered.¹⁴ With EMR-based population monitoring, PH agencies will be able to merge social determinant of health measures¹⁵ to assess subcounty level disparities, target service coordination for subpopulations, and launch quality and community health improvement cycles.¹² The Affordable Care Act progressively increases health care access; increased care access, in an EMR-enabled environment, creates additional data to monitor the impact of coverage on newly insured communities. EMR information incompletely covers a jurisdiction's population; unlike randomly sampled federal population surveys, EMR data may be biased.¹⁶ However, the sheer magnitude of observations and value of merging clinical outcomes with insurance coverage or socioeconomic factors makes these PH analyses potentially timelier and more granular.

Yet PH agency information management¹⁷ readiness factors (i.e., workforce, system structure and performance, financing and economics, and information and technology) are a concern. This paper describes a rapidly changing current technology state and suggests a research agenda through a series of questions using a PHSSR lens. Two fundamental questions frame this discussion: (1)

what technology approaches (e.g., shared platforms, shared services, standards and tools) are available and may be leveraged to support a transformed health care system and population health, and (2) what system approaches (e.g., workforce, structures, financing and technology) would optimize this information opportunity to fill current gaps in public health data and evidence?

Technology Approaches: New Infrastructure to Support Public Health Data Access

Federal initiatives seek to dramatically change American health care; simultaneously, information technology advances have remarkably enhanced capacity to support that change by leveraging new data systems to drive improvement. A set of technology approaches and their current application are briefly described below; these examples suggest directions, emerging opportunities, and areas for exploration to harness investments and systems toward greater population health monitoring capacity in public health.

Cloud-Based Technology Opportunities

Cloud-based computing offers PH practitioners a highly capable and cost-effective solution to interface with health care providers, which is a critical step toward breaking down barriers between public health and health care, and filling gaps in current surveillance data. However, until recently security concerns have limited data exchange. Recently, enormous health care innovation has been seen in cloud-based computing that meets high governmental security expectations for individual privacy protection.¹⁸ Cloud computing is a migration of software platforms away from local desktop or server installations to remote hosting, linked by the Internet for "ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources ... rapidly provisioned and released with minimal management effort".¹⁹ A cloud includes hardware and software that enable six essential cloud computing characteristics (Table 1).

Table 1. Essential Characteristics of Cloud Computing (modified⁶⁹)

Characteristic	Description
On-demand, resource outsourcing	Instead of a public health (PH) agency providing hardware, the cloud vendor assumes responsibility for hardware acquisition and maintenance that the PH agency can unilaterally and automatically provision, as needed.
Rapidly elastic utility computing	PH agency requests additional resources (e.g., processing time, network storage, management software, or application services) as needed, and similarly releases these resources when not needed.
Large numbers of pooled machines	Clouds are typically constructed using large numbers of inexpensive machines so capacity may be added or rapidly replaced as machines fail. Compared with having machines across multiple PH agencies, machines are more homogeneous regarding configuration and location. PH agency usually has little control over exact location of provided resources.
Automated resource management	Various configuration tasks (e.g., automated backup, archiving, data movement for responsiveness, bandwidth, active user accounts, and monitoring for malicious activity) typically handled by a PH agency system administrator are offered by cloud service providers. Resource usage is monitored, controlled, and transparently reported.
Virtualization	Cloud hardware resources are typically virtual and shared by multiple users to improve efficiency. Physical and virtual resources are dynamically assigned and reassigned according to demand. Several lightly utilized logical resources can be supported by the same physical resource.
Parallel computing	Frameworks exist for expressing and easily executing parallel computations using hundreds or thousands of cloud processors. The system coordinates any necessary interprocess communications and masks any failed processes.

The cloud infrastructure contains both a physical and an abstraction layer. The physical layer consists of hardware resources necessary to support provision of cloud services, and typically includes server, storage, and network components. The abstraction layer consists of the software deployed across the physical layer. Several service models, defined in Table 2 and modes of deployment (Table 3) should be considered based on organizational business needs of public health departments.¹⁹

A simple, centralized cloud-based example of cloud computing opportunities for public health is the Centers for Disease Control and Prevention's (CDC's) BioSense 2.0, which serves as a national syndromic surveillance, early warning system.²⁰ Housed in the cloud, the Association of State and Territorial Health Officers provides a governance mechanism for local and state jurisdictions

to leverage Stage 2 Meaningful Use-eligible hospital data. Access to centrally processed data is limited by role and permissions. Jurisdictions recruiting hospitals to send data to this central site have made little technology investment, yet now have a new stream of information for situational awareness. BioSense 2.0, as a centralized, cloud-based repository, still creates concern, as cloud storage for PH agencies is new. Tensions exist around who has the right to access data. PH should proactively promote necessary local or regional sociotechnical discussions regarding new surveillance opportunities from existing technologies. Once political barriers to data sharing are addressed, cloud-based technologies with improved disaster recovery are more cost-effective, rapidly and competently implemented, easily scaled, rapidly updated and upgraded, and user friendly.²¹ Other federal agencies have also been attracted to cloud solutions and have explored new applications and infrastructure design.

