Flexibility in EHR ecosystems: five integration strategies and their trade-offs

Authors: Lars Kristian Roland, Terje A. Sanner, Margunn Aanestad, Department of Informatics, University of Oslo. Emails: lars@roland.bz; terjeasa@ifi.uio.no; margunn@ifi.uio.no

Abstract

In this paper, we address various strategies to integrate Electronic Health Record systems with other software features and information sources. We identify a critical tension between a) the end users’ desire for a seamless EHR workflow, and b) the system architects’ desire for a loose and modular integration, which favors change and evolution of various applications and components over time. Through a qualitative study from Norway, we examined the integration strategies of an EHR system with i) a specialized patient record solution for childbirth, ii) an ePrescription system, and iii) an integrated Summary Care Record system. We complement these empirical studies with related research concerning one additional EHR integration strategy identified in the health informatics literature. We illustrate how four of the strategies compromise either end-users’ need for seamless workflow or system architects’ desire for a changeable and loosely integrated portfolio of information systems. However, one particular strategy, albeit experimental, shows promise in resolving the identified tension to a more substantial degree than the other four.

Keywords: eHealth architecture, EHR, integration, seamless workflows, use-flexibility, change-flexibility.

1 THE PROBLEM OF INTEGRATING APPLICATIONS INTO ELECTRONIC HEALTH REGISTERS (EHR)

Healthcare workers are dependent on the availability of comprehensive information in their work. The Electronic Health Record system (EHR) is a core application in hospital departments, specialists’ and general practitioner offices as well as in nursing homes. Despite its centrality, EHR design still leaves much to be desired in many settings. Friedberg et al. (2013) claim, based on a US study that the IT industry has failed to provide appropriate IT tools for doctors and that the introduction of systems such as EHRs have worsened their professional satisfaction, rather than improved it. Although the study indicates that doctors have an overall positive attitude to EHR introduction, poor user interfaces with slow and overly templated data entry, lack of cross-institutional information access, yet increasing information overload are pointed out as major issues with current solutions (ibid, Payne et al. 2015). In this paper we address one aspect of this complex problem; the need for the EHR workspace to be integrated with other information sources to support clinical practice.

If a health worker’s workflow associated with treating a patient involves interacting with multiple applications besides the EHR, the user who encounters lack of integration between such applications may resort to workarounds (Damsleth 2013). A common workaround would, for example, be the use of Windows clipboard to copy data between applications. The term seamlessness denotes the perceived support for workflow across applications and varies inversely with the number of workarounds required to perform the work tasks. Across hospitals, some use EHR systems that are monolithic (“suite” applications) and others use composite or “best of breed” systems (Koppel and Lehman 2015). In either case, there is a need for some degree of interoperability with additional systems. In the Norwegian health sector, there are thousands of applications at multiple sites that require various levels of integration with the EHR (Heimly et al. 2011, Bygstad and Hanseth 2016). These systems include both local applications (e.g., specialized systems for medical charts, imaging, equipment), or external, inter-organizational systems and national solutions that span the whole sector (such as national solutions for ePrescription or nationally shared EHRs). The approach for integrating
these systems has not been systematically discussed in the healthcare IS or medical informatics literature, and we, therefore, offer a theoretically informed empirical investigation into five different EHR integrations strategies.

A starting point for our conceptualization of EHR integration is the inherent tension involved with providing the health worker with a high level of workflow support (understood in this context as seamless cross-application integration). This seamlessness requires tight integration of relevant information sources in an individual’s workspace (Humphreys 2000, Ellingsen and Monteiro 2006, Weng et al. 2012, Krist et al. 2014). However, from a strategic and architectural perspective, there is a need to provide the solution cost-effectively to a broad population of end-users, who will have different information needs and use a multitude of different information systems. In this article, we use the word *scaling* to describe this need for large-scale solution adoption, expansion, and growth. The tight coupling of two systems that exhibit a high level of workflow seamlessness may negatively impact the efficiency with which IT professionals can meet future needs and provide improved functions to the user population (Ellingsen and Monteiro 2006). Also, tight integration makes future changes more problematic than if the coupling between systems is looser. Our interest here is in creating a better understanding of the issues involved when dealing with this dilemma in the context of the EHR workspace. We contribute to knowledge about how local EHR workflow support can be balanced against cost-efficient governance of the health information infrastructure as a whole. Health professionals need useful systems, and at the same time, managers and architects need their portfolio of information systems to be governable and changeable over time, which ultimately also is in the best interest of end-user clinicians.

