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Evaluating clinical trial management systems: a simulation approach

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Abstract

Purpose – If the use of information technology (IT) supporting clinical trial projects offers opportunities to optimize the underlying information management process, the intricacy of the identification and evaluation of relevant IT options is generally seen as a complex task in healthcare. Hence, the purpose of this paper is to examine the problem of ex ante information system evaluation, and assess the impact of IT on the information management process underlying clinical trials.

Design/methodology/approach – Combining Unified Modeling Language (UML) and system dynamics modeling, a simulation model for evaluating IT was developed. This modeling effort relies on a case study conducted in a clinical research organization, which, at that time, faced an IT investment dilemma.

Findings – Some illustrative results of sensitivity analyzes conducted on error rates in clinical data transmission are presented. These simulation results allow for quantifying the impact of different IT options on human resources' efforts, time delays and costs of clinical trials projects. Notably, the results show that although the technology has no real influence on the duration of a clinical trial project, it impacts the number of projects that can be carried out simultaneously.

Originality/value – The research provides insights into the development of an innovative approach appropriate to the evaluation of IT supporting clinical trials, through the use of a mixed-method based on qualitative and quantitative modeling. The results illustrate two critical issues addressed in the IS literature: the necessity to extend IT evaluation beyond the quantitative-qualitative dichotomy; and the role of evaluation in organizational learning, and in learning about business dimensions.

Keywords Information technology, Health care, Information systems, Clinical trials, Research organizations, Healthcare information technology, Information system evaluation, System dynamics, Unified Modeling Language

Paper type Research paper

1. Introduction

Information technology (IT) is ubiquitous to health care and related activities, given that it has the potential to support health care practitioners, reduce clinical errors, and even increase care efficiency and patient care quality (Ammenwerth *et al.*, 2003). For instance, IT is becoming a core component of the drug research and development process (Augen, 2002).

The drug development process is a long, costly, and strongly regulated process, of which the outputs remain uncertain. This process includes a preclinical testing stage followed by four clinical trials phases required to allow the commercialization of a new drug (Alshawi *et al.*, 2003):

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- phase I involves tests on voluntary healthy individuals;
- during phase II, the effectiveness and side effects are assessed on patients;
- phase III aims at verifying and confirming results of this assessment on a larger number of patients; and
- during phase IV, after obtaining the approval from the national regulatory agency for drug commercialization, patients under medication are watched closely (Robbins-Roth, 2000).

The information management process underlying clinical trials is critical for all involved actors, and in particular for the pharmaceutical firm that carries out clinical trial projects. First, it combines a huge number of data, notably given that new potential drugs are tested on a higher number of people: whereas the first phase is usually conducted on a small number of healthy volunteers, the second involves a few hundred patients and the third includes the testing on hundreds and sometimes several thousand patients (Goldhammer, 2001). Second, using information of the highest quality is not only a means of obtaining a competitive advantage for pharmaceutical firms, but also a constraint regarding rigorous regulation (Alshawi *et al.*, 2003). Third, the duration of the information management process may have serious impacts on both the strategic advantage of pharmaceutical firms and individuals who need medication. Nevertheless, clinical trial projects often suffer from a non-respect of deadlines (Rowe *et al.*, 2002).

In this context, the use of IT supporting clinical trial projects offers opportunities to optimize the information management process, and notably to improve data quality and reduce both costs and time delays. However, the identification and evaluation of relevant IT options is generally seen as a complex task (Huff and Munro, 1985), and the intricacy of IS evaluation seems to be relatively more apparent in healthcare than in other fields (Ammenwerth *et al.*, 2003; Despont-Gros *et al.*, 2005). According to Despont-Gros *et al.* (2005), the main evaluation issues in healthcare are the explosive growth of computer solutions, the particularity of communication patterns, the difficulty of measuring impacts such as outcomes for patients, to name but a few. Dymoke-Bradshaw and Cox (2004) argue that there is a need to develop innovative approaches appropriate to the evaluation of IT supporting clinical trials.

Thus, this paper aims at looking into the problem of IT evaluation in the special case of clinical trial management. It proposes a mixed-method for integrating qualitative and quantitative evaluation approaches, into a coherent model which finally lead to a system dynamics simulation for assessing the impact of IT on the information management process during clinical trials. Although this research puts an emphasis on the technology choice, it is recognized that healthcare IT is only a part of the overall information system (IS) of an organization (Ammenwerth *et al.*, 2003).

The remainder of this paper is organized as follows. The next section reviews existing research related to healthcare IS/IT evaluation, before highlighting the relevance of using system dynamics modeling to support such an evaluation process. Then, the research method based on a case study conducted in a clinical research organization, is explained. Finally, the evaluation models used to analyze the clinical trial management system are described, and some illustrative results are obtained from the simulation runs.

2. Healthcare IS evaluation and modeling

In this section, some IS/IT evaluation research issues in healthcare are reviewed, before introducing and presenting the system dynamics approach.

2.1 IS/technology evaluation in healthcare

The meaning and the scope of the term "IT evaluation" are often unclear (Farbey *et al.*, 1999). A broad and well-known definition was, however, proposed by Farbey *et al.* (1999, p. 190):

> IT evaluation is a process, or group of parallel processes, which take place at different points in time or continuously, for searching and for making explicit, quantitatively or qualitatively, all the impacts of an IT project and the program and strategy of which it is a part.

