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The Visit-Data Warehouse: Enabling Novel Secondary Use of Health Information Exchange Data

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Background: HIE efforts have generally formed for the primary clinical use of individual clinical providers searching for data on individual patients under their care, but many secondary uses have been proposed and are being piloted to support care management, quality improvement, and public health.

Description of the HIE and Base Infrastructure: This infrastructure review describes a module built into the Healthix HIE. Healthix, based in the New York metropolitan region, comprises 107 participating organizations with 29,946 acute-care beds in 383 facilities, and includes more than 9.2 million unique patients. The primary infrastructure is based on the InterSystems proprietary Caché data model distributed across servers in multiple locations, and uses a master patient index to link individual patients' records across multiple sites. We built a parallel platform, the "visit data warehouse," of patient encounter data (demographics, date, time, and type of visit) using a relational database model to allow accessibility using standard database tools and flexibility for developing secondary data use cases. These four secondary use cases include the following: (1) tracking encounter-based metrics in a newly established geriatric emergency department (ED), (2) creating a dashboard to provide a visual display as well as a tabular output of near-real-time de-identified encounter data from the data warehouse, (3) tracking frequent ED users as part of a regional-approach to case management intervention, and (4) improving an existing quality improvement program that analyzes patients with return visits to EDs within 72 hours of discharge.

Results/Lessons Learned: Setting up a separate, near-real-time, encounters-based relational database to complement an HIE built on a hierarchical database is feasible, and may be necessary to support many secondary uses of HIE data. As of November 2014, the visit-data warehouse (VDW) built by Healthix is undergoing technical validation testing and updates on an hourly basis. We had to address data integrity issues with both nonstandard and missing HL7 messages because of varied HL7 implementation across the HIE. Also, given our HIEs federated structure, some sites expressed concerns regarding data centralization for the VDW. An established and stable HIE governance structure was critical in overcoming this initial reluctance.

Conclusions: As secondary use of HIE data becomes more prevalent, it may be increasingly necessary to build separate infrastructure to support secondary use without compromising performance. More research is needed to determine optimal ways of building such infrastructure and validating its use for secondary purposes.

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Keywords

informatics, health information technology, quality, health information exchange

Disciplines

Computer and Systems Architecture | Health Information Technology | Health Services Research

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Conclusions: As secondary use of HIE data becomes more prevalent, it may be increasingly necessary to build separate infrastructure to support secondary use without compromising performance. More research is needed to determine optimal ways of building such infrastructure and validating its use for secondary purposes.

Introduction

Health Information Exchange (HIE) efforts have formed nationwide over the past 25 years to integrate a patchwork of medical information among health care systems and providers.¹ A recent survey identified 315 such initiatives nationwide.² These efforts inherently face significant challenges in implementation,³ usage and adoption,^{4,5} and the building of a sustainable business model.^{6,7} While there is some evidence that HIE can decrease costs by

reducing potentially avoidable hospital admissions⁸ and duplicate diagnostic testing,^{9,10} definitive evidence of the quality and safety benefits of HIE is lacking.¹¹ The recent wave of consolidation of health care provider organizations may in some cases render HIEs obsolete, since an entire region consolidated under one organization would be able to access data more easily, but complete regional control of health care by one organization is likely to remain rare given antitrust regulations.¹²

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HIEs have generally formed for the primary clinical use of an individual provider searching for clinical information on an individual patient across multiple health care provider organizations where the patient has received care. Now many secondary uses have been proposed and are being piloted including HIE-based notification services to support care management,¹³ quality measurement and improvement,¹⁴ public health,^{15–18} and others.¹⁹ HIEs face challenges with data quality as it is,^{20,21} but this becomes especially problematic when data is leveraged for uses beyond the primary clinical use.^{22–25} In this paper we describe a secondary data infrastructure that was built on top of a functioning HIE platform in order to support secondary use and prevent potentially negative impacts these uses might have on HIE system performance by inundating servers and slowing down patient-care queries.