Methodologically we proceeded as follows. We first examine relevant literature to identify integration strategies (or options/styles) that are feasible for integrating the EHR with third-party systems and applications. We then conduct an expert survey to validate our initial analysis, followed by a case study of three Norwegian integration projects. With each of the five integration strategies we identified, we examined their potential to support seamless integration and flexibility, and we compare the experiences regarding the trade-offs between seamless local integration and large-scale standardized infrastructures. We find that four of the strategies prioritize either seamless integration or change-flexibility and compromise the other dimension. Interestingly, one integration strategy appears to resolve the tensions between the two equally desirable goals but remains experimental in practice. Our conclusion supports the view that EHR integration can help reduce the costs and frustrations of IT in clinical practice and help promote the goals of increased quality, accessibility, and efficiency of the provision of health services (Eysenbach 2001), while keeping in mind the professional satisfaction of clinicians (Friedberg et al. 2013, Payne et al. 2015).

2 FIVE INTEGRATION STRATEGIES IN THE EHR WORKSPACE

This article concerns integration related to a single user dividing a task between multiple systems, rather than issues arising when multiple different users access one or more systems as shown in the figure. The term workflow in this paper therefore addresses a single users’ perspective of a sequence of tasks, rather than multiple health workers’ tasks in an integrated patient pathway.

1) Same user accessing multiple integrated applications

2) Integration between two different systems used by different users

*Figure 1 shows two of several possible dimensions in which integration can be considered. Integration can concern communication between two applications that are used by the same health worker (1), for example, an EHR and a connected application. Integration can also concern communication between two systems that are...*
used by different health workers for treating a single patient (2), such as the communication between two different EHRs. This paper is limited to scenario #1, and we expect the more complex scenario #2 to be shaped by additional dimensions.

The extant literature points to several ways in which third-party functionality and data sources can be integrated into an EHR workspace. The following five strategies, named A-E, for EHR-application integration vary for example with regards to the degree of separation and independence, mode of data exchange and sharing of patient context, user log-in and usage pattern (semantic and concept equality), and EHR vendor control and ownership. Other integration strategies may exist but have not been covered in this study and are to our knowledge not widely adopted in practice.

A. A separate application that is distributed and managed independently from the EHR. The application may use EHR interfaces for sharing login, the patient context and data between the EHR and the application. The user works with (i.e., enters and reads information from) each application separately. The EHR vendor is not involved in distributing or managing the external application (Berger and Baba 2009, Skorve and Aanestad 2010).

B. The application is a web application embedded into the EHR. The application is downloaded from a separate server, allowing external parties to update the applications without interaction with the EHR vendor. The EHR may provide interfaces for identity, context, and data sharing for tighter coupling between the application and EHR (Mandel et al. 2016, Mandl et al. 2015, Mandl and Kohane 2009, Mandl and Kohane 2012).

C. The third-party application (e.g., a module) is integrated into the EHR by the EHR vendor. The modules are bundled with the EHR and do not work on their own (Mandr and Kohane 2009, Bernstein et al. 2005, Koppel and Lehman 2015, Pesaljevic 2016, Hanseth and Bygstad 2017).

D. The EHR vendor implements the whole user interface but uses standardized interfaces towards third-party backend services, which can be reused by multiple EHR systems. These central components can have shared storage and/or services (Noumeir 2011, Koppel and Lehman 2015, Pesaljevic 2016).

E. The EHR vendor implements the whole user interface but includes configurable intercept points (sometimes called “hooks”) to external services to fetch and display external information as part of the workflow (Warner et al. 2016).

