Modeling Participation in the NHII: Operations Research Approach

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Abstract

Regional health information organizations (RHIOs) form the core of any approach to creating the National Health Information Infrastructure. RHIOs are computer-supported information sharing alliances composed of health care institutions that exchange clinical, financial or administrative data. Many uncertainties, including institution conversion costs, price-to-participate, and RHIO governance decisions, make estimating the cost consequences difficult to establish. Current approaches to health information technology investment rely on a net present value analysis, which is inadequate to capture the dynamic, uncertain course likely to occur in the RHIO environment. Methods from operations research provide decision makers robust tools for exploring the cost and consequences of RHIO structures. We present here an initial modeling approach that allows explicit examination of RHIO structure and pricing options. Once refined, these models will provide the core of a suite of decision support tools for evaluation of RHIO pricing options, discount rates, and optimal organizational structures.

Introduction

Forty years' efforts to infuse information technology into health care have recently received a political boost from endorsement by key clinical, technical, and federal groups of the vision to provide seamless pathways for health data integration. The need for a National Health Information Infrastructure (NHII) – computer networks that support complete access to clinical records, enhance public health responsiveness, and facilitate authorization for and payment of care services – is widely recognized and accepted[1-3]. Yet the move from technical vision and political mandate to systemic interoperability requires concerted action to establish networks that support secure transmission, agreements on data standards, and sustainable financing strategies[4].

Health information technology (HIT) investment arises from administrators' strong beliefs that HIT will accomplish clinical goals and operational efficiencies[5,6]. Attention is paid to insuring physician buy-in[7], and to market place advantages afforded by this investment[8]. Economic evaluations of HIT generally take an institution-specific perspective and largely address internal information systems. Several models exist that apply net present value (NPV) approaches for anticipating the cost and benefit of these institution-specific information systems. These efforts, both retrospective and prospective, have included initiatives such as in-house implementations of systems incorporating computerized physician order entry[9] and outreach initiatives such as telemedicine[10]. Most analyses to date take the perspective of an individual practice group or health care institution evaluating the ability of its internal information systems to create clinical records or submit claims[9,11]. Few systematic approaches exist to aid decision makers to make investments that will facilitate the interorganizational information sharing envisioned under the NHII initiative. Absent systematic approaches to understanding the financial considerations of RHIOs, institutions have little guidance beyond altruism to examine the costs and risks of RHIO participation.

Background

Early efforts in community health information networks (CHINs) resulted in a diverse set of RHIO exemplars, ranging from interorganizational alliances that maintain secure network communication for claims management[12] to outreach configurations in which a medical center created communication pathways with selected partners[13]. The promise of CHINS to support health data sharing never fully materialized. Indeed, the CHINS' failure may be traced to the absence of business planning models to examine consequences of network configuration, transaction volume and financial incentives[3].

In the emerging NHII environment, several network configurations are proposed including single owner of an enterprise-wide communication channel and community-owned partnerships[2,3]. A few health information exchange relationships stand out as viable prototypes for the regional health information organizations (RHIO) that form core strategy of the NHII. The Indianapolis Health Information Exchange connects 13 hospitals with hundreds of physician offices. The New England Healthcare EDI Network supports authorization and claims processing[14]. The Santa Barbara Care Data Exchange created alliances among medical centers, diagnostic laboratories and primary practice sites[15]. Each RHIO established unique arrangements regarding the nature of data exchange, management of patient identity, assignment of provider subscription costs, and whether to maintain centralized information storage.

Large players in a given market place, usually hospitals or academic medical centers, often serve as the initiators in the drive towards RHIOs[15]. In

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addition to facing the greatest need for information exchange, they are perceived to have the necessary resources and institutional mandate to provide such leadership. Yet the true value and cost of the investment in regional information sharing exchanges far exceeds the set-up cost, conversion expenditures and alliance maintenance, and is not knowable under present economic valuing approaches. Accurate valuation of RHIO participation can only be estimated by approaches that not only account for costs and benefits that arise from the institutions' participation, but also the consequence to the participating institution of the presence and behaviors of others institutions in the alliances.

Operations research methods, including real options analysis and stochastic programming, offer promise in modeling and exploring RHIOs because they allow for explicit representation of the information exchange network. Yet these methods are complex in themselves, so to initiate evaluation of their utility in pricing RHIO participation it is necessary to build and evaluate basic model approaches.