The primary objective of IS/IT evaluation is the assessment of costs and benefits of the underlying investment, or the assessment of its "contribution". While it is suggested that an evaluation should be conducted throughout all the stages of an IS project (Dymoke-Bradshaw and Cox, 2004), two key temporal events are typically distinguished. On the one hand, *ex ante* evaluations are referred to as predictive evaluations carried out to forecast, or to anticipate, and assess the impact of future situations. They aim at justifying the investment and are completed prior to systems development. On the other hand, *ex post* evaluations are referred to as post-implementation evaluations performed to measure the value of existing situations. They aim at assessing and confirming the value of the investment, and thus, are undertaken following implementation (Remenyi *et al.*, 2000). Beyond the main purposes of assessing the costs and benefits of an IS/IT investment and of justifying an existing or proposed new system, IS evaluations can be carried out for a number of reasons (Dymoke-Bradshaw and Cox, 2004; Yusof *et al.*, 2008). For example, Dymoke-Bradshaw and Cox (2004) suggest the following:

- the comparison between projects that compete for resources;
- the support for benchmarking and controlling procedures;
- the understanding and learning about an existing system;
- the appraisal of the degree of organization-technology fit; and
- the opportunity for organizational learning, and even for learning about the business dimensions of an organization.

Definitely, business managers and researchers encounter challenges when it comes to the assessment and the justification for IS/IT investments (Irani, 2002). IS/IT evaluation has been represented as an increasingly complex process (Ballantine *et al.*, 1996; Gunasekaran *et al.*, 2006; Joshi and Pant, 2008). The complexity of IS/IT evaluation seems to be even more striking in healthcare (Ammenwerth *et al.*, 2003; Despont-Gros *et al.*, 2005). Indeed, numerous challenges arise in the specific context of healthcare systems. For example, Connell and Young (2007) reported four issues that make difficult the definition of success factors for healthcare IS/IT:

- the level of IT investment, which may be perceived as a shortcoming in healthcare;
- the scale of most healthcare systems;

- a lack of fit between healthcare application and work practices and the environment that it is expected to support; and
- a subjective set of clinical, managerial and political perceptions of the system's success from various stakeholders.

More specifically, Ammenwerth *et al.* (2003) identified three sets of problems related to health IS/IT evaluation. First, as the evaluation object is broader and more complex, the introduction of IT takes more time in healthcare, and the evaluation target is often unstable. Second, given that the healthcare environment itself is particularly complex, with notably its various stakeholders and its strong dependency on external pressures (such as legislation), it is difficult to determine evaluation criteria and to describe the overall contribution of IT. Third, as healthcare professionals and staff members are often reluctant to participate in IT evaluation, getting sufficient resources and sufficient participants for such an evaluation is an actual challenge.

Consequently, healthcare organizations seem to encounter difficulties when it comes to the choice of IS that will support their business objectives and strategies, and many IS projects conducted in healthcare failed (Bush *et al.*, 2009). Several authors highlighted the sub-optimal adoption rates of clinical ISs (Despont-Gros *et al.*, 2005). If such systems offer opportunities to support and improve healthcare and clinical activities, their adoption can be sometimes perilous (Ammenwerth *et al.*, 2003). Obviously, healthcare managers should evaluate existing or new proposed IS/IT and its effectiveness (Bernstein *et al.*, 2007) and there is a need to draw more attention to established IS/IT evaluation processes in healthcare.

2.2 Relevance of system dynamics modeling in healthcare

There are many evaluation methods and techniques found in the IS literature (Farbey *et al.*, 1999; Stockdale and Standing, 2006). The evaluation research is usually distinguished between quantitative and qualitative evaluations (Kleist *et al.*, 2005). Quantitative evaluation methods mainly draw on conventional financial accounting and economic measures, and employ numerical measures to assess benefits and costs of an IS/IT investment, such as market share, productivity of IT capital, option value, capital market reaction, financial performance. Qualitative evaluation methods mainly draw on behavioral sciences, and employ more subjective, perceptual measures to assess the impact and value of IS/IT. These "softer" methods are thus focused on intangible benefits of IS/IT, such as user satisfaction, perceived net benefit, assimilation, etc. (Davern and Wilkin, 2010). However, many authors highlighted the necessity of using mixed-methods in IS/IT evaluation that combine both financial and non-financial variables, tangible and intangible variables (Davern and Wilkin, 2010; Gunasekaran *et al.*, 2006), in other words, both qualitative and quantitative factors (Asosheh *et al.*, 2010).

As Farbey *et al.* (1999, p. 192) explained, IS/IT evaluation should rely on approaches that are "broader, more insistent on the social nature of evaluation, more situated and contingent than before". To capture the overall complexity of the evaluated object and of the organizational system in which this one takes place, some recent studies called for the need for more holistic evaluation processes (Gunasekaran *et al.*, 2006; Stockdale and Standing, 2006), and some modern approaches tend to favor more systemic evaluations (Connell and Young, 2007). System dynamics modeling is such a systemic approach that was applied for the evaluation of management IS, notably in the defense

and in the pharmaceutical industries (Wolstenholme, 2003), in the assessment of e-collaboration tools use effectiveness in the supply chain (Ovalle and Marquez, 2003), in the evaluation of the performance of medical informatics applications (Anderson, 2002), and in the assessment of the effects of implementing an IS on a logistics organization and on a military battlefield operation (Wolstenholme *et al.*, 1993).