3 ANALYTICAL PERSPECTIVE: SEAMLESSNESS AND FLEXIBILITY IN HEALTHCARE INFORMATION INFRASTRUCTURES

Studies of information infrastructures constitute the exploration of large, complex and evolving information system architectures, where immediate and local needs are continuously contested and negotiated against large-scale efforts to harmonize and standardize across local settings (Rolland and Monteiro 2002, Monteiro et al. 2003). This tension has been expressed as inherent with generic solutions to particular needs (Ellingsen and Monteiro 2003), or as a tension between standardization and flexibility (Hanseth et al. 1996, Ellingsen and Monteiro 2006). In particular, Ellingsen and Monteiro (2006, p 443) argue, in the context of health information system integration, that “[e]nforcing order in the form of standards across multiple local settings, seemingly a prerequisite for tight integration, simultaneously produces disorder or additional work in other locations for other users.” Here, we draw on an information infrastructure perspective to explore how the five EHR integration strategies outlined above balance tensions between “local” end-user needs for seamless workflows and “global” concerns for long-term configurability and change of national and inter-organizational eHealth architectures, of which EHR systems are essential components. Specifically, comprehensive and integrated EHRs have been proposed as a means for integrating heterogeneous systems in healthcare information infrastructures, but too comprehensive standardization and consolidation efforts may also lead to stagnation, curb innovation, and negatively affect evolving clinical practice (Ellingsen and Monteiro 2003, Ellingsen and Monteiro 2006).
With traditional information systems development, it has been noted that system flexibility can be realized both at the time of implementation/change and at the time of use (Orlikowski 1992). An information infrastructure, with a high level of interdependence between actors (e.g., client organizations, vendors, IT-departments and governance bodies) and system components, typically has low flexibility for further change (Hanseth et al. 1996, Hanseth and Lylytinen 2004, Roland et al. 2017, Sanner et al 2012), due to high technical complexity, diverse interests among heterogeneous stakeholders and challenges with coordinated actions across systems and actors. Further, the flexibility for change of large and complex systems has been linked to modularity, in the form of architectural layers and “lean” modules that are loosely coupled (Braa et al. 2007, Edwards et al. 2007, Hanseth et al. 1996). Modularity is a design principle that emphasizes the development of small and reusable components with clearly defined interfaces between them, rather than developing one comprehensive system or product where functional interdependencies are hard to discern (Baldwin and Clark 2006, Baldwin and Woodard 2008, MacCormack et al. 2006).

Gebaur and Schober (2006) build on Hanseth et al. (1996) to discern two types of information system flexibility: (i) flexibility in the pattern of use (short: use-flexibility) and (ii) flexibility for further changes (change-flexibility). Gebauer and Schober define use-flexibility as the range of process requirements supported without major changes, where a major change constitutes “adjustments and modifications that require a fresh system setup, including re-installation and re-testing” (ibid, page 128). Use-flexibility thus refers to flexibility “out of the box” for use across a range of different, even unanticipated purposes and tasks. Design and use-flexibility have been described as relational in the context of information infrastructures because a high level of use-flexibility reduces the need for change-flexibility, and vice versa (Hanseth and Lylytinen 2004, Hanseth et al. 1996). In relation to the current study, we further specify that use-flexibility is closely tied to the choices and activities of end users or IT support functions close to and responsive to end users' needs, while change-flexibility is more closely associated with design decisions made by system architects, IT governance bodies and external vendors of “off the shelf” software packages such as EHR solutions. We further note that different actors in an information infrastructure can tap into a varying degree of use-flexibility and change-flexibility, depending on their roles, skills, ownership, and interdependencies.

Change-flexibility in the context of healthcare information infrastructures is shaped by both social and technical arrangements. These factors include IT personnel’s skills and mandates, contractual arrangements and regulations, the choice of standards and interfaces between integrated data sources and applications in the overall architecture, and modularity, for instance, provided by re-usable software modules and vendor-independent database connectivity. In essence, change-flexibility constitutes different actors' ability to provide new functionalities, recombine and reorganize access to various data sources and to allow for modifications of the user interface for instance to support more seamless EHR workflows. Hanseth et al. (1996) emphasize the importance of exploring the relative degrees of flexibility with different solution types to maximize flexibility for future change. In this study, we examine the flexibility to change associated with five EHR integration strategies and juxtapose it with the ability of the integrated EHR solution to support clinical tasks through seamless workflows. Hence, we use the term seamlessness as a quality of EHR workspace integration, indicated by the accomplishment of a task that traditionally spans multiple applications and data sources.

When users attempt to accomplish tasks and encounter lack of seamlessness (i.e., lack of integration between data sources and applications), they fill gaps by introducing their own workarounds (Damsleth 2013). A workaround can, for example, be the use of Windows clipboard to copy patient data between applications or manually edit and manipulate text files generated by one system before they are uploaded to another system for sharing with other professionals. Lack of design-time integration is compensated by use-flexibility workarounds (ibid). As such, the necessity for workarounds can be seen as an indication of how well applications and data sources are integrated. We understand the total flexibility of an integrated EHR solution as constitutive of use-flexibility and change-flexibility, in addition to manual workarounds that may be both intended and unintended from the system architects’ perspective to meet the limitations with EHR integration (Gebaur and Schober 2006). Beyond seamless workflow to support tasks, we note some prerequisites to any integrated EHR solution including security, certification, data protection and following laws and standards that are
mandated within the region/country. These requirements will most likely affect the choice of EHR integration strategy and, as we show with the five strategies identified in this paper, will, in turn, shape the balance between change-flexibility and the seamlessness of integrated EHR workflows.

