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Quantitative metrics for evaluating the phased roll-out of clinical information systems

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ABSTRACT

Objectives: We introduce a novel quantitative approach for evaluating the order of roll-out during phased introduction of clinical information systems. Such roll-outs are associated with unavoidable risk due to patients transferring between clinical areas using both the old and new systems.
Methods: We proposed a simple graphical model of patient flow through a hospital. Using a simple instance of the model, we showed how a roll-out order can be generated by minimising the flow of patients from the new system to the old system.
Results: The model was applied to admission and discharge data acquired from 37,080 patient journeys at the Churchill Hospital, Oxford between April 2013 and April 2014. The resulting order was evaluated empirically and produced acceptable orders.
Discussion: The development of data-driven approaches to clinical Information system roll-out provides insights that may not necessarily be ascertained through clinical judgment alone. Such methods could make a significant contribution to the smooth running of an organisation during the roll-out of a potentially disruptive technology.
Conclusion: Unlike previous approaches, which are based on clinical opinion, the approach described here quantitatively assesses the appropriateness of competing roll-out strategies. The data-driven approach was shown to produce strategies that matched clinical intuition and provides a flexible framework that may be used to plan and monitor Clinical Information System roll-out

1. Introduction

The implementation of hospital Clinical Information Systems (CISs) is known to be complex. Poor implementation has previously led to delays in full functionality, and in the worst cases, systems remaining partially deployed for long periods [1–3]. In many instances, poor performance following the introduction of a CIS may be attributed to the system not functioning as intended. For instance, Darbyshire reported how one such CIS was considered unsuitable by clinical end users [4]. In contrast, Huerta et al. showed that the effect of a CIS on hospital productivity depended on the rollout strategy, which suggests an effect due to the implementation process itself [5].

One key decision during CIS implementation is the roll-out strategy used to determine how the system is introduced into each clinical area. CISs can be rolled-out according to one of two broad approaches. In a big-bang approach, the whole system is adopted over a very short period of time for a whole hospital site. Alternatively, in a phased approach, subsections of the hospital are moved to the new system over an extended period of time. The phased approach may also refer to the gradual release of system functionality, such that users are not immediately exposed to a system's full capabilities.

Big-bang implementations have previously been recommended for stable systems that do not contain critical functionality [6]. In practice, technical constraints mean that a big-bang approach is often appealing [7]. For instance, in the case of Computerised Physician Order Entry (or e-Prescribing) systems, simultaneous deployment in clinical areas and pharmacy, is necessary to ensure that drug orders can be completed using the new system [8]. Other practical considerations such as financial and time constraints may also influence the implementation approach (for example, if required human resource is only available for a short duration). The drawback of the big-bang is that it exposes an organisation to a large degree of short-term risk. A successful big-bang must ensure that all IT infrastructure and organisational processes, including staff training and down-time procedures, are in place ahead of roll-out [9]. Phased roll-out limits risks by confining initial deployment to a small area. This allows early validation of the system and also

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reduces the initial resource required [9,10]. After the initial validation, the phased approach allows for mid-course corrections that are not possible in a big-bang methodology [11]. Furthermore, a phased roll-out offers opportunities to study the effect of a new system using a stepped-wedge approach [12,13]. This methodology monitors an intervention over time, allowing the effect of temporal confounders to be identified.

Phased roll-outs introduce their own problems, including an extended transition period between the existing and new system. During this transition phase, uncertainty in clinical process may lead to duplication of documentation on both the old and new systems, or worse, omission of data from either system [14,15]. For this reason, current UK guidelines on the implementation of e-Prescribing systems recommend rapid phased rollouts, colloquially described as 'rolling thunder' [16].

The order in which clinical areas, or groups of areas, are introduced to the new system is a key design decision for phased roll-out. The order of the roll-out is determined by multiple factors. Technical factors include the system's usability which may be influenced by more widespread IT infrastructure failings such as poor Wi-Fi coverage, as well as system performance and financial cost. Social considerations include how well staff engage with a new system. For example, the reticence of clinical staff to engage with new systems has been well-documented as a key problem [17,18].

Organisational factors include effective change management, provision of clear leadership (clinical champions), and successful evaluation of the system [19,20]. Finally, patient safety must be considered. One possible approach is to minimise the number of patient episodes documented using both old and new systems.

In practice, the order of clinical areas in a phased roll-out is usually chosen in an *ad-hoc* manner. In the best cases, CIS roll-out strategy is informed by qualitative information such as on-site interviews to assess human resources, emotional ability to support an CIS, and office dynamics [16,21], whereas often there is no documented strategy.