System dynamics modeling allows for analyzing complex systems. They include various elements in interaction and are deemed dynamic due to the existence of feedback loops (Forrester, 1975). The underlying modeling tools are influence diagrams and level-rate models. Influence diagrams make it possible to conceptualize the dynamics of a complex system, to facilitate the exchange about mental models between individuals and groups, and to communicate assumed important feedback loops. Such a qualitative model highlights both the variables of a system and the links between these variables that are embedded into reinforcing feedback loops (that generate an exponential growth or decline behavior over time) and balancing feedback loops (that generate an equilibrating, or asymptotic, behavior over time). Level-rate models are quantitative simulation models, which represent a system with stock and flow variables. They aim at testing and comparing alternative scenarios about decision policies or actions, to foster learning and anticipate possible alternative future behaviors of the system under consideration (Sterman, 2000).

Hence, system dynamics is a set of qualitative and quantitative modeling principles, used to conceptualize the feedback structure of a complex system and simulate the repercussions of potential actions over time. Because system dynamics simulation models often work as decision support systems, this approach has been applied to numerous complex problems in IS management (Park *et al.*, 2008), but also in healthcare with specific subject such as the introduction of medical technology (Homer *et al.*, 2000), the dynamics of research and development investments in biotechnology (Cloutier and Boehlje, 2002), and the management of waiting lists for elective surgery (Van Ackere and Smith, 1999). Given that healthcare organizations work as complex systems (McDaniel and Driebe, 2001) where there is fierce resistance to policy change (Sterman, 2006), system dynamics may be relevant for evaluation of IS that are implemented in such complex organizational settings, and notably for *ex ante* healthcare IS evaluation. As mentioned by Remenyi *et al.* (2000, p. 26), in the case of *ex ante* evaluations:

> [...] the evaluator has to understand the existing system in order to predict and understand the future investment, as well as be able to estimate the potential impact of the situation.

Because of simulations, changes envisioned to a system may be tested risk-free and their impact may then be anticipated over time, before engaging or continuing on a given IS project effort. In other words, simulations allow exploring potential changes or improvements to a healthcare IS without disrupting the real setting (Anderson, 2002). In this context, the benefits of system dynamics rest on its capacity to provide a decision support system to guide the *ex ante* evaluation of complex healthcare IS/IT; and yet IS literature suggests that there is a real need to use such support systems (Gunasekaran *et al.*, 2006).

3. Research method

The modeling effort presented below is based on a case study research conducted within a clinical research organization, in which a system dynamics simulation model was designed to support its technology choice.

3.1 Execution of the case study

The case study was conducted within a Canadian clinical research organization, that is, a private contract research organization. This case was chosen for two main reasons. First, over the past 25 years, the pharmaceutical industry has increasingly outsourced its clinical trial activities to specialized clinical research organizations. Second, the research context provided by the studied organization was appropriate because this one, at that time, faced an IT investment dilemma. Besides, given the generic nature of clinical trials activities and process, a single clinical research organization was deemed sufficient for the in-depth understanding of the information management process related to clinical trials. Indeed, due to strong regulation underlying the projects of clinical trials, the information management process is basically generic for all firms involved in a clinical trial context, and similar constraints (rules and norms) standardize the information management process within these firms: the intensive processes of information management carried out during clinical trials can be generalized through a dynamic set of interrelations in a specific timeframe.

The studied organization, which employed about 20 people, mainly managed clinical trials in phase IV for which specific software (referred to as a clinical trial management system that integrated fax and computer technology) were used. However, this organization encountered some challenges in addressing its market growth potential given its available resources, and planned to intensify the automation level of its processes using new IS. In short, the adoption of new computer software was considered to replace the existing one, and it was necessary to identify and evaluate the various IT available options for supporting both the data collection by fax and the full management of clinical trials activities.

This organization has contributed to the IT evaluation effort by making available all expertise and data required to develop a simulation model for IT evaluation, and by allowing one of the team's researchers to participate in its day-to-day activities as a means to gain an intimate understanding of the work processes, information management needs and business objectives. The activities carried out by the users of the clinical trial management system were observed over a one-month period. More precisely, one of the researchers adopted a role of "observer-as-participant", which relied on more observation than participation but could include short interviews (Adler and Adler, 1994). Semi-structured interviews were also conducted every two or three weeks with three main respondents over a seven-month period: the business manager, the IT manager and the financial officer. At that time, these respondents were those who had the most specific understanding of the information management process, and of organizational constraints. Their knowledge was notably useful to challenge the understanding developed throughout the observation of users'activities. Hence, following the recommendations of previous studies in IS evaluation, not only IT managers, but also senior management (Joshi and Pant, 2008) and users (Ballantine *et al.*, 1996), were involved.

Furthermore, a secondary information source was required from software providers, on the availability of different product offerings, as well as their characteristics and functionalities. The analysis of several brochures was first conducted. This documentation was further enriched by attending product demonstrations and holding meetings with software providers such as ClinTrial, Datafax, Oracle Clinical and TeleForm, to name a selected few.

3.2 Development of the evaluation models

The methodological framework used in this study is generically based on Sterman's (2000) modeling process to structure the research sequence (Figure 1). The modeling process used in this research involves five steps.

The first two steps involve qualitative modeling. The first step consisted in articulating the problem, to define the scope of the model. Given the complexity of the information management process under investigation and of the context in which it is carried out, this step called for a more structured approach than those typically suggested in the system dynamics literature. Thus, the information management process in clinical trials was represented using the Unified Modeling Language (UML), as a preliminary and complementary tool for system dynamics modeling. UML is a visual modeling language, which allows capturing the features and requirements of an IS (Li, 2007). Among the diagrams that provide a dynamic view and describe the behavior of a system over time, the activity diagrams give the opportunity to highlight both sequential and concurrent logical processes (Li, 2007). Hence, the first step of the modeling work included the representation through activity diagrams of:

- the initial process of clinical trial management carried out by the studied clinical research organization, which represents the case of low IT support; and
- the improved process, that is, with the use of an "efficient" IS.

