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A System Dynamics Approach to Analyze Laboratory Test Errors

Shijing GUO[a,1], Abdul ROUDSARI[b] and Artur d'Avila GARCEZ[a]
[a]*Department of Computer Science, City University London, UK*
[b]*School of Health Information Science, University of Victoria, Canada*

Abstract. Although many researches have been carried out to analyze laboratory test errors during the last decade, it still lacks a systemic view of study, especially to trace errors during test process and evaluate potential interventions. This study implements system dynamics modeling into laboratory errors to trace the laboratory error flows and to simulate the system behaviors while changing internal variable values. The change of the variables may reflect a change in demand or a proposed intervention. A review of literature on laboratory test errors was given and provided as the main data source for the system dynamics model. Three "what if" scenarios were selected for testing the model. System behaviors were observed and compared under different scenarios over a period of time. The results suggest system dynamics modeling has potential effectiveness of helping to understand laboratory errors, observe model behaviours, and provide a risk-free simulation experiments for possible strategies.

Keywords. Medical errors, clinical chemistry tests, laboratories, quality control

Introduction

Laboratory test results are closely associated with clinical diagnosis, and at least 10% of all diagnoses are not considered final until clinical laboratory testing is complete. [1] An error in laboratory testing may lead to an error in diagnostic decision-making. Many studies have been carried out to investigate laboratory errors and to find solutions via improving test sensitivities or proposing process interventions. However, it has been suggested that researches from a systemic view are needed, especially on tracing the errors and evaluating potential interventions. [1] System dynamics modeling is a problem-focused approach. It analyzes the problem through a whole picture of the system instead of seeking localized solutions. [2] This study using a system dynamics approach investigates the laboratory error problem and understands the ways in which errors happen and the system could be improved. It provides a way of tracing the errors and of simulating model behaviors while varying the value of variables. The value variation could come from a change in demand or a proposed intervention.

This study started with interpreting laboratory errors into a qualitative model based on the laboratory process, and the qualitative model was further translated into a quantitative model to represent the number of errors in different phases. Furthermore, a review of literature on laboratory test errors during the past 20 years was conducted. It is the main input data source of the model. Finally, the model was tested and simulated

[1] Corresponding Author: Shijing Guo. E-mail: Shijing.Guo.1@city.ac.uk

under three scenarios. The scenarios aim to observe system behaviours while changing of system variables that could be caused by either projected changes in demand or proposed interventions. Model outputs are compared under different scenarios and relevant changes were observed in the result session.

1. Methods

This section describes how system dynamics represents the laboratory errors, and provides a review of literature on laboratory errors with its findings.

This study initiated with illustrating a conceptual model or a qualitative model, based on the findings from our previous study [3] and discussions with 3 experts. The qualitative model is to describe interrelationships between variables during the laboratory test process. It was further mapped into a quantitative model in the second step. The quantitative model is represented using a "stock and flow" diagram. Compared to a data flow diagram, it can quantitatively simulate the accumulation of flows over time. Concretely, it uses stocks to represent the quantitative level of a variable, which is the integration of its inflows and outflows over a period of time, and arrows to represent the inflows or outflows of the stock at every time unit.

A simplified stock and flow diagram for laboratory test errors was built using software Vensim [4] and shown in Figure 1.

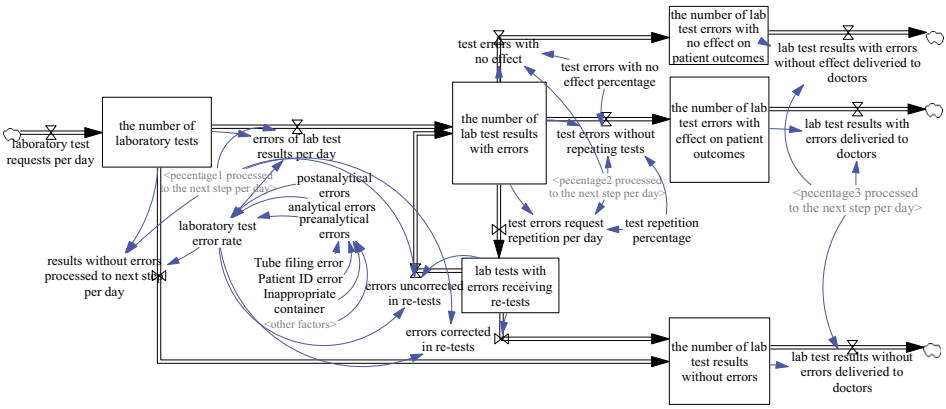

Figure 1. System dynamics modeling of laboratory test errors.