Table 2. Cloud-based Service Models (modified¹⁹)

Model	Consumer Controlled	External to Consumer
Software as a Service (SaaS) <i>Example: Public health department Facebook account</i>	<ul style="list-style-type: none"> Use provider applications running on a cloud infrastructure. Access applications from various client devices through a web browser (e.g., web-based email), or a program interface. Configure application settings (possibly). 	<ul style="list-style-type: none"> Manage or control underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities.
Platform as a Service (PaaS) <i>Example: BioSense 2.0; ASTHO hosted web service</i>	<ul style="list-style-type: none"> Deploy onto the cloud infrastructure consumer-created or acquired applications created using programming languages, libraries, services, and tools supported by the provider. Control over deployed applications and possibly configuration settings for the application-hosting environment. 	<ul style="list-style-type: none"> Manage or control underlying cloud infrastructure including network, servers, operating systems, or storage.
Infrastructure as a Service (IaaS) <i>Example: Public health department fully outsources all information technology (IT)</i>	<ul style="list-style-type: none"> Provision processing, storage, networks, and other fundamental computing resources. Deploy and run arbitrary software, which can include operating systems and applications. Control over operating systems, storage, and deployed applications; and possibly limited control of select networking components (e.g., host firewalls). 	<ul style="list-style-type: none"> Manage or control underlying cloud infrastructure.

Table 3. Deployment Models for Cloud-based Solutions (modified¹⁹)

Cloud Type	Description
Private <i>Example: Mini-Sentinel project: FDA automated, postmarket reporting system</i>	Infrastructure is provisioned for exclusive use by a single organization comprising multiple consumers (e.g., business units). It may be owned, managed, and operated by the organization, a third party, or some combination of these. And it may exist on or off premises.
Community <i>Example: BioSense 2.0: CDC syndromic surveillance system</i>	Infrastructure is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be owned, managed, and operated by one or more of the organizations in the community, a third party, or some combination of these. And it may exist on or off premises.
Public <i>Example: HealthData.gov</i>	Infrastructure is provisioned for open use by the general public. It may be owned, managed, and operated by a business, academic, or government organization, or some combination of these. It exists on the premises of the cloud provider.
Hybrid	Infrastructure is composed of two or more distinct cloud infrastructures (private, community, or public) that remain unique entities, but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load balancing between clouds).

An alternative to the CDC’s centralized approach to data storage is the distributed data model used by the Food and Drug Administration (FDA) to conduct postmarketing surveillance for approved drugs and devices. This infrastructure (Mini-Sentinel Study²²) uses a federated query tool (PopMedNet²³) to identify risk of adverse events, from a broad network of providers each of whom have standardized their EMR data into a “virtual data warehouse”²⁴ or common data model. Data owners maintain absolute control of who may query their data and of what results are returned; and they never release data without prior review.²⁵ Unlike the relatively limited BioSense 2.0 chief complaint data model, the more comprehensive Mini-Sentinel clinical data warehouse is more flexible, extensible, and generally “agnostic” to the types of questions that may be asked.

The Patient Centered Outcomes Research Institute (PCORI) now has also invested heavily in this same distributed technology.²⁶ PH agencies with their health care partners should explore local instances of distributed, cloud-based query models;²⁷ with hundreds of millions of Americans monitored through FDA and PCORI ini-

tiatives; there is great momentum in this distributed technology. Potentially even more important for local acceptability and participation is that data are not deposited into a central repository.

Interoperability Standards for Data Reuse

Assuming cloud-based architecture becomes a viable platform for public health systems, the ability to share and efficiently reuse data produced in other contexts requires strong interoperability standards. Sharing and efficient data reuse require strict adherence to message standards in three key component areas: (1) structure, (2) content, and (3) transport (see Table 4).²⁸ Without all three—format (i.e., syntactic), vocabulary (i.e., semantic) and transmission standards (i.e., pragmatic)—monitoring systems will not benefit from automation and technology efficiencies. True interoperability between computers requires all three components be standardized. For structure, the Meaningful Use program requires transition of care document exchange using Health Level 7 (HL7) Version 3 consolidated clinical document architecture (c-CDA) and for other message types uses a variety of HL7 Version 2. Many very successful PH messaging systems (i.e., immunization registries²⁹ and electronic laboratory reporting³⁰) have been implemented using these HL7 standards. Without