Description of the HIE and Base Infrastructure

Healthix is an HIE based in the New York metropolitan region. As of January, 2014, Healthix comprised 107 participating organizations with 29,946 acute care beds in 383 facilities, included more than 9.2 million unique patients, and had approximately 6,500 users performing more than 10,000 searches per month.

Healthix's infrastructure (Figure 1) is based on the InterSystems vendor platform (InterSystems, Cambridge, Mass.), which is designed to support interoperability across multiple health care systems and is installed and in use by multiple health information organizations in Healthix to support HIE functionality. Each participating health care organization has a dedicated Caché "edge" or local server. All edge servers utilize a common data model, each with their respective site's patient-level encounter and clinical data. This network of edge servers allows them to act as a single distributed database. Caché is a proprietary hierarchical database system developed using the M or MUMPS programming language and is optimized for transactional use. It differs from relational databases such as SQL Server that are optimized for queries and reporting.²⁶ This means that the HIE's Caché platform is designed to support the primary use case of individual queries looking for detailed information on single patients, but is not well suited for cross-population queries that are often needed for secondary use.

When patients register for an encounter at participating organizations, their demographic information is sent in real time across an interface to the hub's master patient index (MPI) using standard Health Level 7²⁷ (HL7) messages and utilizing virtual private network (VPN) encryption technology to maintain security. The MPI performs a probabilistic match based on the patient demographic information,²⁸ uses predetermined thresholds tuned to maintain a low false-positive match rate to link individual patients to records across multiple sites, and assigns a unique enterprise patient identifier (MPI ID). Clinicians generally look up patient information using a Web-based portal, which queries the MPI for patient records at the various sites. If records are found, a "record locator service" at the hub creates pointers to the patient's clinical data on the various edge servers, allowing the data to be viewed in

the Web-based portal. This federated technical platform,²⁹ which supports the primary clinical use case, has been operational since 2008 and allows each site to maintain physical stewardship of their own clinical data since only the patient demographic data is centralized at the HIE's hub.

Issues with the Base Infrastructure

The HIE architecture was designed to support the primary clinical use of patient record lookups through a clinical portal as described above, and this results in hundreds or thousands of transactions per minute. There was concern that layering additional services for secondary use cases on top of it would cause server performance issues, since additional demands on the existing technical platform could cause slow response times for end users making clinical portal queries. Additionally, because the operational platform utilizes the proprietary Caché hierarchical data structure, we needed to have a more common relational database model in place for developing custom software and performing analytics. As requests for secondary uses of HIE data became more prominent, the need for a separate, real-time database to support them became necessary and led to the development of the visit-data warehouse (VDW).

Secondary-Use Cases That Prompted the Development of the Visit-Data Warehouse

Four specific proposed uses prompted the creation of the VDW. First, as part of a Centers for Medicare & Medicaid Services (CMS) funded project to improve geriatric emergency care in a new dedicated geriatric emergency department (ED), it was proposed initially to use HIE data to track metrics through a weekly report including the following: (1) average number of ED visits per patient per year, (2) average number of hospitalizations per patient per year, (3) average number of 30-day hospital readmissions following hospital discharge per patient per year, (4) average number of 6-month hospital readmissions following hospital discharge per patient per year, and (5) average number of 72-hour ED return visits following a treat and release visit from the ED per patient per year.

Second, as part of the same CMS-funded project, and as an enhancement to the weekly reports, the creation of a dashboard was also planned, using standard business intelligence tools. The dashboard provides a visual display as well as a tabular output of near-real-time, de-identified encounter data from the VDW. Built-in queries are based on the above five metrics with additional parameters based on user input for date range, hospital name, report type, and patient age range. The results are exportable in standard format for additional analysis. The user is able to view information on a summary level (all hospitals with aggregated results) and at a detail level (specific hospital to patient level information).

Third, frequent ED use has been identified as a general marker of high utilization of health care resources,³⁰ and frequent ED users as a population may potentially benefit from intervention such as

intensive case management.³¹ Use of HIE data has been previously shown to significantly increase the ability to identify frequent ED users.¹⁴ While previous efforts have identified potential candidates for intervention via retrospective analysis of ED visits,^{32,33} the VDW will be used to detect, in near real time, when any patient registers for a fourth ED visit within 30 days across all EDs in the HIE. Such detection then triggers an automatic notification to an ED case manager to screen the patient for potential benefit of additional services aimed at reducing ED recidivism. This feature has been developed and is undergoing technical testing against the VDW data source.