A NETWORK VIEW OF HIT INVESTMENT

Many advocate incremental approaches to building the NHII that begins with establishing institution-specific electronic health records systems that will eventually scale into the platforms needed to effectively participate in RHIOs. Chismar and Thomas[16] demonstrate by using models from supply chain manufacturing that a given institution's return on investment in HIT is a function not only of the operational benefit incurred within the organization from HIT investment but also from the opportunities for cross-institution information integration enabled by that HIT investment. Only a single institution's incentives are considered, and participation in any RHIO-type relationship is risk-free and permanent.

Middleton and colleagues[17] proposed an investment-return framework for health information exchange and interoperability. Envisioning a 10-year rollout, a net cost-benefit return of $337B to the American health care system was anticipated. Central to this framework are standards that provide full machine-interpretable data. The framework restricted the analysis to known participants (hospitals, clinics) and ignored conversion of legacy data from existing health information systems as well as possible losses to individual participants (e.g. laboratories) arising from reduced redundancy in test ordering.

Financial considerations must address not only a single institution's investment, but also the consequences to that investment of the participation of other members in the information exchange. Berman, Zahedi and Pemble[3] applied integer programming to create a framework for assessing the optimal size of a RHIO. Their approach offers insights into a multi-institutional alliance, and applies one class of operations research models relevant to RHIO structure and performance. However, it limits considerations to sequential choices at single time points, and it ignores risk and uncertainty. Models that explicitly incorporate uncertainties and risk over time will provide more realistic and actionable depictions of RHIOs' performance.

Effective guidance regarding the structure and economic consequences of RHIO must move beyond the net present value (NPV) approach. The deterministic NPV method is appropriate provided the problem satisfies two conditions: (1) there is no risk, and (2) the alternatives among which a choice is to be made are independent. Neither of these conditions is satisfied in RHIOs. In order to create the testbed environments for examining investment in RHIOs it is necessary to construct more complex models that explicitly account for risk. We provide here a preliminary description of a base model as a first step, in a system of models to capture RHIO performance over time.

MODELING RHIO INVESTMENT DECISIONS

Complexity of a decision process increases the need for formal tools to aid analysis of the underlying system. Many disciplines have embraced the notion of optimization as a key tool to enhance the quality of decisions taken. Stochastic programming and real options models have significant potential for treating the uncertainties found in the RHIO problem. By determining a distribution of possible future events such as hospitals' joining or leaving a RHIO, and modeling system response to those situations, we can formulate a multi-stage decision model to evaluate present courses of action with uncertain futures. However, before full-scale models can be evaluated in a stochastic environment, it is necessary to construct basic models to understand key parameters and their consequence on RHIO participation.

Methods and Approach

We developed preliminary models formulated as mixed-integer linear programs within the GAMS modeling system[18], utilizing CPLEX as the solver. CPLEX solves linear and mixed-integer programs, utilizing state-of-the-art branch-and-cut and branch-and-bound procedures for exploring the solution space. The models are multi-period but static (in that the data are not time-dependent) and deterministic (no accounting for uncertainties).

The models estimate the benefit of the RHIO as the sum of several factors. The *base benefit* of enterprise HIT is added to an *incremental benefit* of RHIO membership, which is a (increasing) function of the current size of the alliance. *Entry costs* of joining the RHIO and *membership costs* are subtracted from these benefits. We have considered data from a variety of existing alliances to estimate several of the parameters in the models. The incremental benefit of joining an alliance is adjusted not only for the size of the alliance, but also for the relative size of the participating hospital and the effects of an unwieldy transaction environment. Entry cost includes a fixed cost of entry (depreciated over time) and a unit cost that varies with alliance size.

The model has a set of hospitals *H*, characterized by bed size, and 16 time periods *T*. In order to predict behavior of these hospitals, the model needs to estimate both the costs and benefits associated with joining, remaining in, or leaving an alliance. The benefit to a hospital of infrastructure is estimated by two components, a base and incremental benefit. *Base benefit* reflects the value of enterprise HIT as measured in monetary units. The model assumes this is fixed throughout the time period considered. Base benefit is unaffected when a hospital joins an alliance. The model fixes the base benefit as a multiple of hospital size.

