CSCanada
Management Science and Engineering
Vol. 8, No. 3, 2014, pp. 35-40
DOI: 10.3968/4319

ISSN 1913-0341 [Print]
ISSN 1913-035X [Online]
www.cscanada.net
www.cscanada.org

Improving Laboratory Performance in Healthcare Delivery Systems Through Optimal Stage Selection: The Analytic Network Process Approach

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Received 26 February , 2014; accepted 12 June 2014
Published online 15 September 2014

Abstract
Laboratory services in healthcare delivery systems play a vital role in inpatient care. Laboratory testing alone accounts for approximately 10% of hospital billing. A goal for the U.S managed healthcare delivery system is to considerably reduce laboratory costs. To aid in achieving this goal, a research study is performed that focuses on the optimization of a clinical laboratory in a local hospital system. This paper shows how the analytic network process (ANP) model can be applied in assessing and ranking the three stages of the laboratory process to determine the stage that is most critical for optimization purposes. Once the most critical stage is identified and optimized significant cost savings can be achieved. The final results of the ANP model in this study indicate the preanalytical stage is the most critical among the three stages in the laboratory process.

Key words: Hospital; Laboratory; Stage; Analytic network process

Leaven, L. (2014). Improving Laboratory Performance in Healthcare Delivery Systems Through Optimal Stage Selection: The Analytic Network Process Approach. *Management Science and Engineering*, *8*(3), 35-40. Available from: URL: http://www.cscanada.net/index.php/mse/article/view/4319
DOI: http://dx.doi.org/10.3968/4319

INTRODUCTION

Laboratory medicine, which can also be described as clinical pathology, is a field where pathologists provide testing of patient samples (generally blood or urine). Hospital laboratories are healthcare facilities where laboratory medicine is conducted. Laboratory testing is a significant component of healthcare delivery costs (Plebani, 1999). Studies have shown that laboratory data affect approximately 65% of the most critical decisions on admission, discharge, and medication (Plebani, 1999). For example, the presence of bacteria can be detected from a patient sample, which provides information for the necessary treatment. A clinical test conducted on a sample can determine the level of enzymes in the blood that reveals a risk of a heart attack or the level of glucose in the blood that is an indicator of diabetes. Moreover, service quality is critical in laboratory medicine. Every time high quality service is not provided to a patient requiring a laboratory test, another blood draw will have to be performed. This will cause excessive and unnecessary needle sticks for patients, which will over time decrease customer satisfaction and increase laboratory costs. Largely, laboratory medicine is a key component in healthcare delivery systems due to the amount of spending, the great need for high service quality, and the impact on medical decisions.

In the laboratory process there are three core stages: preanalytical stage, analytical stage, and postanalytical stage. Each of these stages is discussed in further detail in the following section. In each of the stages it is important to consider the amount of cost savings that can be obtained, the amount of time that can be reduced, and the increase in the quality of the procedures performed. The specific objective for this study is to identify which of the three core stages is the most critical and should be selected for process improvement. Selecting the most critical stage to improve could result in achieving the most cost savings and the highest increase in service quality.

Healthcare delivery systems recognize a large number of areas for improvement, in which they develop projects

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and strategies for implementation. It is not feasible to implement all improvement projects simultaneously. Therefore, there is a need to prioritize and choose the most effective ones, which can be performed using the analytic network process (ANP) modeling technique. Improvements in healthcare decision making are needed in order to solidify benefits for patients and health care professionals. There are a variety of popular tools that assist with the process of medical decision making. However, this research focuses on the application of the ANP model. Certain problems do not always indicate a hierarchical structure and therefore should be modeled as a network. From a review of the literature, there are not many studies that utilize ANP modeling in healthcare decision making. Due to this finding, the research study presented in this paper will provide an academic contribution to the literature. There are studies that have indicated decision problems are best investigated through both the ANP and analytic hierarchy process (AHP) models (Saaty & Vargas, 1998; Carter, et al., 1999). This allows for a thorough analysis and comparison to be performed to determine if the same results are obtained from both models. If the same results are obtained, this will provide additional validation for the decision to be selected.