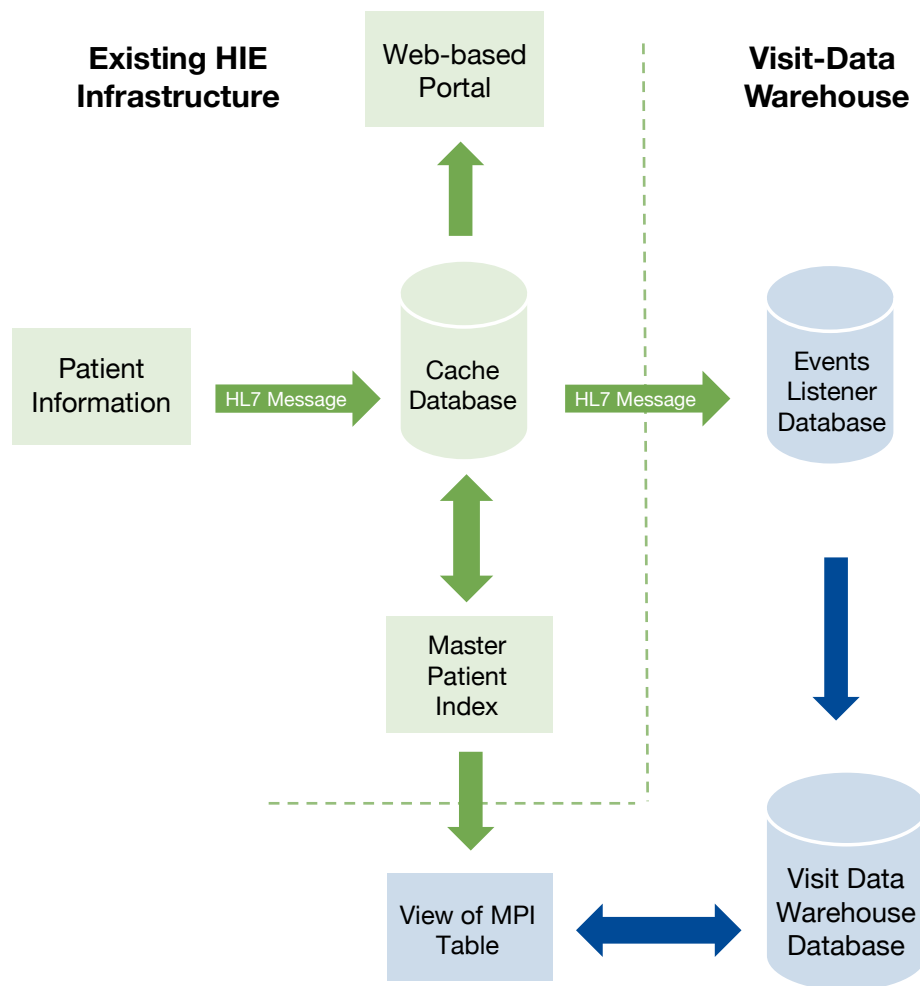
Fourth, patients who revisit the ED within 72 hours of ED discharge may represent errors in diagnosis and management.^{34,35} Furthermore, a patient receiving suboptimal care at the first visit might be more likely to visit another hospital for that “return” visit. Indeed, a preliminary study across a relatively small HIE showed increased detection of patients visiting an ED again within 72 hours by 11.6 percent when compared to individual, site-specific ED analysis.³⁶ The analysis included only a small portion of EDs in that region, possibly underestimating the effect 72-hour returns analysis would show if a substantial portion of the region’s EDs were included. The VDW allows a monthly report

to be used as the basis of improving an ongoing 72-hour returns, continuous quality-improvement program by providing information on return visits to 31 hospitals participating in Healthix. The latter two secondary-use case projects were funded by a grant from the Agency for Healthcare Research & Quality (AHRQ).