Table 4. Message Standards Adopted by the Federal Health Architecture²⁸

Name	Full Name	Purpose	Public Health Example
Structure			
HL7 Version 2.x	Health Language 7	HL7 balloted structured message specific to domain need	Immunization reporting, electronic laboratory reporting, syndromic surveillance.
c-CDA Version 3.x	Consolidated Clinical Document Architecture	HL7 balloted flexible message with templates for each domain need	<i>Cancer case reporting (proposed)</i>
Content			
LOINC	Logical Observation Identifier and Nomenclature Code	Unique identifier for each laboratory test or radiologic procedure	Sending a positive gonorrhea result to the state electronic laboratory reporting system.
SNOMED	Systematized Nomenclature for Medicine	Unique resulted value for many laboratory test results	Sending a cancer report to a state registry.
ICD9/10	International Classification of Diseases (9 th or 10 th edition)	Unique diagnosis code for inpatient and outpatient administrative purposes	Sending a record of all patients who have a diagnosis of hypertension (ICD9=401.x) to a registry.
RxNorm	RxNorm	Normalized names for clinical drugs and links its names to many of the drug vocabularies	Determine if hypertensive patient or population has been prescribed and is receiving appropriate medications.
CVX	Vaccine Administered	Standard used for reporting to immunization registry	Determine the up-to-date rate for an individual or population.
Transport			
Direct SMTP	Direct Messaging Service—Simple Mail Transport protocol	Method to securely send a health information message from sender to receiver	Transition of care document after hospitalization or for e-referral (e.g., specialty services, Quitline).
Direct XDM	Direct- and Cross-enterprise Document Media Interchange	Provides document interchange using common file and directory structure over several standard media.	Patient can use physical media (e.g., USB drive or CD-ROM) to carry medical documents or person-to-person email to convey medical documents.
Direct XDR	Direct- and Cross-enterprise Document Reliable Interchange	Permits direct document interchange between EHRs, PHRs, and other health care IT systems in the absence of a document sharing infrastructure such as XDS Registry and Repositories.	Patients can develop their own personal health records (PHRs) across multiple providers.
XDS	Cross-Enterprise Document Sharing Within an Affinity Domain	Shares documents to a community enterprise.	Community of Care record supported by a regional health information organization serving all patients in a given region.

Table 5. Early Examples of Public Health Data Aggregation

To inform knowledge-driven PH practice, data must be aggregated into information that drives decision-making and quality improvement. PH agencies need to incrementally learn how to curate data and promote data sharing partnerships. To benefit from newly available data flow, specific interoperability requirements need to be met. While there may be technical methods and solutions, (e.g., cloud-based technologies and messaging standards), there are, fortunately, several exceptional examples of data successful aggregation for a learning health system. Among many that exist,³²⁻³⁷ just a few examples are briefly reviewed here.

Example 1: New York

In New York City, the Primary Care Information Project^{36,38} seeks to improve disadvantaged community population health focusing and reporting³⁹ in three areas: (1) information systems oriented toward prevention, (2) changes in care management and practice workflows, and (3) payment that rewards effective prevention and management of chronic disease. Results to date provide insight on data value and PH's role in HIE.⁴⁰ First, systems are not without flaws. Parsons et al.⁴¹ found systems used to measure provider performance and payment may misclassify and adversely impact EHR use by clinicians. Having the right input (e.g., leadership from PH, clinicians, and technical resources) during requirements definition, design, and system implementation has significant impact on ultimate system value, trust, and purpose. Transparent translation and integration from clinical to engineering perspectives require innumerable interactions and iterations to test and ensure the right output.⁴² Tracking population health improvements in delivery of recommended preventive- and health-promoting services is possible, but interrupted or failed transmissions may occur due to intermittent technology issues within each practice. Designing for greater stability and real-time queries has been a recent effort. The next version is focused on avoiding data transmission errors, greater data validation, and limiting privacy and security concerns with clinical data extraction.⁴³

Example 2: Massachusetts

In Massachusetts, another group has been developing a federated query tool to support PH surveillance.⁴⁴ This infrastructure, similar to Mini-Sentinel, has been developed primarily through collaborative informatics initiatives with Harvard,^{45,46} and has broad application to national²² and regional efforts.³⁵ Specific studies have algorithmically identified cases of acute hepatitis B,⁴⁷ active tuberculosis,⁴⁸ and distinguishing between type 1 and type 2 diabetes mellitus.⁴⁹ This same technology supports postmarketing adverse event reporting for drugs and devices across more than 100 million Americans. Further application and dissemination of this same technology, at community levels, is exciting and promises to be an area for extensive research and development in the next decade.