4 RESEARCH APPROACH AND METHODS

4.1 Research context

Norway had an early adoption of EHRs at all levels of the health service. The first rollout started in 1985, and the penetration had reached 90% by 2000 for general practitioners and 2005 for hospitals (EPJ Monitor 2008, Heimly et al. 2011). In 2008 the last of the public hospitals implemented an EHR system. The early and distributed introduction of EHRs led to a fragmented EHR landscape. One implication of this fragmentation is that making common EHR changes across the whole healthcare sector is difficult (EIEJ 2015). There are multiple EHR vendors for the hospitals (>2), municipalities (>3) and general practitioners (>3). While there is a national program in place to consolidate EHR systems into fewer systems (EIEJ 2015), the current situation is that rollout of any national services requires a tremendous amount of integration work with each of the EHR vendors.

Two of the national solutions targeting health workers in Norway are ePrescription and Summary Care Record (SCR). Both these applications are integrated into the EHRs using Norway-specific mechanisms that include several of the integration types described in this paper. The hospitals in Norway currently integrate a large number of local solutions covering vertical usage needs into their EHR system. One of these applications is a solution that offers a structured user interface documenting data around pregnancy and childbirth.

4.2 Qualitative case study

This research is based on a qualitative study of three Norwegian cases that highlight different aspects of the dilemmas associated with the integration of EHRs and other applications. The three cases represent five different integration strategies and their outcomes. The first case (Childbirth record) represents type A (a separate application operated in parallel with the EHR), the second case (ePrescription) represent types C and D, and the third case (Summary Care Record/SCR) represents type B, but is moving towards type D. We could not identify any Norwegian implementations of category E and had to rely on the limited experiences reported in the literature. The SCR and ePrescription solution are national solutions that have been integrated into a large number of EHR systems in Norway and are by many considered templates for future similar projects. Learning more about how these templates perform in sustained use is therefore useful for future EHR integration projects. The study was designed to collect information about the experiences with these different integration strategies, explicitly concerning the trade-off related to workflow seamlessness and change-flexibility.

4.3 Data collection

The primary author is a part-time Ph.D. student and works at the Norwegian Directorate of eHealth as a solution architect. In this role, he has engaged in projects that include architecting application integration with EHRs. All interviews and other data collection were conducted by the primary author, while the two other authors have participated in framing the study, analyzing data and have given feedback on the study and manuscript. The data collection covered several data sources: 1) participation by the primary author in meetings and user forums regarding EHR and application integration over a period of 2 years, 2) informal discussions with project members and colleagues, 3) review of documents from the Norwegian Directorates of eHealth and Health, including user survey reports, 4) review of previously published case studies concerning the Norwegian Summary Care Record and ePrescription (Hanseth and Bygstad 2017, Pesaljevic 2016, Larsen and Mydske 2013), 5) formal, semi-structured interviews with 20 managers, architects, product managers, developers and end users. The formal, semi-structured interviews followed an interview guide that started with a general discussion about application integration into EHRs, followed by the interviewees being introduced to the five types of integration as described in Figure 1, which prompted a discussion about the five integration types. The description and comparative evaluation of the types evolved during the
study, based on feedback from interviews. As examples, strategy A, which exemplifies separate applications, was initially portrayed as an undesirable alternative, but based on interview feedback this strategy was considered to be both important and sometimes necessary. Many interviews led to a discussion on how real-life implementations used a combination of the different integration strategies over time. The five integration strategies were initially founded in extant literature, backed by empirical data from data collection points 1-4 above, but were then refined and validated through the semi-structured interviews.

4.4 Data analysis

Interviews were recorded and transcribed. In the analysis phase, keywords, concepts, and quotes illustrating characteristics of the types and dynamics between them were highlighted. Contradictions between assumptions in the categorization and the interview observations led to iterative changes of the integration strategy typology. Data were further analyzed using data displays (Miles and Huberman 1994) to exemplify contrasts between the different integration types, some of which were refined and included in the discussion part of this paper. For example, the weighting of the different integration strategies regarding tradeoffs related to seamlessness and flexibility were a result of data display analysis and repeated iterations of data display revisions after discussions between the three authors and with informants during interviews.

The three empirical cases served slightly different purposes in the analysis process. The childbirth journal case served to explore the aspect of seamlessness (in cross-application integration). The four seamlessness characteristics derived from the first case were then used to analyze the second and third case in more detail. For these two cases, we collected more data and focused on the implications of the chosen integration solution for both the initial implementation and for further change.

![Diagram of integration strategies]

Figure 2 shows the final version of the figure that was used during interviews to get feedback on the categorization of integration types. The figure was revised from interview to interview.