The relevant variables inserted into the UML activity diagrams, and consequently calibrated within the system dynamics model, were hence highlighted from the start of this first step. Whereas several preliminary variables were identified by the IT manager, most of them emerged from the observation of users'activities. The list of variables, which was adjusted and refined until the end of the second step, was also discussed with and validated by the business manager, the IT manager and the financial officer on a regular basis. Subsequently, from these activity diagrams, the second step involved the development of an influence diagram that represents the dynamic hypothesis of interacting feedback loops within the information management process.

The last three steps concern the quantitative modeling, that is, the computer-based simulation. Using the software Powersim, the third step aimed at formulating the simulation model, in other words, at translating the qualitative influence diagram into a level-rate diagram based on stock and flow variables. The variables highlighted in the

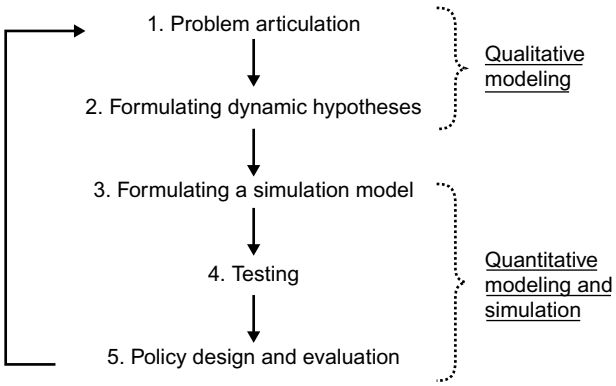

Figure 1.
Modeling process using system dynamics

influence diagram were treated either as stocks (accumulators of past/future decisions about monetary flows, material goods and information, calibrated to characterize the state of the system at a given point in time, and that generate the information on which actions rest) or as parameters (exogenous constants). Then, the relationships identified within the influence diagram were taken into account through rate variables (flows that provide a measure of change per period of time and increase or decrease stock variables) and auxiliary variables (to allow for the conversion of variables). This step also involved the development of decision rules (i.e. mathematical equations), the quantification of variables, and the model calibration using parameters to define initial conditions. To do this, Forrester's (1994) approach was followed where three types of data were collected for modeling: numeric data, written data and mental data. To be more specific, data were collected from four previously completed and well-documented projects (for clinical trials in phase IV) carried out by the studied organization, from participants'experience, and from several software documentations.

The objective of the fourth step was to make sure the model was appropriate for the task at hand. A behavior reproduction test was conducted and then validated by the firm's managers, to insure the external behavior consistency of the simulated model corresponds and reproduces, to a strong extent, the behavior found in a real life setting (from the data collected).

The fifth and final step focused on the scenario building to simulate alternative potential IS strategies with the analysis for the IT software decision. To determine the changes in parameters and to display the simulation results for the sensitivity analyses, an Excel interface was created. Therefore, the simulation model developed from the activity and influence diagrams were used to highlight the impact of potential changes in clinical trial management system in support its *ex ante* evaluation.

4. Clinical trial management modeling and simulation results

The results presented rely on qualitative and quantitative models that were developed, and on an illustrative simulation run.

4.1 Qualitative modeling of the clinical trial management system

The information management process within the clinical research organization under study relies on fax and computer technology. The information to be managed is mainly external: from physicians who meet with patients, faxed forms (questionnaires) are received, with data relative to clinical tests that have to be treated and analyzed. The data treatment process differs little between clinical trial phases.

A clinical trial project starts with the definition of a clinical trial protocol, which determines the basis of the clinical study to be carried out and indicates the number of physicians to be recruited and of patients to be enrolled, the contents of data fields to be filled up on the form, etc. When physicians are recruited and the forms are ready for distribution to them, the clinical study can begin. These forms, referred to as case report forms (CRF), are then completed by the recruited physicians following a patient's "visit" and transmitted by fax to the clinical research organization. Through optical character recognition, faxed data that are received into the IS of the clinical research organization, are automatically converted into electronic data. Data are treated upon receipt, in other words, verified, corrected and subsequently, stored. If a CRF contains errors (non-evident error in data or missing entry on the form), a data clarification form

(DCF) is generated and will be faxed back to the physician for correction. Finally, when all the required visits by patients are completed, that is when the clinical study has met its target, the stored data are analyzed, and a statistical report analysis is carried out.

First, the existing and expected information management processes were represented through the activity diagrams. Given the number and the size of these diagrams, only one generic excerpt is shown (Figure 2), in order to highlight this complete but simplistic process.

Second, the influence diagram was developed to represent the feedback structure of the information management process underlying clinical trial projects. As seen in the excerpt of this diagram (Figure 3), one positive feedback loop (R1), seven negative feedback loops (B1-B7) and two delayed influences (//) were highlighted. These loops illustrate, in part, the dynamics of the patients'enlistment, of the CRF treatment, and of the information quality.