broad PH enterprise standards, each PH agency would need to create local standards and then convince health care providers to adopt them. This challenges those health care providers operating in the adjacent county or state where that health department encourages a different standard. To effectively use newly available data, PH agencies must gain knowledge, acquire experience, and contribute to development of messages that adhere to standards for these three essential components. More recently, an emerging HL7 standard is the Fast Health care Interoperability Resources (FHIR, pronounced “fire”), which simplifies implementation of data exchange between health care applications.³¹ Leveraging the latest web standards and tightly focused on implementation, FHIR solutions use *modular components* or resources for easy and cost-effective assembly into working systems.

Toward System Approaches to Address Key PH Systems and Services Research (PHSSR) Questions

Meaningful Use-promoted health information exchange (HIE) will support improved population health monitoring for specific areas (i.e., immunization, laboratory reporting, syndromic surveillance, and cancer registries). To achieve even broader monitoring capacity (e.g., New York City⁵⁰) requires potentially more intensive collaboration from partner health care organizations and a longer time frame for trust building. Population health for many health care organizations is narrowly focused on that group using a specific clinical entity or service (e.g., patient panel). However, secondary use of these data by PH agencies permits assessment for all residents in a jurisdiction that can provide a systems level perspective.⁵¹ Such assessments can help PH agencies, as they uniquely bridge clinical and community environments and reinforce and monitor prevention efforts.⁵² PH can build on successful early models,^{53,54} and then identify cost-effective dissemination strategies to spread these approaches.

Seminal PH systems and services research has identified^{55,56} four distinct domains that influence collective PH impact on population health: (1) PH workforce, (2) PH system structure and performance, (3) PH financing and economics, and (4) PH information and technology. HIE benefits to the last category are obvious. However, a narrow focus would limit opportunity and positive impact on developing a competent informatics workforce,⁵⁷ reusing data for quality improvement,⁵⁸ and achieving cost efficiencies,⁵⁹ across the PH enterprise. Below, each domain and its associated data and information needs and issues are described, followed by some potential PHSSR research questions that will benefit from both a systems approach and ever-growing technology opportunities.

Public Health Informatics Workforce

To turn volumes of unfamiliar health care provider data into information, skilled informaticians must transform data into information tools (e.g., registries) of value to PH officials, communities and individuals. Most PH agencies have a workforce incapable of successful linkage and utilization of new information. PH is challenged to extract key messages from near-real-time data streams given inadequate informatics skill and limited knowledge of standards, within its own workforce.

This absence of a robust and savvy informatics workforce is partially a consequence of competing markets; inequities exist in pay and benefits between governmental and private sector informatics positions. Recent clinical and private sector growth from HITECH incentives have drawn away many skilled personnel. Beyond these substantial recruitment hurdles, cost-cutting measures to restrict staff costs (e.g., hiring caps or freezes, travel freezes, and furloughs) challenge the capacity to attract, expand,

and retain qualified PH informatics personnel. The reality for most health departments is that informatics workforce investment is generally insufficient; thus, qualified new trainees often land in private sector jobs.

Given these personnel challenges, a broader, enterprise approach might help build a knowledgeable workforce corps through collaborative projects and a shared PH infrastructure. PH executive leaders should approach workforce competency development as a strategic informatics investment. While PH agency assets (e.g., systems, knowledge, and personnel) should be extensible and repurposed across programs, strategic decisions may require an even larger systems perspective. PH leaders need a cadre of skilled systems thinkers who critically understand requirements gathering, design, construction, deployment, and system maintenance for both internal and external exchange opportunities. Multiagency information exchange should reinforce a broader operational definition for the PH system (e.g., health department programs, health care providers, and accountable care organizations). Working across these systems, PH may find greater workforce synergies and better return on informatics investment. A savvy, systems-thinking and cost-conscious PH informatics workforce would contribute to the strategic multiagency planning, seeking cost-effective exchange solutions.

Research questions for PH informatics workforce investigation include the following: What are key governance skills⁶⁰ and methods to support technical solutions? How do managers most effectively leverage their community engagement experience toward strategic informatics alliances and investments? How does a skilled PH workforce help HIE members clearly articulate the intended usefulness of exchange to their organization? What are well-defined value propositions and how do they drive constituents to complete required legal, compliance, and governance documents (e.g., business associates agreement and data use agreements)? How do health departments achieve (e.g., internally or externally) subject matter expertise in these technology, legal, compliance, and privacy aspects?