5 FINDINGS

5.1 Childbirth record solution (Type A: separate applications, minimal linkages)

Clinicians use a structured user interface in the childbirth record application to document observations and treatment, some of which is exported to the core EHR as documents. The clinicians also use the EHR directly to view other relevant information about the patient, including data entered by other departments and historical data. The childbirth record and EHR system are accessed as separate applications, and the user must log in separately to each of them. The systems are linked so that
selecting a patient in one application also synchronizes the patient context with the other. Patient safety is the primary reason for this context synchronization: “In a heterogeneous environment, maintaining context is the main problem … there are many applications in a hospital” (source). Patient safety is not the only reason: “This is primarily about patient security, but it is also a matter of saving time for clinicians” (architect). The two systems are also linked on the data-level by exporting documents from the childbirth record to the EHR (the level of integration and type of integration interfaces varies between hospitals and software versions). The EHR and childbirth record exhibit different conceptual and semantic approaches, as the childbirth record application requires more structured data and the EHR uses more unstructured free-text documents. This difference between structure and free-text was perceived to be a change in documentation “culture,” and was “a barrier for the doctors who were more used to the [EHR]. Some doctors felt that the narrative and some subtle nuances were lost in the structured data.” (Architect).

From this case we identified four aspects that relate to the integration of workflows between the applications: 1) Is there a shared user identity and login? If yes, this lowers the hurdle of having to log in multiple times. 2) Do the applications share patient and treatment context? If yes, this prevents having to find the patient and consultation in each application. 3) Do the applications share relevant data? If yes, this prevents double-entry and inconsistency between data. 4) Is there visual, semantic and concept equality among the systems? If yes, this prevents having to switch documentation and reading style/cognitive style. In the following we thus conceptualize systems integration as related to 1) user’s identity; 2) patient/treatment context; 3) data exchange; and 4) visual, semantic and concept equality.

5.2 National ePrescription solution (Types C and D)

Two different integration patterns emerged in the evolution of ePrescription. Overall, the Norwegian national solution for ePrescription uses a message-oriented, client-server architecture, with a national server and distributed clients at pharmacies, general practitioners, hospitals, and municipalities.

The ePrescription project started in 2003, with the first successful pilot beginning in 2009. The initial plans were to reuse the prescription modules that existed in the general practitioners’ EHRs and integrate these with a national prescription database (integration type D). The integration strategy required the vendors to undertake development, and this route turned out to be a lengthy and challenging process. The central project decided to develop and freely offer an alternative, external prescription module, to support EHRs that lacked ePrescription support. This module required lower investment from the EHR vendors and resolved the problem of the delayed roll-out. The external prescription module comes with its own ePrescription user interface, logic and local storage, pre-integrated towards the central component. However, the module is not usable on its own, so we classify the external module as an instance of integration type C. Thus, the resulting architecture allowed for two different ways to integrate the EHR with the national ePrescription infrastructure as is shown in figure 2. These two approaches use the same standardized messages towards the central prescription server.

![Diagram](https://via.placeholder.com/150)

Figure 3 shows the two ePrescription implementation alternatives, with or without the external prescription module.

Integrating the external prescription module into an existing EHR is considerably cheaper than developing a vendor-specific prescription module from scratch. However, when EHR vendors develop
own modules, these are typically more seamless with the rest of the EHR workspace and have a similar look-and-feel.

In contrast, the visual appearance of the external prescription module looks different from the rest of the EHR, though there are plans to allow vendors to adapt the external module’s appearance. If vendors are allowed to adapt the external module’s appearance to fit their EHR, this integration model also approaches the type D category, because the EHR vendor will have stronger control over the development.

Whether the user interface was consistent with the rest of the EHR was found to be significant for the user experience. During the rollout of ePrescription, it became evident that many clinicians are sensitive to the look-and-feel and semantics of their workspace. Even minor differences in views seemed to make a difference, as stated by a project member: “The clou is work process. You must ensure a consistent work process for the doctor. During quality surveys of ePrescription, we have seen that just filling in a simple checkbox can be a huge barrier. To enable consistent work processes and to ensure that this is an efficient tool that supports the user’s needs, it is required to be an integrated solution. If not, it will not be used.”

Let us consider the change-flexibility of the ePrescription solution. Introducing new functions into the ePrescription infrastructure has proven difficult, given a large number of independent actors and a distributed architecture that requires all involved actors to be part of implementing new features. No actors have end-to-end control. Although the implementation of ePrescription is widely considered a success, there are therefore challenges with introducing changes and new functions into the existing infrastructure. Even adding a single attribute to the standard messages requires work in all EHRs. However, there is a difference between the external and internal implementations related to the ability to change, because the external module can be installed and updated independently of the EHR vendor’s roadmap.