The dynamics of patients' enlistment emerges from the interactions between three balancing feedback loops (B1 to B3): if the visits process by patients ends when the enrollment objective is achieved, this process can be slowed down due to balancing effects relying on factors external to the contract research organization, such as the

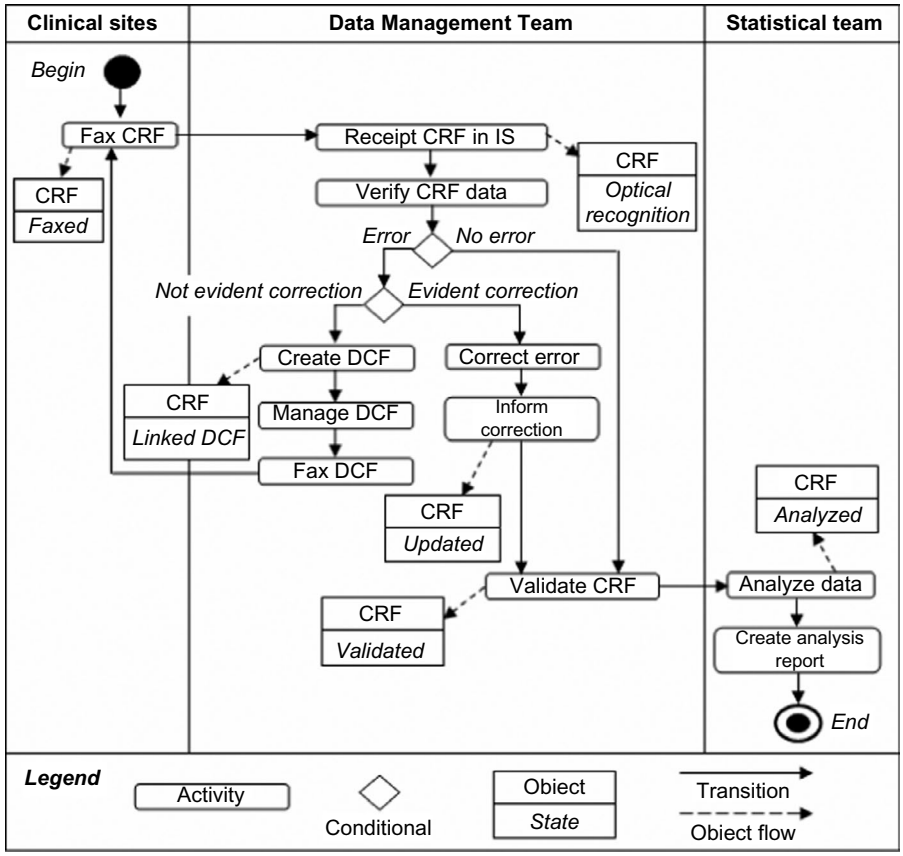

Figure 2.
Excerpt of the UML activity diagram

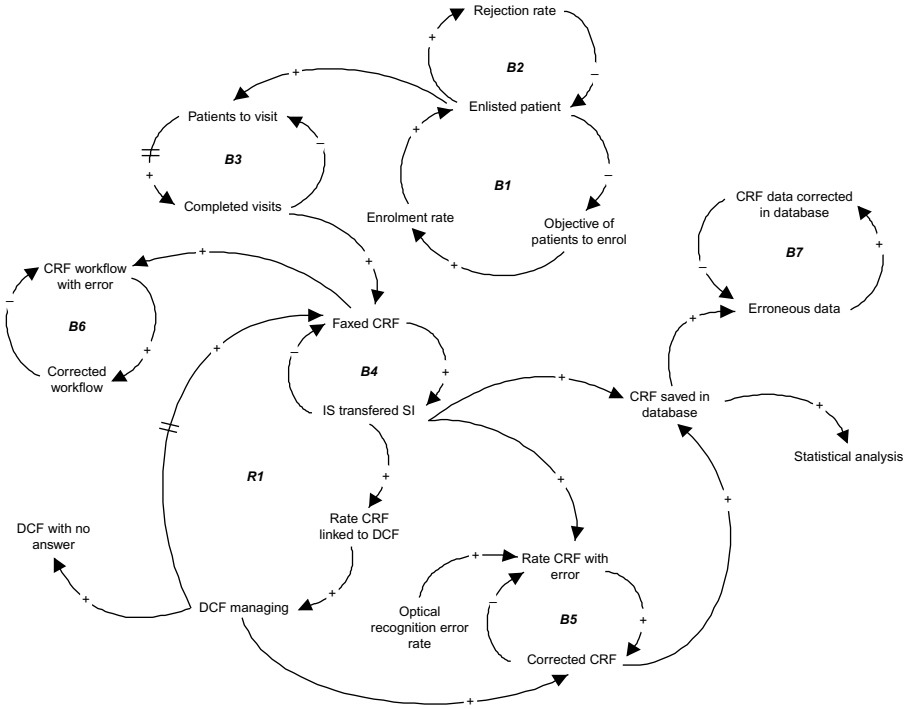

Figure 3.
Excerpt of the influence diagram

outflow of patients (who give up the study or fail to meet a criterion) and physicians' tardiness to complete patient visits. The generation of each visit by a patient leads to the transmission of a CRF to the clinical research organization.

Then, the dynamics of CRFs treatment involves one reinforcing feedback loop (R1) and two balancing feedback loops (B4 and B5). The underlying issue is mainly resting on data correctness. On the one hand, the CRFs treatment process risks to be dramatically slowed down when a new CRF must be faxed back to the pertained physician following a DCF, to correct or complete the data. Indeed, the physicians' response can occur after a certain time delay. Even worse, some DCFs will remain unanswered by physicians and thus, the corresponding CRFs will never be treated or analyzed. When it allows an efficient monitoring and a systematic reopening, the automation of DCFs management helps to reduce this risk. For the specific case of the organization under consideration, the return fax of DCFs back to physicians was not automated, and the problem of time delays and of non-responses from physicians arose. On the other hand, the CRF requiring a manual correction also depends, among other factors, on the performance of the IS relative to the optical recognition. In sum, the reinforcing phenomenon leads to the storing up of more and more CRFs to be treated as the project progresses. As the number of CRFs reaches its target for the project and the task nears completion, it does so asymptotically, at a marginally decreasing pace, due to the existence of favorable balancing effects which mainly are based upon the performance of the IS and of the data management team.