Public Health (PH) Systems Structure and Performance

To benefit from EHR data exchange and reuse opportunities, local PH leaders with their communities should mutually develop a governance structure and resources for data sharing. Beyond existing mandated reporting, establishing a community structure and rules for why and how identified or de-identified information is shared is a nontrivial task. Abiding by federal and state regulations, the community needs a secure (e.g., authorized, authenticated, controlled access, and audited) network. Efficient reuse of health information from health care systems calls for standardized, minimally burdensome solutions for PH, health care providers, and EHR vendors. Processes for reporting and data sharing should be standardized to reduce PH investments to

receive and interpret new EHR data streams. Health care organizations will share information with PH agencies for community benefit when trust, standard systems, and responsibilities for both parties have been established. Trust is built on direct local relationships; participants must mutually do the following: (1) describe and approve a governance process; (2) build methods to assure quality, confidentiality and security; and (3) be good information stewards.

PH agencies need to explore and identify best practice HIE models from other jurisdictions. Finding the right tool may require significant effort since the modes are neither well developed nor broadly disseminated. To build broad local interest and for greater return on investment, a clear requirement should be organizing systems, knowledge, and data for maximal reuse. Resources are limited; federation with or replication of existing successful models is less costly than building *de novo*. PH leaders should consider regional and even national alliances (e.g., community platforms hosted at ASTHO⁶¹) to assure greater investment return using secure and transferable technologies (e.g., cloud-based solutions, see Table 2) to accelerate information and knowledge exchange.

Stakeholders (e.g., data partners, data users, and consumers) should be collectively involved in defining permitted disclosures and uses (e.g., identified line lists versus aggregated counts), through a local governance process.^{62,63} A fundamental benefit of distributed data queries is greater data partner operational control for when, what, and how data are shared. Yet governance structures are often highly specific and sensitive to local conditions (e.g., competitive markets, PH leadership). Engendering trust to share information may need to organically develop, based on a local imperative or champions. Alternatively, a financial incentive for health care provider participation in a distributed data network would be achieving a Meaningful Use measure (i.e., specialized registry). To ensure and enforce communitywide governance, external structural elements (e.g., data use and business associate agreements) build the information trust framework. A principle that encourages willingness to participate is adherence to fair information practices—share the minimum necessary information for a specified purpose.⁶⁴

Beyond governance, data sharing and reuse will operationally be facilitated when health care providers and the entire PH enterprise use a common set of component standards (i.e., security, data model, definitions, and query tools). Given its long tradition of safe and secure protected health information use for community benefit around notifiable or mandated PH surveillance,⁶⁵ PH has credibility in issues of security. Building on that skill set and use case, a common security framework and infrastructure should be established where PH agencies exchange data with health care partners.

The PH enterprise has been slow to embrace structural and semantic rules, unlike many other information rich industries (e.g., banking, food chain suppliers, shipping, and inventory control). PH agencies, as information stewards, need to actively oversee and protect these rules on the public's behalf. Stewardship extends beyond just the knowledge (e.g., rules), information, or data; there are important community relationships, resources, and services that are likely also shared. Within a PH agency, each program may have specific informatics needs and ideas. However, when considered as a system, all programs may better benefit from a common interoperability approach. EHR data will have higher PH value if multiple program-specific data streams are collaboratively curated. Using cost-effective and infrastructure-consolidating solutions, cross-PH agency registry capacity should be coordinated through a set of shared strategies and business intelligence tools. Good stewards might focus on achieving greater component (e.g., security, data models, and query tools) reuse, cost-effective solutions, dissemination, and transferability especially using cloud technologies.

Achieving one unified reporting infrastructure across a range of PH use cases (e.g., disease reporting, immunization registries, and syndromic surveillance) and jurisdictions may not be immediately possible. However, incremental progress toward secure, privacy protecting, cloud-based services shared across jurisdictions may rapidly accelerate health agency capacity and increase investment value. The current absence of multijurisdictional trust models, integrated infrastructures, and concordant and reconciled standard vocabularies limits local, state, and federal system synergies. Lack of a unified PH strategy and inadequate PH engagement (both nationally and regionally) results in dysfunctional standards and imperfect data sharing.

Research questions for PH systems and performance investigation include the following: What design requirements best support within- and cross-jurisdictional data sharing, standardization, and knowledge transfer? What has aided jurisdictions to maximally use HIE and effectively monitor PH intervention effects? How have jurisdiction- or region-specific lessons learned been leveraged for broader and more scalable enterprise solutions? What procurement regulations facilitate or create barriers for building common solutions? What governance, legal, and policy issues need to be addressed to build more multipurpose platforms that store and analyze exchanged data? What role should PH play in messaging rule adherence, promotion, and enforcement?