Visit-Data Warehouse Infrastructure

The VDW (Figure 1) is built on a Microsoft SQL Server database model using specific HL7 messages and utilizes an “events listener” database, which captures a predetermined list of patient events based on those HL7 messages. Specific data elements in each message include hospital name, patient medical record number, admission- and discharge dates and times, encounter type (emergency, inpatient or outpatient), and a unique identifier for the current visit. Once an event is captured, a patient lookup is performed using the MPI service. The VDW database is then linked to a view of the MPI table. Using the MPI ID, the patient can be tracked across multiple sites within a specific time frame. Essentially, the VDW provides a separate, near-real-time relational database model for all inpatient and ED encounters across the entire HIE that is updated on an hourly basis, which can then be utilized for secondary use cases and for analytics and reporting using standard business intelligence tools.

Figure 1. Workflow Diagram for the Interaction between the VDW and the Primary HIE Infrastructure



Many electronic health records (EHRs) use Caché-like hierarchical databases for routine transactions, while moving data to a separate data warehouse based on a relational database, such as SQL server, on a regular basis (usually nightly) to be available for queries. The VDW is based on this model but its structure allows near-real-time updates of the data to support alerts for use cases that are time sensitive, something that EHR-based data warehouses do not typically support. Additionally, the VDW differs from EHR-based data warehouses in that it is built on an HIE and offers analytics and reporting capabilities across 31 hospitals, many of which have their own separate EHRs and data warehouses that are not able to interoperate directly with one another. This allows the VDW to harmonize data across multiple care settings in order to facilitate reporting and analytics across the entire HIE.

Development of the VDW is complete, and it is deployed in a “stage” environment to undergo technical and data validation testing. As an example, during a 24-hour period on July 25, 2014, there were 21,724 ED visit “admission, discharge, or transfer” (ADT) transactions; the average latency between the ADT message being sent from the local server and the update taking place on the VDW’s events listener database was 2.56 minutes (SD 10.5). We set the VDW to update on an hourly basis since this was all that was required by the use cases discussed above.

Early Lessons Learned from Visit-Data Warehouse (VDW) Development and Testing

Initial implementation and testing of the VDW in 2014 and feedback from testing protocols used to validate the VDW data led to some important lessons learned, which might apply to others embarking on similar projects. The following paragraphs describe these lessons learned.

Nonstandard Implementation of HL7 2.X

Although HL7 provides standard message types for the transactions of interest—namely admissions (using an HL7 “ADT^A01” message), discharges (using an HL7 “ADT^A02” message), and updates (using an HL7 “ADT^A08” message)—HL7 has not been consistently implemented by all 31 hospitals contributing data to the VDW. For instance, some hospitals are sending repeated HL7 updates as A01 messages, which are typically used for admission messages, not for updates. This has made it very difficult to accurately define the beginning and end of encounters across sites, and will likely require the creation of a mapping table to translate the flow of various message types from across multiple providers to a common standard, since the various message types do not necessarily have the same meaning from one site to the next.

Missing HL7 Messages

Since the HIE was originally built, beginning in 2008, there have been variations in the HL7 messages sent from various sites, with some of the sites only sending A01 admission messages for ED visits without a corresponding A03 discharge message to end the visit. Since the discharge date and time is never displayed in the clinical portal, and as this was not an absolute requirement for the

primary clinical use case, the implementation decision was made to place the date and time from the A01 admission message in both the ED admit- date and time and the ED discharge- date and time fields so that the two values are equal. This was necessary in order to close out the visit since the HIE platform required an entry for discharge date and time. While this does not affect most of the above-described intended uses of the VDW, it does pose problems when calculating 72-hour ED returns. Seventy-two hour returns are typically calculated from the discharge time of the first visit to the admission time of the second visit, and since ED visits sometimes extend over days, the margin of error may approach the 72-hour mark in some instances. To correct this, imputation techniques based on average ED length of stay may be used during our analyses, but a permanent fix will need to be implemented at the Healthix interface level on a site by site basis.