Finally, each valid CRF can be saved in the database in anticipation of the comprehensive statistical analysis. The information quality dynamics is represented by two balancing feedback loops (B6 and B7). In particular, these loops are related to CRFs tracking and to data quality. Indeed, errors can crop up, notably when the CRF status is conferred or when missed or false entries occur in the database itself. Error risks can be reduced not only by improving the task control conducted by the data management team and the statistical team, but also using a performing IS: IS with strong data control functionalities may help to avoid this kind of errors, while it was not the case of the software used by the organization at the time of the study.

In sum, the main role of a clinical trial management system, in addition to support the clinical trial project management, is the reception of forms by fax, the optical character recognition, the data control, the fax and error tracking, and finally the archiving of data for further consultation and analysis. These functionalities and their performance levels may vary from one software editor to another. Furthermore, the information management objectives may differ amongst organizations due to key process tradeoffs. The problem selection relates to the choice of an IT appropriate to the specific criteria of the clinical trial process and organizational policies, but also to the financial constraints that are even more decisive for small to medium-sized organizations.

4.2 Quantitative modeling of the clinical trial management system

From the qualitative diagrams, and the steps of the modeling method, the quantitative simulation model was developed to anticipate the impact of some potential IS strategies, and in particular to support the selection of a new software. This quantitative model is a detailed representation of the management process of clinical trials supported by an IS, and more exactly by fax and computer technology.

The simulation model takes into consideration five interacting "themes" at the core of the clinical trial projects (Figure 4):

(1) visits generated by physicians, that depend on the clinical study characteristics and size;

(2) new clinical trial project configuration, which includes all preliminary steps prior to the diffusion of the blank CRF to the physicians;

(3) the treatment of faxed forms (CRFs and DCFs) and of their underlying data;

(4) the statistical analysis of the clinical data; and

(5) the global strategy of the organization that carries out the study and orients the strategic actions.

It includes all the feedback loops highlighted in the influence diagram, 44 stocks (referred to as level variables) and 49 parameters that can be specified to conduct sensitivity analyses about different IT options and ultimately to test alternative scenarios about different IS strategies. These parameters then represent both organizational and technological dimensions of the management process of a clinical trial project. Given the size of the simulation model, only one excerpt from the Powersim software is shown in Figure 5.

Hence, the simulation model allows the production of quantitative IT evaluation measures of performance for predicting the main impacts of potential improvements in the information management process during clinical trials, through

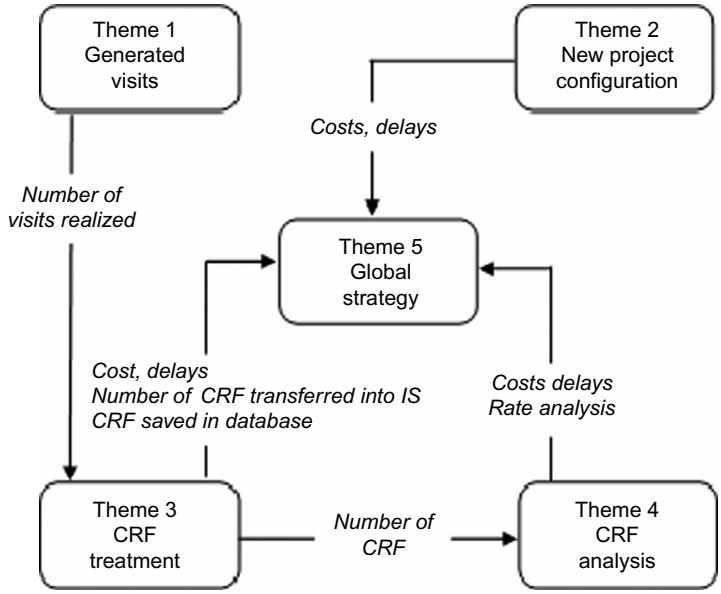

Figure 4.
General structure of the simulation model

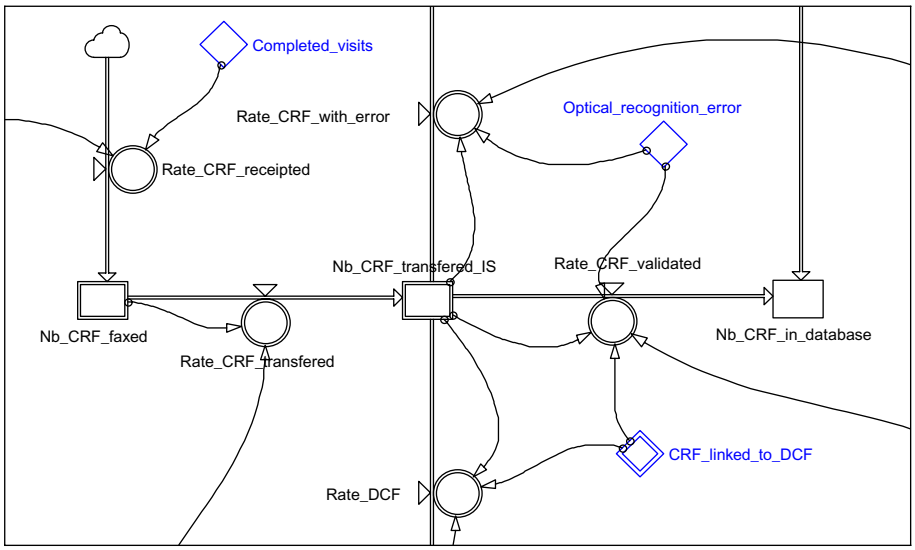

Figure 5.
Excerpt of the level-rate diagram

the parameterization of alternative software functionalities and scenarios on an Excel interface.