Curved single-line arrows in the graphic indicate the two variables have a cause-effect relationship. Double-line arrows connected with blocks indicate the "flows" which are the possible routes that errors may be delivered. Laboratory test requests are delivered into the system at the start, then errors are generated via three phases: *pre-analytic, analytic, and post-analytic*, and finally errors are divided into three types in terms of their impact on patient outcomes and delivered out of the system. The three types of output errors are: *the number of lab test errors with no effect on patient outcomes, the number of lab test errors with effect on patient outcomes,* and *the number of lab test results without errors*, which are shown as blocks in Figure 1.

A literature review was conducted as the data source of the model that are used as input data in Figure 1 to accumulate in stocks for stimulating the numbers of errors. Relevant papers on laboratory errors from 1994 to 2014 were reviewed. Table 1 shows

a comparison on the relevant data from different studies. Data in Table 1 is shown as absolute percentages, and defined by mixed patient groups of inpatients and outpatients.

Table 1. Review of the literature on laboratory errors

Papers	Year	Study Area	Laboratory test error rate	Pre-analytical error rate (ppm[b])	Analytical error rate (ppm[b])	Post-analytical error rate (ppm[b])
Abdollahi et al [5]	2014	Iran	6.30%	41007	14616	7358
Carraro & Plebani [6]	2007	Italy	0.31%	1914	463	715
Wiwanitkit [7]	2001	Thailand	ND[a]	1100	58	147
Stahla et al [8]	1998	Germany	0.61%	4575	976	549
Plebani & Carraro [9]	1997	Italy	0.47%	3183	621	863
Nutting et al [10]	1996	North America	0.11%	612	146	330
Lapworth & Teal [11]	1994	UK	0.05%	158	158	154

[a] *ND: Not identified;* [b] *ppm: per million*

Results show *pre-analytical errors* take the largest percentage in the laboratory errors, compared with *analytical errors* and *post-analytical errors*. The percentage lies around 55%-77% for a 60% likelihood. According to the study in 2007 [6], the top 3 causes of pre-analytical error are: tube filling error(13.1%), patient ID error(8.8%), and inappropriate container(8.1%). Significant differences in the lab error rate among study areas were observed.

2. Results

Three "what if" scenarios were selected to execute model simulation and results were shown in this session. The purpose of choosing the scenarios is to test the model, understand current system outputs, simulate the changes of model variables and observe system behaviours.

2.1. Scenario 1: one year over look

The aim of the scenario is to test the model, as well as provide simulation outputs of the current system. The model was simulated over a one-year period from Month 0 to Month 12. It is assumed that the number of laboratory test requests is 10000 cases per month, and also assumed that the data from the literature review represents the current system. Thus, a statistical analysis of the data was done before sending it into the system for a more reasonable representation, and input data was randomly selected with the circa 70% likelihood range. The consequence of relevant admission rates was not considered in this simulation due to the lack of data. The variable *laboratory test error rate* was selected to test the model, and literature review data was used to compare the output from the model.

The simulation output of the lab test errors rate is shown in Figure 2 (a). The graphic indicates a mean value of lab test error rate is 0.27%, which agrees with the data range in Table 1 from 0.195% to 0.42%. The density of the graph means that data were plotted every day for 12 months. The error numbers with relevant patient outcomes under current dataset were also provided as system outputs, and are shown in Figure 2 (b). The two curves respectively represent the changes of *the number of lab*

test errors with no effect on patient outcomes and *the number of lab test errors with effect on patient outcomes* along time. This indicates the current system averagely deliveries about 2 errors with negative effect per month out of 10000 tests/month from Month 6, while 20 errors with no effect over the same period.