Data Latency and Automated Monitoring

The VDW was designed with a near-real-time data “currency” goal, aiming to have all data current within one hour. Because there are a large number of HL7 messages flowing from the HIE’s Caché database edge servers to the events listener database and then to the VDW, with an MPI lookup being performed in order to link patients across sites, there are multiple potential points of failure that could prevent information from being updated in a timely manner. As part of testing, a daily report is run that looks for problems caused by interfaces malfunctioning or by messages queuing up. The report calculates current time minus the last message time for each site, then color codes the results as green (< 1 hour), yellow (2–12 hours), or red (> 12 hours). The report also tracks system downtimes by site, showing periods of missing data over the course of the last month so data can be restored through a separate process. As a more permanent solution, automated monitoring tools are planned for at various critical points in the information flow described in Figure 1 that will automatically notify systems administrators if data stops flowing at an expected rate across various junction points.

Governance Issues

The Healthix Participant Agreement, signed by all participating organizations, and the Healthix Privacy and Security Policy, approved by the Healthix Board of Directors, both provide for the sharing of clinical and encounter data across the HIE for clinical care coordination and quality assurance purposes, provided that the patient has given consent. Since the secondary use cases described above all fall within the Healthix definition of care coordination or quality assurance, the projects themselves posed no issue from a governance standpoint. However, since Healthix was set up as a federated HIE in order to allow each organization to maintain stewardship of its own clinical data through the use of dedicated edge servers at each site, setting up this centralized encounter-data warehouse was met with some concerns. The trust and close communication built among the participating organizations over the years through the Healthix governance structure, which includes a Board of Directors and Privacy and Security, Clinical Advisory, and Data Use committees, was an important factor in overcoming initial reluctance and allowing the VDW creation.

Suggestions for Future Use and Implementations

In addition to the four secondary uses described earlier, other potential use cases include 30-day readmission alerts to empower various care-coordination efforts aimed at decreasing these events. In this use case, care managers would be alerted that a recently discharged patient has registered in an ED or been admitted at any of the HIE sites. Another potential use case is a duplicate imaging alerting system. This would allow a real-time, clinical-decision support alert to be displayed at the point-of-order entry if a patient for whom a clinician is ordering an imaging test, such as a CT scan, has had multiple prior similar tests. This functionality would require the addition of indicator variables for imaging studies to the VDW. We are exploring both of these potential uses for implementation into our HIE.

Although we believe this work should be easily generalizable, further work should be done to assess the various needs of other HIE efforts across the country to enable secondary use, and to assess how requirements for parallel data infrastructures might vary. HIEs that use a centralized data model with a single database rather than the federated model our HIE uses would likely also face the issue of server overload in a real-time reporting system requiring the separate reporting database we describe. While the implementation described in this paper was “homegrown,” there are various vendor platforms that could potentially be used to accomplish the same. We would have likely faced similar implementation challenges with other platforms since the issues we describe revolve around data sources and governance.

Besides the technical issues described above, much work needs to be done to develop standard ways of measuring data quality in HIE environments, and to validate the use of HIE data for secondary uses.^{21,23,24} Once adequate data has accumulated in the VDW it should serve as a good platform for performing descriptive analyses to ensure that the data is of sufficient quality by further testing for data concordance, comprehensiveness, and timeliness.

As mentioned, HIEs face challenges in building sustainable business models. We believe HIEs can use data from their existing primary infrastructure, as we did, to showcase the potential benefits of secondary uses when attempting to procure funding for building this secondary use infrastructure.

Conclusions

In summary, secondary use of HIE data holds significant potential benefit in areas such as quality measurement, population management, and care coordination. If leveraged appropriately, these secondary uses could prove even more valuable than the primary clinical use case for which most HIE networks were developed. In this paper we describe the creation of a parallel infrastructure that takes advantage of existing HIE systems to enable novel secondary uses of the data despite the distributed and proprietary nature of the existing HIE platform. This new infrastructure allowed development of secondary use cases without compromising the

performance of the existing primary HIE platform. HIE data should allow for more accurate measurement of various metrics, reflecting the way in which many patients access health care across multiple providers. However, adequate infrastructure must be developed to support secondary data use in an HIE environment, and steps must be taken to ensure HIE data quality.

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