4.3 Illustrative simulation results

For the needs of the studied organization, the simulation model was used in two ways. On the one hand, some sensibility analyzes were conducted to compare different

software. By changing some parameters that determine the performance levels and the functionalities of a given technology, the simulation results were used to anticipate and compare the impact (mainly in terms of time delays, costs, human resources efforts, and data quality) of keeping the actual software and of investing in a new technology among three other software of different scales (in this case, Clindex, Datafax, Oracle Clinical). The obtained simulation results showed that a "large" IT investment (such as Oracle Clinical or to name another, Clin'Trial) was justified for this organization to achieve the desired improvement in efficacy and efficiency, but under some conditions of growth. On the other hand, the simulation model examined changing parameters linked to the use of an IS through different scenarios. For example, the effect of variations in the business throughput was simulated to highlight the optimum the process could reach depending upon the software used. The results notably showed that, although at the time the business throughput was of two projects per year, a growth until at least five projects per year would be required to profit by big-scale software. Other examples of scenarios rely on simulations conducted on the number of human resources in the IT team (given that a human resources effort is necessary for technical configuration at the beginning of each project) or on the error rates related to the performance of optical recognition. For this latter, some illustrative results are presented below. This choice is motivated by the fact that the optical recognition error rate is directly linked to the performance level of one of the expected functionalities of IT that support clinical trial projects based on data collection by fax.

Initially, the optical recognition error rate is set at 15 percent (base case specification, or *H1*), the error rate is then set to 0 percent (*H2*) and to 50 percent (*H3*). While an error-free situation does not depict a real-life situation, such a simulation allows the comparison of extreme conditions. Furthermore, even with an error-free rate for optical recognition, the number of CRFs to be corrected would not be entirely zero, given that other kinds of errors can occur. From the calculated means of data collected from several phase IV clinical trial projects that the clinical research organization under study carried out, the model was calibrated on the basis of 1,000 patients enrolled by project (with three required visits per patient). The initial number of CRFs to be treated was fixed to 6,000, and the total revenue generated was established at CAD$180,000. The simulation results show that a variation in the optical recognition error rate has a direct influence on the number of CRFs to be corrected, the CRFs treatment activities and project costs (Table I). For example, the results revealed that an error-free optical recognition rate would lead to a 12 percent cost reduction relative to a 50 percent error rate. This is due to the variation in the duration of activities for the treatment of CRF, given that the number of days required for CRFs processing depends on the extent of errors.

Table I.
Impact of optical recognition error rate variations

Hypotheses	1	2	3
Error rate due to optical character recognition (%)	15	0	50
CRF to be corrected (number of CRFs)	900	0	3,000
CRF processing (number of days)	185	176	207
Costs associated with CRF processing (CAD$)	14,815	14,056	16,586
Gross benefit margin per project (percentage of revenue)	40.9	41.3	40.1

It may be suggested that the smaller the number of CRFs to be corrected, the more rapidly the project will be completed. However, the results show that the statistical analysis of clinical data, which is the final step of a clinical trial project and which requires that all CRFs are saved in the database, always takes place in month 13, whatever the specification under consideration (Figure 6). Indeed, CRFs are always corrected over the same period, whatever the number of CRFs to be rectified (Figure 7). Actually, the clinical research organization should correct more CRFs for *H3*, but using the same time period to get the work completed as in *H1* and *H2*.

In short, the variation in the optical recognition error rate has almost no impact on the duration of the project. Indeed, no matter the IT strategy selected, the time delay associated with the treatment of CRFs is much more dependent on the velocity of patient enrollment and on the frequency of visits that follow, than on factors endogenous to the information collection process itself. Nevertheless, such error rates influence not only costs, but also the human resources' efforts required for fixing these errors. The software performance should hence have a non-negligible impact in multi-project situations, given that resources can be allocated to other tasks when error rates – amongst others – are lower. For the studied organization, and given its limited available resources, only the equivalent of two large-scale projects could be carried out over a year. In this context, the capacity to perform more clinical trial projects simultaneously, because of the use of more efficient technology, became a potential source of competitive advantage.

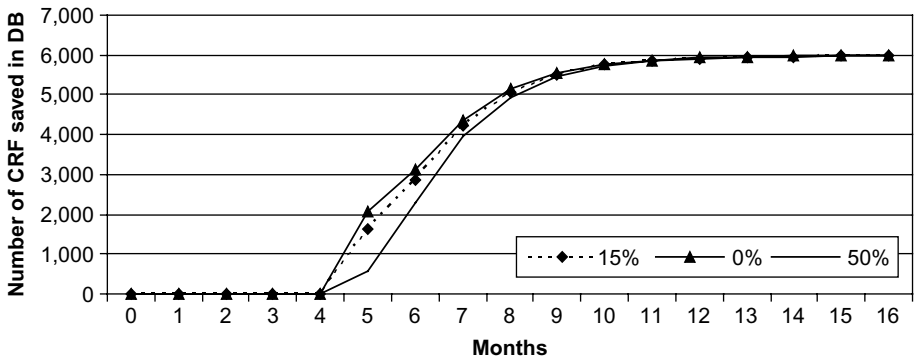

Figure 6.
Impact of the optical recognition error rate specification on project duration