The following example illustrates this difference: A function that has been planned since the beginning of the project is the support for multidose prescriptions, a necessary feature for patients who use multiple drugs that should be prescribed and dispensed together. The current method for handling multidose is a paper card that is faxed between the general practitioner and pharmacies. Introducing an electronic version of multidose is therefore considered a priority in the Norwegian health care sector. The external prescription module has supported multidose functionality since 2014, but EHR vendors have not yet implemented this feature into their own prescription modules. Hence, EHRs using the external module can already support multidose.

5.3 The Norwegian Summary Care Record (Type B, migrating towards type D)

The SCR is a national solution that collects information about patients (including recently dispensed medication, visits to health facilities, allergies, etc.) in a national database that health workers can access when necessary. The data available is not a complete shared record, and availability of some data depends on clinicians entering data manually. To access the SCR, the health worker starts from the standard patient view in their local EHR. If the integrated SCR-button in the patient view is red, this indicates that there is critical information stored in the national database. Clicking the button brings up the national web application in an embedded browser. The patient context passes from the EHR to the central web application, but no data integration is available yet. The clinician must enter data manually or use Windows clipboard to transfer data between the EHR and the web application, i.e., requiring the use of workarounds. The lack of seamless data integration with other views of the EHR has been pointed out by users as a significant barrier to adoption. The SCR provider is currently implementing standardized interfaces that can allow structured data to be integrated seamlessly into the EHR by the EHR vendor, as an alternative or complement to the web application (e.g., prescriptions and allergies). Both the web application and information exchange through tightly integrated standardized interfaces are planned to operate in parallel, to fit different usage and solution scaling needs.

The choice of an embedded web application was deliberate, prioritizing the need for national scaling of the solution. “The strategic choice was considered carefully and still feels correct. With the limits
The project had at the time, within the first year, it was impossible to integrate tightly with all EHRs for all the necessary content. There were many EHR vendors, and the pilot had to cover the whole chain. This complexity was the reason for the decision to use web integration” (project member). This strategy required an initial investment in aligning actors, setting standards and implementing the technology in the EHRs. However, the investment was rewarded by the simpler deployment of new applications since the web application can be updated centrally without making changes to the local EHRs. “With the web application, updates become super flexible. We can fill the portal with lots of new content and have it spread overnight to the whole health service. This is one of the greatest advantages. It works in practice. We deliver four times every year, and the new functionality is available when we have finished deploying.” (Project member). However, the same project member acknowledges that the tight integration could have come earlier: “to reduce the noise we should perhaps have implemented the service-oriented interfaces and tight integration earlier, to avoid double registration of data.” Establishing the web platform capability in the EHRs has been a painful process.

The initial rollout had to deal with delays in EHR version rollout, differences in web browser vendors and versions, infrastructure connectivity, the need to introduce electronic signatures and the resolution of other required infrastructure issues, all contributed to slow down the implementation.

The US initiative called “SMART-on-FHIR” represents a more widely standardized, but similar web-based integration strategy as that used in SCR. “SMART-on-FHIR” is an open framework that enables embedding web applications into EHRs, with standardized mechanisms for authentication, authorization, context and data sharing (Mandel et al. 2016).

5.4 Strategy E – Allowing external “intercept points” to engage with the workflow

We could not identify any Norwegian implementations of category E and had to rely on limited experiences reported in the literature, although one informant argued that the red SCR button is a standardized EHR intercept point. An open initiative for embedding intercept points and micro-services into EHRs is the Clinical Decision Support hooks (CDS-hooks), which connects small external services as part of an EHR-supported workflow (Warner et al. 2016). CDS-hooks is currently being included in the HL7-FHIR standard.

6 ANALYSIS

6.1 Summary of findings

The various cases illustrate different trade-offs between seamlessly integrated workflows across applications (tight integration) and change-flexibility (loose integration).

Table 1 shows a comparison of the five integration types, along the dimensions of seamlessness and flexibility. The rating is based on interview data and specific feedback from interviewees when asked about the seamlessness and change-flexibility of each integration strategy. These judgments have been assessed and supplemented by the researchers’ analysis of the other empirical material (e.g., documents and surveys).

<table>
<thead>
<tr>
<th>Integration strategy</th>
<th>Cases</th>
<th>Seamless workflow</th>
<th>Change-flexibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>A - Separate applications</td>
<td>Childbirth Journal</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>B - Embedded web</td>
<td>Summary Care Record (SCR)</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>C - Native modules</td>
<td>ePrescription using the external module</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>D - All UI implemented by EHR vendor</td>
<td>ePrescription using the EHR system’s internal prescription module</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>E - Standardized intercept points into workflow</td>
<td>No Norwegian case. CDS hooks is an example, but not yet widely deployed.</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

The score in the column “Seamless workflow” relates to how well four dimensions of seamlessness are supported. These were: 1) shared user identity, to prevent having to log in separately; 2) sharing...
patient, encounter and treatment context, to prevent having to find the patient and encounter in each application; 3) sharing of relevant data between applications, to prevent double-entry and inconsistency between data; and 4) semantic and visual concept equality/similarity.