We address the issue of roll-out order in phased implementation using a graphical framework. The framework explicitly models patient transit between clinical areas using the old and new systems. In doing so, it directly quantifies factors related to both patient safety and clinical workflow. Whilst consideration of patient transits does not account for Organizational or Technical factors, the proposed framework may be adapted to include such factors. We show a simple example of this framework applied to the rollout of an electronic vital sign observation system. The example shows how different ordering strategies can be compared to identify areas at greater risk of patient information being stored on multiple systems, which may complicate clinical care.

2. Methods

2.1. Model

We model a hospital as a directed graph in which clinical areas are nodes. Each area, w, has a state, s, indicating whether it is on the old ($s = 0$) or new ($s = 1$) system. Clinical factors that may impact the effectiveness of a CIS rollout are modelled in two ways. First, the net number of patients transferring between two areas per unit time are modelled as weighted edges. The set of transfers into area w is denoted by $\boldsymbol{I_w}$, and the set of transfers out are denoted $\boldsymbol{O_w}$. Other clinical factors associated with area w are represented by a feature vector, $\boldsymbol{V_w}$. In practice, elements of $\boldsymbol{V_w}$ might include ward acuity (on a scale of 0–3) [22], staff to patient ratio. The general model is depicted in Fig. 1.

The impact of an area changing state from 0 to 1 is evaluated through a cost function, $\delta(w) = \delta(\boldsymbol{I_w}, \boldsymbol{O_w}, \boldsymbol{V_w})$. The form of the function is set on a case-by-case basis and determined by the relative importance of each factor. The need to explicitly choose a function, a priori, is comparable to other modelling techniques such as Gaussian Process regression [23].

Having developed a model and cost function, a greedy algorithm (Algorithm 1) can be used to determine a roll-out order [24]. In a greedy algorithm, the ordering is constructed one area at a time. Each area is chosen by selecting the one that minimises the cost function given the order that has been constructed so far. The chosen area is then appended to the current order.

Algorithm 1. Clincal area order algorithm

Assuming W is the set of all clinical areas, P is a list of ordered clinical areas, and δ is the cost function

while $W \neq \emptyset$

find $w \in W$ *that minimizes* $\delta(w)$

let $W := delete(w, W)$

let $P := append(w, P)$

2.2. Model instance

One instantiation of the model is now described for the problem of phased roll-out between paper and electronic (e-Obs) systems for recording vital signs. Fig. 2 shows a simple model of a hospital containing 6 clinical areas, labelled A to F. Patients arrive at the hospital from the pre-hospital population, σ, and leave to the post-hospital population, τ. The number of patients transferring between wards per unit time are denoted by the edge weights − for example, 3 patients/time transfer between A and C.

To generate a rollout order, the cost function, $\delta(w)$, must first be defined. To define the cost function we consider that, during a phased rollout, patients may transit between the two systems in the following ways:

1. paper → paper
2. paper → e-Obs
3. e-Obs → paper
4. e-Obs → e-Obs

Transition 1 represents current practice where a paper based system is ubiquitous and is considered to be of acceptable clinical risk. Transition 4 represents patient movements in which the receiving and sending areas are using e-Obs. We consider this to be of acceptable clinical risk, since this is the desired transition after roll-out. Transitions 2 and 3 pose greater clinical risk, since these only occur during the phased roll-out. In both of these situations, data must be stored on two separate systems. This may result in situations where clinical staff are unable to quickly synthesize the full patient record. However, transition 2, from paper to e-Obs, is unavoidable in a phased roll-out.

Therefore, the simplest usable cost function considers only the number of patients with an electronic → paper transition. No other features are included, so $\boldsymbol{V_w}$ is not used in this instance. The number of e-Obs → paper transitions is simply the sum of the subset of $\boldsymbol{O}$ for which adjoined areas have a state $s = 0$:

$$\delta(w) = \sum_{i \in W} o_i \times \overline{s_i}$$

In the event that two or more areas have the same value of $\delta(w)$, we may consider the net number of paper → e-Obs transition as a tie-breaker.

A rollout order can now be generated by applying Algorithm 1 using this cost function. The result of two steps of the algorithm is presented pictorially in Fig. 2. In the first step, all clinical areas are considered and their cost functions are calculated. The cost and tiebreaker are shown as the pair $(\delta(w), tiebreak(w))$ in the first column of Table 1. Initially, area E is activated, since $\delta(E) = 0$ and the tie break is smaller than that of area F (for which $\delta(F) = 0$). In the second step, $\delta(E)$ is no longer