The second component of the benefit calculation is an *incremental benefit* to the hospital from joining the alliance. The benefit is calculated using

$$\text{incben}(h,t) * (X(t) - \text{size}(h))$$

where $X(t)$ is the size of the alliance at time t, size(h) is the bed size of hospital h, and incben(h,t) is given data representing the incremental benefit of h being in the alliance at time t. Since we believe that alliance membership is a function of use of the data, as well as access to large amounts of data, we modify this additional benefit in two ways. First, a <u>capacity limit</u> is applied to the incremental benefit allowed in a given period that is a multiple of the base benefit. The hospital's ability to use additional information is implicitly limited by its size. We account for the reduction in benefit that might occur as the alliance grows and hence access to information becomes more cumbersome. The model reduces the incremental benefit by a small factor of

$$\max\,(X(t) - \Phi \textstyle\sum_h \text{size}(h), 0),$$

where Φ is a factor representing when we believe access incurs a <u>penalty</u>. Thus, below a certain size, there is no reduction in benefit, but above a threshold value, the reduction in benefit from the alliance grows as a function of the excess size. Various simulations for different values of this data are needed to quantify the effects of incremental benefit.

Costs in the model arise from several places and are simply aggregated together. First of all, there is an infrastructure *maintenance cost*, which is incurred whether or not the hospital is in the alliance. However, if a hospital is outside the alliance, we assume there is a fixed percentage reduction in this maintenance cost. This maintenance cost is some fraction of the size of the hospital. Note that we could envision a separate maintenance charge from the alliance that depends on $X(t)$. For simplicity, we incorporate this charge as a reduction to the incremental benefit of being in the alliance.

Conversion costs reflect modification to enterprise HIT necessary for joining a RHIO. Such cost is incurred at most once (when the alliance is joined), and is depreciated over the period of the model using a multiplicative factor λ.

Hospitals incur a unit price or receive a subsidy to join the RHIO. This cost/subsidy only occurs at the time a hospital joins the alliance. It is unclear how to set this price in the model, but various simulations can be run to see the effects of different pricing policies on the hospital/alliance interactions. This cost is calculated as price(h)*$X(t)$, so it reflects the size of the alliance at the joining time step.

Additional model considerations. The model currently only allows hospitals to join the alliance and to leave the alliance at most one time in the time period. An alliance has to have at least two hospitals in it, and a hospital must remain in the alliance for at least one period. The model has the ability to limit the number of hospitals that join at any time step. Currently, this is only limited at the first period. The model forces every hospital to incur at least the benefit that it would receive should it not join the alliance (thus, the model does not allow a subset of hospitals to lose out, in order that others gain more). The model attempts to configure the alliance at every time stage to maximize the overall net benefits of the system.

Results

The model has been populated with data that approximates the situation in a large Midwestern city. There are 15 hospitals, ranging in size between 50 beds and 700 beds. We classify the hospitals into four types, namely tiny, small, medium and large, with only one large hospital in this dataset. The model has perfect foresight, in that an optimization is carried out over a 16-period time setting for which all the data are known with certainty. The optimization looks for system optimal solutions (as opposed to single hospital optimal solutions), and attempts to ascertain the participation patterns under various scenarios.

In Figure 1 we depict the effect (with everything else fixed) of changing the "capacity limit," which on the left is set at 1.2 (thus the incremental benefit is limited to 1.2*base) and on the right is set at 2.8. The key thing to notice is that the RHIO grows larger in the second case, and that small and tiny hospitals join. (The fact that the large hospital does not join is due to the threshold setting and penalty).

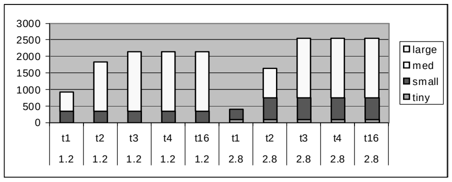

Figure 1. Effect of capacity limit

Figure 2 demonstrates the consequence of RHIO decisions to restrict its size (for example, to insure a manageable transaction environment). To simulate the consequences of increasing size, a penalty parameter is imposed when the size of the RIOH exceeds a given point. When the penalty is small (left side of Figure 2), the large hospitals join late and the RHIO gets very large, a condition likely to cause congestion effects. Under a high penalty (right side of Figure 2), to indicate the burdens of congestion, high levels of transactions, etc, the RHIO peaks out and larger hospitals never join.