Public Health Financing and Economics

A 2010 National Association of County and City Health Officials (NACCHO) assessment identified limited local PH agency ability to access quality, timely, and actionable data for decision- and policymaking. Less than a third of PH agencies said their staff had

adequate levels of physical infrastructure including information technology necessary to receive, house, and manage data as part of their jobs.⁶⁶ Local health departments have great challenges in responding to HIE afforded by the HITECH Meaningful Use program. The NACCHO survey found that 72 percent of respondents identified insufficient funding among their top three barriers to system development.

Budget shortfalls have resulted in extensive staffing shortages at local, state, and federal levels. These seriously challenge PH agencies' ability to build the physical infrastructure and staff competencies to leverage the HIE opportunity. Reaching high information exchange functionality requires enormous investments. The Primary Care Information Project received nearly \$30 million from a combination of sources⁶⁶ to achieve the momentum, penetration, and evaluation capacity it has achieved. The New York City experience, with a ready supply of resources and manpower, is unlikely to be replicated across nearly 3,000 local and state health departments.

To fully maximize HIE opportunities, a PH agency should share resources between program areas. Archaic funding approaches and congressional politics have resulted in tremendous inefficiencies within health departments. Program-specific funding regulations directly inhibit development of program "agnostic," multiuse business-intelligence infrastructure. Architects do not design separate plumbing systems for each room in a house; one hot water heater serves the entire building. Similarly, a PH agency should be able to share technologies and gain efficiencies across program areas. Technologies are ever-changing; PH departments need to strategically manage their technology portfolio⁶⁷ to assure reasonable upfront and depreciated costs and investment return. By designing and building for aligned, cross-program, and cross-department functionality, PH agencies can encourage technology reuse, make more affordable investments, lower total cost of operations, and improve investment return.

Nationally, research should describe which laws, regulations, and federal policies inhibit or promote investment synergism and effective cross-program and jurisdiction collaboration (e.g., BioSense 2.0). Federal funding rules often promote silos throughout the PH sector. Cloud-based "platform as a service" (PaaS)⁶⁸ technologies offer alternative and potentially less costly approaches. Jurisdictions should review data management alternatives and potential need for remote hosting policies.⁶⁹ Multijurisdictional information system costs under alternate (e.g., cloud-based) solutions should be studied; comparison with current methods (e.g., PH agency-based) should identify which solution yields the best return on investment.

Research questions for public health financing include the following: What drives PH agencies to invest in informatics initiatives? What are the characteristics of effective crosscutting systems for regional and internal environments? What are the

unintended PH costs and risks for maintaining highly separated (silos) programs and information systems? How do those silos create burdens for vendors, eligible hospitals, and eligible providers who seek common or unified methods for sharing data with programs at health agencies, regardless of the jurisdiction? What standard language might federal program funding announcements use to hold funded agencies accountable for system integration and adherence to standards? What guidance strategies would encourage the following: (1) identification of PH agency commonalities, (2) multijurisdictional collaboration, and (3) economies of scale?

PH Information and Technology

An emerging strategic plan⁵⁸ and the Standard and Interoperability (S&I) Framework⁷⁰ are federal initiatives focused on greater HIE through better interoperability (e.g., computers communicating without human intervention). Current or recent S&I efforts of interest to PH agencies are summarized in Table 6.

HIE should support essential PH service delivery by making secondary use of information accessible to monitor health indicators.⁷¹ Despite emerging technical opportunities, there has been relatively limited local or state PH strategic enterprise planning. Some approaches might help develop more cost-effective tools and solutions for indicator measurement. Several multidisciplinary groups^{72,73} promote joint action planning for better PH community standards alignment and greater interoperability. Similarly, key CDC leadership and multiagency agreements (e.g., ASTHO hosting BioSense 2.0) create value and begun to fill infrastructure gaps. Having adopted a common syndromic surveillance monitoring platform (with relatively little PH agency investment), state and local PH agencies might look to that shared model and review opportunities for replication⁶¹ or further dissemination.

To generate meaningful information from new data streams requires standardized methods for frequent data communication between clinical environments and PH agencies. Case reports or observations in a registry (e.g., disease state, behavior, physiologic condition, or exposure) all need to adhere to structural message standards (e.g., c-CDA or HL7 2.x). Content, captured during care, needs to be conceptually organized in a standard manner. Completeness may be sacrificed as clinical workflows incompletely collect all required case reporting information. Even having a partially populated and timely form appear to the clinician who is using the EMR, permits the clinician to contribute key data in a structured format (Structured Data Capture⁷⁴). Forms should be presented to clinicians for completion at the best point in the workflow to get additional information. At the appropriate time, clinical decision support (Health eDecisions) should trigger a reportable (i.e., mandated or voluntary) health observation prompt to an end user, for sharing with PH agencies for situational awareness and decision-making. The Data Access Framework⁷⁵ proposes queries that happen locally (by providers within an organization), from one organization to another, and finally in a federated manner across organizations for a broad population view. The latter approach is a key PH function and reminiscent of the New York City³⁷ and Massachusetts⁴⁴ examples.