In this study, the ANP model is used to rank the three stages in the laboratory process. The stage with the highest priority number when ranked from highest to lowest will be selected as the most critical stage to improve. This paper is organized into the following sections. First, the hospital laboratory process is discussed in detail. The ANP methodology used in this research study is explained next followed by a case study application of the ANP approach. Finally, future directions are summarized in the conclusions of this paper.

1. BACKGROUND ON THE HOSPITAL LABORATORY PROCESS

The hospital laboratory process includes three core stages: preanalytical stage, analytical stage, and postanalytical stage. The preanalytical stage includes the physician placing an order, patient identification, dietary considerations of the patient, medication considerations, coordination of care and treatment for the patient, assessment of the physical status (IV's, access ports, etc.), selecting proper tube type and the actual blood collection process. Figure 1 illustrates each step of the preanalytical stage. For the preanalytical stage, the aim is to decrease the amount of errors that occur within this stage of the process. It has been determined that over 60% of the errors that occur in the hospital laboratory take place in the preanalytical stage (Carraro & Plebani, 2007). The way to reduce the errors is to identify the root cause of the errors and prevent them. Thus, laboratory professionals, physicians, and nurses should focus more on the source of the error and not just the error itself (Plebani, 2009)..

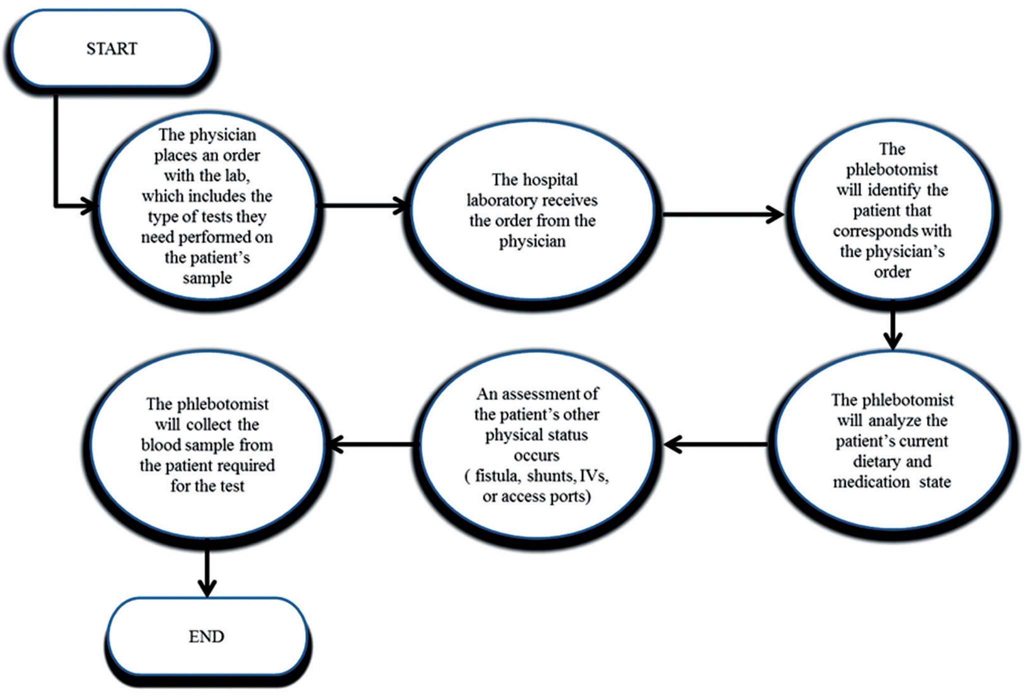

Figure 1
Preanalytical Stage in Hospital Laboratory

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The analytical stage involves the testing aspect. There are several different testing methods used depending on the test request. The medical technologist or technician is responsible for tasks pertaining to the instrumentation or testing requirements, instrumentation calibrations, and on-the-spot maintenance. The analytical stage consists of running tests on the specimen, analyzing the specimen, and retrieving the results. Figure 2 illustrates each element of the analytical stage.