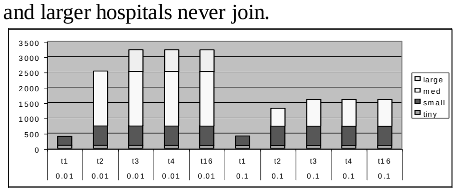

Figure 2. Effect of size penalty

In general, hospitals do not leave once they have entered an alliance. While we can formulate scenarios where hospitals will leave (i.e. have positive incremental benefits at early time stages, and negative incremental benefits at later stages), we note that such scenarios seem artificial, and furthermore typically result in all hospitals leaving at the same time, i.e. the collapse of the alliance, or non-participation in the alliance throughout. While collapse, or reduction in alliance size, are possible outcomes, it is only by modeling uncertainty in future data that such effects will be captured.

Discussion

The modeling approach provided important insights into the behavior of key parameters.

1. Conversion costs are a multiple of a dominant (hospital independent) changeover cost, and additional size dependent charge. Thus small hospitals have a slightly smaller conversion cost than larger ones. Since the model has adequate time to recover this one-off charge, multiplying this charge by 1, 4 or 20 has little effect on participation. The only noticeable effect is for hospitals to delay joining for one or two periods to allow discounting effects to accrue. Small hospitals are eventually forced out of the alliance if conversion costs dominate.

2. Changing the cap that limits incremental benefits has a distinct influence on the joining profile of the smaller hospitals. If the cap is increased (i.e. hospitals can accrue a larger multiple of their base benefit), then smaller hospitals join at earlier time periods. If the cap is decreased, then at some level the smaller hospitals do not join the alliance at all—the costs of joining are larger than the accumulated benefits over time. Estimating this cap correctly is important.

3. Changing the price to enter the alliance influences its growth. The number of periods in the model alters the effect of this one-off cost. If there are relatively few periods in which to recover the cost, then, as expected for large entry prices, the alliance never materializes. However, if either the number of periods in which to recover increases, or the relative size of the entry price decreases, an alliance forms. In general, as the price increases, smaller hospitals join earlier. Furthermore, as the price grows relatively large, strategies that reduce entry cost materialize—for example, hospitals delay their joining pattern so that earlier joiners come in at a lower cost. This is a result of system optimization, since later joiners will incur more cost. Which hospitals join the alliance are typically unaffected by these data; other features of the model such as changing the cap on incremental benefits affect strategic behavior more strongly.

4. Benefit reduction due to the alliance's exceeding a threshold size is an important feature of the model. Two factors that change this effect are the threshold value itself and the amount of the penalty that is applied once the threshold is exceeded. The alliance tends to grow to this threshold value, unless the penalty is very small. When the alliance is efficient

(i.e. the threshold value is large compared to the total size of the potential participants), then all hospitals tend to join, with some possible delays by larger hospitals. When the alliance is inefficient and hence the threshold for penalty incursion is smaller, then larger hospitals no longer join the alliance. Also, as the penalty increases, the larger hospitals delay entry for longer, and eventually do not join at all. Threshold values can even force large hospitals to leave the alliance in a system optimal solution.

Summary. Conversion costs of the form we impose have little effect on joining profiles. The cap that usage of information provided by the alliance generates limits the participation of smaller hospitals. Benefit reductions due to an overly large alliance limit the participation of larger hospitals. Entry price increases can delay entry of large hospitals.

Validation of the models requires additional input, to confirm decisions about model parameters and to examine the extent to which behavioral assumptions are realistic. Nonetheless, the results of the base model produce plausible scenarios. Moreover, the model is sufficiently stable to allow different scenarios to be further investigated. It has enough generality to help understand optimal growth patterns of alliances, based on the cost model that underlies it. Populating the model with case specific data will facilitate clearer understanding of regional alliances.

Further work requires adding sophistication to the model to explicitly incorporate uncertainties. The real options framework allows for examining costs and performance under conditions where RHIO participants (e.g. individual hospitals) can make independent decisions regarding joining or leaving. Additionally, we will explore hierarchical relationships among sets of RHIOs, and the impact of different infrastructures on participation and costs.

Conclusion RHIO participation can be modeled using existing operations research approaches. The models require considerable enhancement, the use of more realistic data and parameters, and greater validation before they will be sufficiently robust to capture actual behavior of RHIOs and to inform decision makers.

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