PH distributed queries and responses in PH are possible.²² Facilitated by the S&I Framework components described, those functionalities can be achieved with a common data language adopted across the ecosystem.⁷⁶ Similar to efforts in many state Medicaid agencies,⁷⁷ the PH enterprise needs to adopt a common conceptual and logical data model to limit variation in definition, meaning, and value sets across programs and jurisdictions. This would avoid unnecessary confusion, inefficiencies, and inability to rapidly reuse data. As active partners PH has an obligation to help build this data model and collectively develop enterprise standards.

Table 6. Standards and Interoperability Framework Components of Interest to Public Health

Component	Purpose	Example
Consolidated CDA	Standard message format	Cancer case report form completed by a clinician.
Query Health	Population based queries	Ability to query how many people have hypertension in a jurisdiction.
Public Health Reporting Initiative	Harmonized methods for PH reporting	Standards and implementation guides support bidirectional interoperable communication between clinical care and public health entities.
Structured Data Capture	Populate standard forms	A pertussis case report form is presented to a health care provider to collect a few data elements unlikely to be collected during routine clinical care.
Health eDecisions	Clinical decision support (e.g., triggers for PH screening or collecting data)	EMR presents a query to clinician asking if a newly diagnosed case of gonorrhea should be reported to the state or local health agency; or collect more complete data through structured data capture.
Data Access Framework	Query data: (1) locally, (2) to targeted organization, and (3) distributed across multiple organizations	Ability to conduct population queries (e.g., within a clinic, across an integrated delivery system or in a jurisdiction) regarding adequate control of hypertension.

Greater EHR data access and sharing for PH surveillance purposes requires a standard data model for optimal reusability. Beyond data modeling, concepts (e.g., population health indicators) and knowledge (e.g., rules engine for calculation of immunization up-to-date status) should be explicitly defined and easily shared across the entire health and health care enterprise. Once data, concepts, and knowledge are readily available, disseminated, and implemented in computable format, distributed partner queries are possible. With proper security, PH (e.g., Massachusetts⁴⁴) should be capable of submitting queries and receiving responses from providers to measure population health (e.g., registries) and support various reporting needs (e.g., nonprofit hospital IRS obligations,¹⁰ ACO,¹¹ and PH agency¹²). For urban areas, with access to routinely collected data (i.e., resident address), multi-institution registries could easily represent subcounty (e.g., census tract level) place-based population health assessments. These would blend well with place-based measures of the social determinants of health.

Poor vocabulary-standards adherence results in errors, incorrect results, and widespread inefficiencies. Meaningful Use incentives may offer greater data access, but progress toward standardization is often lacking. PH programs and departments need standard definitions, codes, and greater uniformity of workflow (e.g., inputs and outputs) before we might see benefits from consolidation and cloud-based solutions. To improve health outcome and health indicator monitoring,⁷⁸ PH should have tools that monitor and provide feedback on adherence to standard vocabularies. The goal may appear clear: consistent, uniform, and reliable population metrics (e.g., behaviors or outcomes). However, work remains as PH terms are variably defined, leading to confusion in surveillance measures.⁷⁹ To cost-effectively monitor populations and assess performance, the PH enterprise needs a logical, standard vocabulary. That vocabulary needs to be precise, yet adaptive or extensible for the advent of new data sources or concepts.

Federated query systems are not without their challenges. Similar to the internet, an efficient exchange system requires standard protocols to ensure that computers and systems “talk” to one another. Across systems, the nonuniformity of data structures, significant quality-control variations, and inconsistent programming are nontrivial data and systems management issues. Modeling data for storage and query needs to be cost-effective to encourage greater data partner participation. At the same time, it needs to have sufficient flexibility and extensibility to economically address new and emerging PH questions. Spending significant time planning for an optimal data model, and defining enterprise requirements and necessary quality assurance procedures,⁸⁰ prior to building data warehouses, will reduce partner inconsistencies (i.e., data quality, file structures, and variable definitions). Data partners need to be acknowledged for the public value and significance of their contribution. Efforts should limit overburdening these partners, as PH needs to set realistic query expectations.