The postanalytical stage involves a review of the results prior to sending them to the ordering physician. Medical technicians are involved in this process by reviewing the lab results for normal or abnormal ranges. A pathologist review might also be required. Results are sent to the ordering or referring physician once they have been analyzed for abnormalities. The auto verification process has been implemented in the last few years for many hospital laboratories. In the auto verification process, rules are written in the Laboratory Information System (LIS) to evaluate the results and if all criteria are met, the results are sent directly to the patient records. Figure 3 illustrates each step of the postanalytical stage.

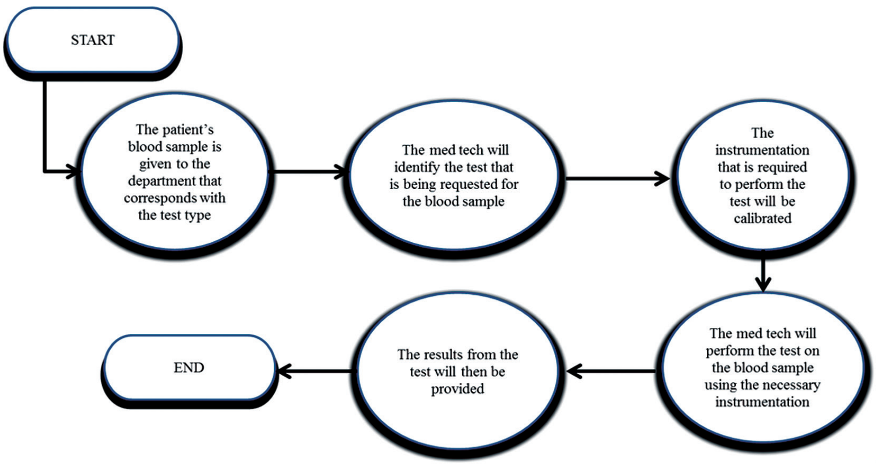

Figure 2
Analytical Stage in Hospital Laboratory

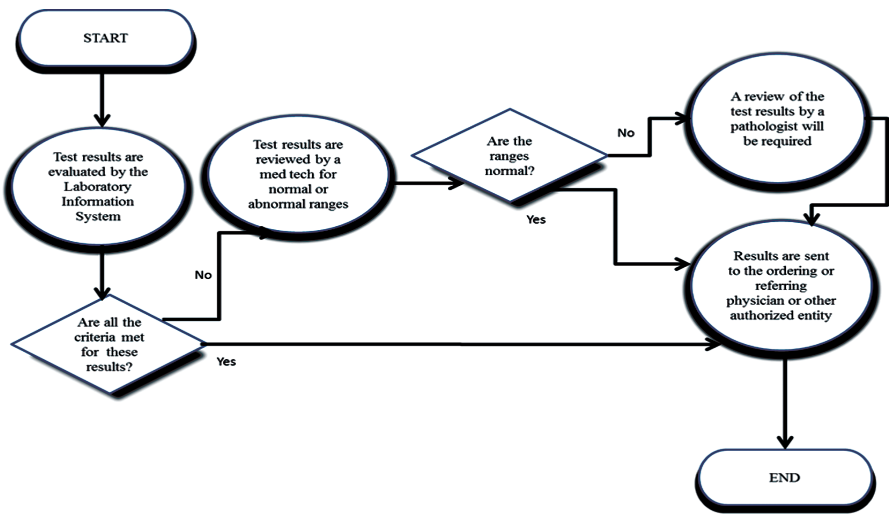

Figure 3
Postanalytical Stage in Hospital Laboratory

2. METHODOLOGY

• The Analytic Network Process (ANP)

The analytic network process (ANP) is a theory that extends the AHP to occurrences of dependence. It permits interactions within clusters identified and between clusters as well. The ANP provides a thorough framework to include clusters of factors connected in any way to examine the process of obtaining ratio scale priorities from the distribution of influence among elements and among clusters. In AHP Modeling, every factor in the hierarchy is independent of the other factors, the decision

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criteria and the alternatives are independent of each other as well. The concern with the AHP modeling technique is that with many practical cases, interdependence is present among the items and the alternatives. ANP allows for dependence amongst factors; therefore it is utilized as an effectual technique in real world cases. Figure 4 illustrates the flow diagram used for ANP modeling.