A - Separate applications: Low seamlessness + Medium change-flexibility

The category of separate applications rarely achieves full workflow seamlessness according to the four criteria. The childbirth journal case met some criteria since the patient context and data was shared between the applications, but users did have to log in twice. Data integration was limited, and the structural concepts were very different between the two applications. Type A has therefore been rated as low on context seamlessness. However, support for richer context APIs in the EHR would improve context seamlessness. Other instances of this integration type may therefore score differently. It scores higher on change-flexibility, as the separate applications can be updated without mutual adjustment between the vendors. We classify the change-flexibility to medium since this type of local application still requires updating a large number of installations to deploy new features nationally.

B - Embedded web applications: Medium seamlessness + High change-flexibility

Embedded web applications have varying degrees of integration with the local EHR workspace. The Norwegian SCR web application is currently integrated at step 1 and 2 of context seamlessness, while sharing of data is achieved through the use of the Windows clipboard. The introduction of full SMART-on-FHIR support or other structured interfaces would allow for better sharing of data between the application and EHR. It is however unlikely that step 4 could be reached with a web application in the short term. Step 4 would require that the two applications appeared as a single application to the end user, sharing user interface concepts and semantics. The change-flexibility of this solution is very high, allowing over-night updates of the core solution and full availability of new features immediately without any local changes. However, this positive flexibility rating may underestimate the organizational aspects such as training required for new and updated functions.

C - Bundled third party application modules: Medium seamlessness + Medium change-flexibility

Because the EHR vendor is responsible for integrating the module in type C, this type can provide better context seamlessness than both A and B, though dependent on the module’s integration capabilities. The visual appearance and semantic interoperability of applications are critical to clinicians, and the considered ePrescription feature of allowing adaptation of the module’s user interface appearance would further improve the level of context seamlessness, possibly addressing level 4. Adapting the user interface per EHR would, however, lower the change-flexibility dimension of the solution. In respect to change-flexibility, type C is classified as medium, somewhere between A/B and D, because implementing new features may require mutual adjustment between stakeholders. The implementation of automated update tools in the ePrescription case improved the change-flexibility of the solution.

D - User interface entirely developed by EHR vendor: High seamlessness + Low change-flexibility

When the EHR vendor implements the whole user interface, they are better equipped to provide consistent views that flow well between different tasks, even if some of the functions require backend calls to external components. The level of context seamlessness for this integration type can therefore be high, as the feedback of the ePrescription project shows. However, we saw from the ePrescription project that integration type D scores poorly on change-flexibility. For example, the multidose functionality that was quickly introduced in the external ePrescription module has still not been introduced by EHR vendors using type D, even after several years.

E - EHR workflow with standardized hooks for apps: High seamlessness + High change-flexibility

Type E has not been treated in any vignettes, and it remains to be seen how well this type supports context seamlessness and change-flexibility in practice. The vision of those behind initiatives such as CDS Hooks, one implementation of type E, seems to be that it would be a win-win for both dimensions. The ability to plug in external functions into various parts of an otherwise seamless workflow may be a dream worth pursuing, perhaps combining the best parts of type E and B. The
success of this type would be highly dependent on a successful establishment of the EHR as a platform for external services, a vision that not all informants of this study considered realistic.

6.2 Change-flexibility of EHR ecosystems

The integration scenarios described in the vignettes above engage and link the stakeholders in the EHR ecosystem differently. These different stakeholder relationships have significant implications for the overall change-flexibility of the ecosystem, understood as the ability to evolve. With evolve, we, for example, mean adding new functionality and recombine different data sources. Choosing an architecture for integration, will among other things shape and impact the innovation dynamics in the EHR ecosystem as a whole. We illustrate two different dependency variants in figure 3 below.

1) For the integration strategies A, B, and C, where the EHR plays a central role as an ecosystem enabler, the project first goes through an ecosystem enablement phase and secondly enters an innovation phase. In the first phase, the standardization, creating central enablers for platform services and implementing platform support in the EHRs are prerequisites for open application development. During this enablement phase of the ecosystem, we see reciprocal interdependence between the involved actors as the core platform functions are forged. Subsequently, we see an innovation phase where external parties can develop applications with limited involvement from the ecosystem enablers. In this phase, new applications using standards and central infrastructure can be developed without changes to the EHR platform enabler. Evidence of this platform creation was seen in the SCR case and ePrescription when using the external prescription module.