Research questions for information and technology include the following: What barriers exist to achieving a comprehensive and community-engaged information strategy? What role should data partners play in data validation and interpretation of findings? What are (1) the costs for data partner participation, (2) the comparative data management techniques, and (3) the security measures across organizations? Formative consultative research with many data partners,⁸¹ suggests a variety of enhancements for effective, secure, and efficient data sharing and analysis. What is needed to establish a PH conceptual and logical data model; how is that model shared between PH agencies; and how do requirements change over time (e.g., incorporating new data types or elements)? How should a PH common data model leverage health care coding standards and support standard vocabulary mapping services? How should query tools work with a data model? How does the data model help design more transparent, intuitive, and user-friendly tools? How should knowledge (e.g., rules and decision support) be managed for efficient deployment, maximal reach, and proper results interpretation?

Conclusions

The PH enterprise has learned that collaborative approaches and greater information flow generally improve the timeliness of our response. Meaningful Use provides unique opportunities for quick wins from EHR-enabled HIE using newer and more easily deployable technologies (e.g., cloud solutions). While eligible hospitals and providers are challenged by near-term regulatory efforts (e.g., JCAHO, ICD-10 and Meaningful Use), the next three years of mandated Stage 2 exchange (i.e., immunizations, electronic laboratory reporting, and syndromic surveillance) and menu exchange (i.e., cancer registry and specialty registries) should create substantial gains in information access for PH.

Adopting consistent standards that vendors, hospitals, and providers perceive as a reasonable burden has been challenging for PH. Limiting the variation in interfaces (e.g., building common or unified business cases, and more scalable solutions) requires multiprogram and multijurisdictional PH collaboration. This requires a broad systems approach. PH agencies should actively engage in information system changes that limit implementation burden on partners through content, structure, and transport standards. For decades, immunization programs across the nation have adopted functional, technical, and semantic standards. Having standards facilitated the earlier inclusion of immunization data in Meaningful Use exchange, beginning in 2014. Future standards will emerge as PH creates compelling business cases and the benefits from health information sharing become more evident and achievable through uniformly applied interoperability standards.

Moving forward, PHSSR should inform practitioners about ways to replicate successes through vetting of pressing stakeholder business cases and consideration of cloud-based solutions. De-

fining value propositions, which empower and energize community stakeholders while cost-effectively supporting multiple PH programs and jurisdictions, is our current task. Using cloud-based solutions, a PH informatics infrastructure based on standards can emerge and be easily disseminated for HIE. PHSSR should study and then share informatics' best practice results (e.g., standards development, program-specific standards, standards sharing, knowledge management systems, and common data models) to achieve the greatest value.

Decades of experience with jurisdiction-specific initiatives leave PH agencies weary from failed exchange partnerships, idiosyncratic standards, and stories of poor implementations. Despite potentially dampened enthusiasm for PH, collaborative technology and systems-based solutions (e.g., emerging cloud-based services, adherence to national standards, and shared resources) offer enormous opportunities, particularly if PH focuses on improved interoperability. PH, along with community stakeholders affected by standards adoption, should drive the process. PHSSR should study these collaborative technology and system efforts in identifying key attributes of successful collaborators (e.g., end users, developers, and informatics experts), which may inform what workforce competencies are required to fully leverage and may make useful the information explosion. PHSSR should also help PH practitioners develop, define, and evaluate a strategic technology innovation roadmap. That roadmap should acknowledge the shortcomings of monolithic siloed and inflexible PH information systems.

Recent experiences suggest that the key components likely to maximize PH value from recent federal investments are modular systems, reusable data, shared services, and standards-based business intelligence design. To accelerate creation of these components and PH value from certified electronic health record technology, a cadre of local and state PH officials should collectively focus on achieving sufficient PH and health care interoperability capable of truly monitoring population health. PHSSR will be an essential component of building the evidence base needed to support local and state PH capacity to participate in the learning health system.

Acknowledgements

The paper was made possible through the funding of the Robert Wood Johnson Foundation and the leadership of AcademyHealth in organizing and supporting this author and others. The author would like to thank the many thoughtful individuals who commented on various earlier drafts of this paper: anonymous manuscript reviewers, as well as Scott Afzal, Linda Bilheimer, PhD, James W. Buehler, MD, Elizabeth Cole, Erin Holve, PhD, MPH, MPP, Barbara Ferrer, PhD, MPH, Med, Seth Foldy, MD, MPH, J.P. Leider, PhD, Remle Newton-Dame, MPH, Marguerite J. Ro, DrPH, Charles J. Rothwell, MBA, MS, Paula Soper, MS, MPH, PMP, and Matthew C. Stiefel, MPA.

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