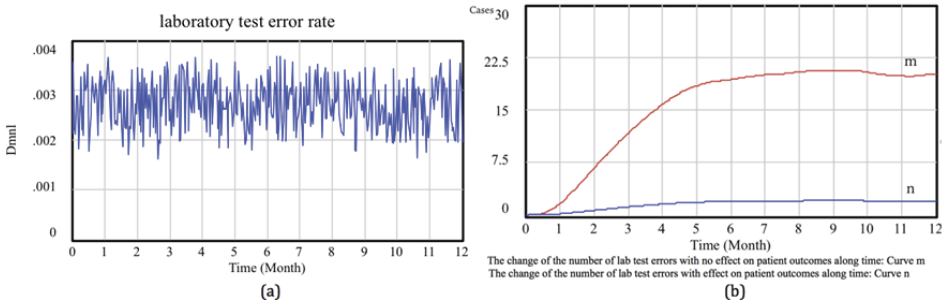

Figure 2. Simulation outputs under senario1.

2.2. Scenario 2: changing the test repetition rate

To observe the system behaviours in terms of sensitivity, the "laboratory test repetition rate" was used as an example of probabilistic sensitivity test. Probabilistic sensitivity analysis helps to quantify the confidence level of a variable for decision-makers.

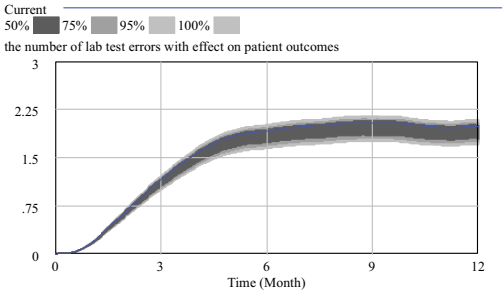

Figure 3. The sensitivity of the error number to the test repetition rate.

The current value of the test repetition rate is assumed at 16.9% according to a relevant study [6], and also it is assumed that the impact of a 1.5% changing range of the rate is to be observed. Thus, test repetition rates with a band from 16.5% to 18.0% were simulated. Results are shown in Figure 3. It represents the impact on *the number of lab test errors with effect on patient outcomes* under the given range of test repetition rate. A darker area means a higher probability that the output value has. The other two types of errors: *the number of lab test errors with no effect on patient outcomes* and *the number of lab test results without errors* did not appear as significant changes, because they are based on large quantitative data sets.

2.3. Scenario 3: changing the error rate of the tube filling

Tube filling errors were witnessed as the top error during the pre-analytic phase. [6] Thus, it was chosen as an example to demonstrate the change of system behaviours while changing the value of a variable. The tube filling error rate was assumed as 130

per million (ppm) under the first scenario simulation, and changed to 330ppm under the second simulation. Table 2 shows the comparison of the outputs of the two simulations, where *error number with effect on patient outcomes* increases by 7.7% roughly when the tube filling error rate increases by 200ppm.

Table 2. The laboratory errors under different values of the tube filling error

	The number of laboratory test errors with effect on patient outcomes per month (case)				
Variable	**Min**	**Max**	**Mean**	**Median**	**StDev**
Tube filling error: 130ppm	0	1.973	1.472	1.848	0.6510
Tube filling error: 330ppm	0	2.122	1.585	1.990	0.7009
Difference:	0	0.149	0.113	0.142	0.0499
Difference percentage:	0	7.552%	7.677%	7.684%	7.665%

3. Discussion

This study using system dynamics modeling provides a useful structure for analyzing laboratory test error flows. By comparing outputs under different scenarios, the model can investigate the system behaviours and provide simulation of possible interventions or strategies, which helps decision makers. Additionally, risk-free simulation experiments encourage creative thinking of possible solutions.

At the same time, this study has its limitation mainly due to its insufficient data resource. Current data resource is limited by the availability of literature, and literature data sets are based on different study areas and patient groups. Also, lack of real-time data makes predictions very difficult, and means the current model does not reflect the impact of admission rates, such as delays. However, an expert elicitation method has been proposed to collect more data evidence. Furthermore, machine-learning methods such as logistic regression could be used to present more complex relationships between factors and effect, and to extend laboratory test process in the future work.

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