2) For integration strategy D, the sequence of events and interaction between players is different. The EHR vendor must be involved for each new application since the full user interface and logic are implemented by the EHR vendor and must be planned as part of the EHR roadmap and deployment rollout. The central standards for the applications must be developed ahead of EHR development of the user interface. After standardization and creation of central components, the actors are reciprocally interdependent and require mutual adjustment during development. For each new application and function to be deployed, one may need to return to the first step of standardization and re-engage with EHR vendors. This strong interdependence was seen in the ePrescription case when adding multidose functionality. The feasibility of this scenario for implementing new functions will depend highly on the number of EHR vendors and the complexity in upgrading on-premise EHR installations. The outcome may be favorable regarding workflow seamlessness through context sharing.

A, B, (C): Create platform and ecosystem supporting multiple applications

D, (C): Work independently through whole chain for implementation of new applications

Figure 4 shows how an initial investment of a platform may enable the development of several parallel applications after the platform has been established.
6.3 Trade-offs in EHR ecosystems

Figure 4 maps out how the various EHR integration strategies balance the trade-off between workflow seamlessness and change-flexibility:

![Diagram showing trade-offs between seamlessness and change-flexibility.

Figure 5 shows how change and design flexibility contrast with seamlessness.]

The vignettes indicate that EHR integration efforts may target multiple integration strategies within the same project, drawing benefits from different strategies for separate use cases. Two of the vignettes show that one may also decide to leverage different integration strategies over time to fit the scaling requirements of the initiative. In both the SCR and ePrescription projects, types B and C that favored change-flexibility were chosen early on to help scale the solution across the national base. Accessing all users in the country was more important than optimizing seamlessness for specific users. These early strategies were followed by type D that improved workflow seamlessness for clinicians. An emphasis on usefulness and simplicity for clinicians (e.g., through close user involvement) may initially favor integration strategy D since this is experienced as more seamless by the end user and reuses existing EHR functions. However, such initiatives could encounter challenges of scaling and change-flexibility in the EHR ecosystem. In the childbirth record case seamlessness could be prioritized over reaching many users. In this case, the project could benefit from giving priority to measures that improve seamlessness for type A or choose D instead. The real world challenge that faces implementers is, however, a careful balance of multiple types of integration and related concerns, governed by conflicting project goals.

7 CONCLUSION

In this paper, we have analyzed the relationship between seamlessness and flexibility when integrating applications with the EHR workspace. Seamlessness was found to include 4 characteristics: 1) shared user identity, to prevent having to log in separately; 2) sharing patient, encounter and treatment context, to prevent having to find the patient and encounter in each application; 3) sharing of relevant data between applications, to prevent double-entry and inconsistency between data; 4) semantic and visual concept equality. Five different types of integration strategies were found in extant literature, and their characteristics were refined through an empirical case study. We compared the five integration strategies with respect to change-flexibility and seamlessness. Some integration types exhibited higher change-flexibility (A, B, C) while one (D) showed high potential for seamlessness. Future empirical research is required to assess whether the fifth type (E) indeed lives up to the expectations to deliver both change-flexibility and workflow seamlessness.
The empirical cases from Norway showed that IT professionals can and do choose different strategies based on their requirements for reaching a large number of users, or optimize workflow seamlessness of the solution, and that a single project can plan to employ more than one integration strategy throughout the project lifecycle to optimize for example national scaling in one phase and workflow seamlessness in the next.

The more change-flexible types (B, C, and D) require an enablement phase where platform features are developed. These types need open interfaces in the EHR to be able to deploy, as well as a functioning ecosystem where the EHR vendor plays an important role. We can see signs of such platform enablement of EHRs in the healthcare industry (Mandel et al. 2016), but it remains to be seen how successful these initiatives will be. A shift may occur when the EHR vendors start basing their application development on their own open interfaces (Roland et al. 2017).

The study is based on an examination of three Norwegian projects, and a more comprehensive study, including an international perspective, might have yielded other insights. We also wish to clarify that there are additional factors (beyond change-flexibility and workflow seamlessness) that play a role in making decisions on the types of integration. Some other factors include whether the solution was located on-premise or in the cloud, or if the integration efforts were implemented by one of the vendors, the healthcare organization itself or a third party. We believe that our study demonstrates the need to pay careful attention to the balance between workflow seamlessness and change-flexibility to succeed with visions an integrated EHR ecosystem.

8 REFERENCES