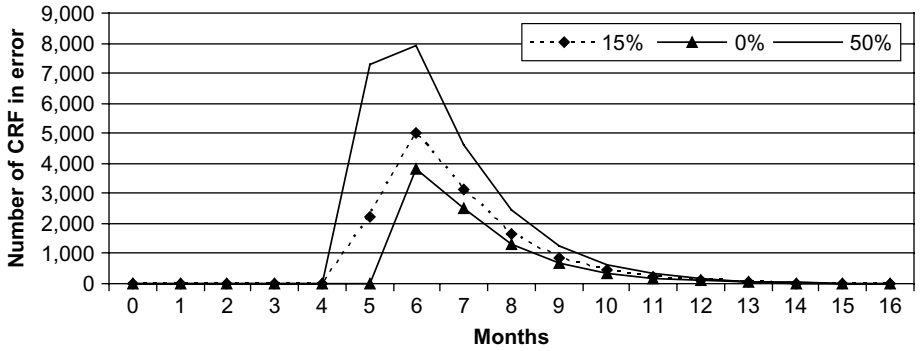

Figure 7.
Impact of optical recognition error rate specification on the number of CRF with error

5. Conclusion

This paper aims to examine the information management process underlying clinical trials. This process is a complex one: it is characterized by numerous interacting feedback loops, which are mostly balancing and trigger non-linear behaviors. Its dynamic behaviors are difficult to understand and anticipate, justifying the need for using innovative and systemic approaches that support *ex ante* IT evaluations. In this perspective, this research leads to a system dynamics simulation model that works as a decision support system for clinical settings. According to Ammenwerth *et al.* (2003, p. 133), "evaluation studies in health care IT take a lot of time, resources, and know-how". Whereas system dynamics modeling is a systemic and dynamic approach that allows capturing the complexity of the evaluation object, it is also an approach that allows simplifying the tasks of the evaluator without disrupting the real setting. Notably, this model allows for the comparison of software technologies: it can be used to anticipate the costs and benefits of several potential IT investments under different scenarios. For example, simulation results reveal that although the technology has no influence on the duration of a clinical trial project, its impact on the work-tasks intensity, data quality and information treatment capacity can be substantial. Moreover, the application of system dynamics for IS/IT evaluation in this study contributes to debate on two critical issues addressed by IS literature.

First, IS/IT evaluation has to take into consideration qualitative and quantitative factors (Asosheh *et al.*, 2010). While system dynamics modeling relies on mathematical representations of problems under investigation and decision rules, the information used in such models is not only numerical in nature, but also qualitative (Luna-Reyes and Andersen, 2003). The quantitative modeling itself relies, in part, on qualitative data as informational sources (Forrester, 1975) and can as well involve soft variables (Luna-Reyes and Andersen, 2003). The mixed-method of evaluation proposed and applied in this research hence offers the possibility to go past the quantitative-qualitative dichotomy, even if the quantification of qualitative variables in a simulation model is recognized to be a fragile task (Coyle, 2000).

Second, it was suggested that a key purpose of evaluation in the context of clinical trial management systems concerns the opportunity for organizational learning, and for learning about business dimensions (Dymoke-Bradshaw and Cox, 2004). And yet, system dynamics aims at supporting the learning processes about complex systems for knowledge creation and sharing (Sterman, 2000). In particular, using systemic modeling is needed when the system under consideration has so many components and interrelationships that they may not be easily taken into account by managers' mental models, which are by definition "elusive" and often imprecise (Forrester, 1975), and when developing a shared understanding of complex issues is difficult to achieve using unstructured representations. For example, during the modeling effort carried out for the organization under study, the IT manager expressed that the activity and influence diagrams are useful tools not only to understand the interconnected activities performed by IS users, but also to have a global and more justified picture of the organizational business; he realized that before participating in the qualitative modeling process, his knowledge was fractionated and even limited. The issue of IT evaluation is also a behavior and an organizational one: the qualitative and quantitative simulation modeling process conducted in this paper allows also for the development of a shared understanding of the behavioral aspects of the IT evaluation process. Recall, as

emphasized by Ammenwerth *et al.* (2003), there is a need in healthcare IT evaluation to account for aspects such as: the complexity of the IT evaluation object and the complexity of the environment itself (regulation), and that there are deep human resources reluctance to provide the required information richness required to succeed.

However, several limitations should be noted. Whereas clinical trial management software are only a part of an IS of an organization, this paper put the emphasis on technology-based dimensions. As the simulation model also takes into account organization-based dimensions, an in-depth analysis of some scenarios representative of different organizational contexts would be interesting for enriching the results obtained in this research. Moreover, although systems that support data collection by fax are still highly used by clinical research organizations, those that support data collection by electronic data capture (EDC) over the internet are increasingly used and modern systems even tend to support both. Indeed, if older physicians and patients may be reluctant to use modern technology (Parravicini and Patterson, 2011), it is recognized that the web-based EDC offers opportunities to improve data quality, increase productivity, and reduce cost in clinical trial management (Sahoo and Bhatt, 2003). Consequently, the evaluation models should be extended to take into consideration an EDC process over the internet.

Nevertheless, this study has implications for practitioners. It demonstrates that the selection of efficient technology plays a great role in a business growth strategy, given its capacity to support the performing of multi-projects over the same period. In other words, IT may support the management of multiple projects at the functional level, by reducing the challenge of the resource allocation between simultaneous projects (Engwall and Jerbrant, 2003; Payne, 1995). Furthermore, this research proposes a decision support system that could be used by managers who act in a clinical setting. In particular, such a decision support system may be of a greater interest for small- and medium-sized clinical research organizations given that poor IT investment decisions can dramatically affect the organizational profitability of small- to medium-sized enterprises (Love *et al.*, 2005).

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Further reading

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