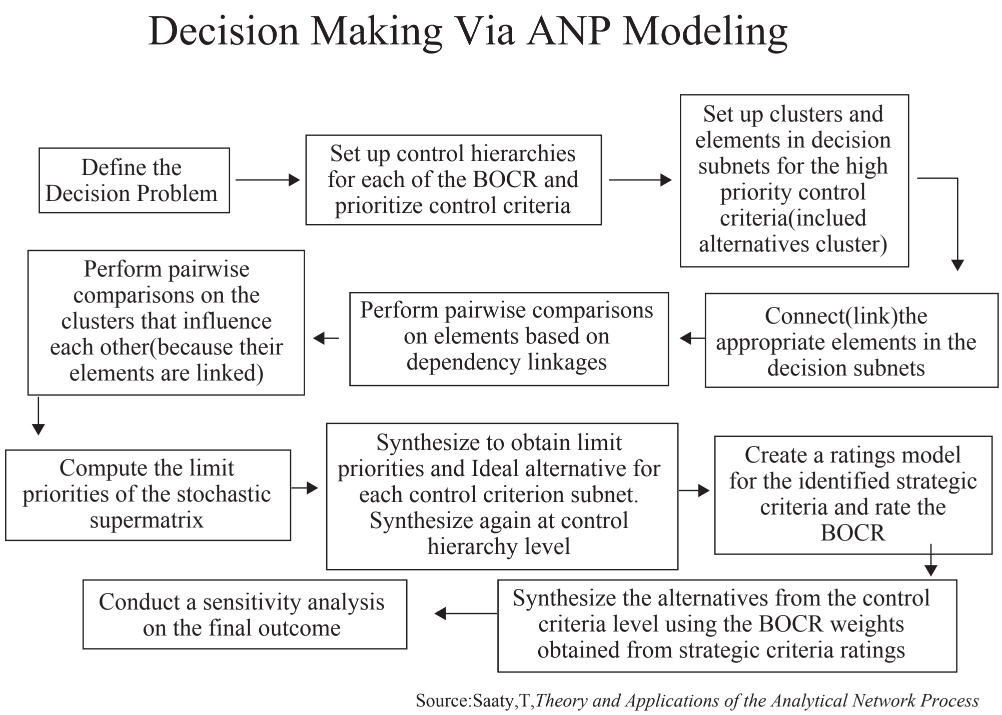

Figure 4
Flow Diagram for ANP Modeling

3. CASE STUDY

3.1 Establishing the Alternatives

The alternatives for this study consist of the three stages in the laboratory process: preanalytical stage, analytical stage, and postanalytical stage. Once a test order for a patient is received by the hospital laboratory it must go through all stages of the laboratory process. Only one of the three stages can be selected initially for process improvement and optimization. Thus, it is imperative to identify the most critical stage in the laboratory process.

3.2 Establishing the Evaluation Criteria

Four process improvement techniques are utilized in the ANP model as the evaluation criteria to determine the impact that could be achieved with regards to improving each of the three core stages. The four process improvement techniques are: Theory of Constraints, Lean, Critical Business Process, and Six Sigma. Based on the literature, these are widely used improvement techniques for several areas of the healthcare delivery system. In this section, we briefly introduce these four process improvement techniques. The objective is to determine how these process improvement techniques together will affect each of the alternatives and in what capacity in order to select the most critical stage for improvement and optimization purposes.

• **Theory of Constraints:** This is an approach to solve constraints and problems through determining its roots and determining steps to remove the root of the problem. The output of one step depends on the output of one or more previous steps and the system will be constrained by the least productive steps. The system's constraint specifies the performance and in order to increase the system's performance one must identify and explore the system's constraint.

• **Lean:** The basis of this methodology is to maximize customer value while minimizing waste. The objective is to provide perfect service to the customer through a process that has zero waste. To achieve this, lean optimizes the flow of services through the entire value stream. Eliminating waste along the entire value stream, instead of at specific points, creates processes that require less manpower, less money, and less time ensuring much fewer defects.

• **Critical Business Process:** The critical business processes are those processes necessary to achieve business objectives. An organized approach to identifying critical business processes requires one to: Define the critical business processes; rank the critical business processes; classify independent business processes; and lastly determine the minimum requirements for each of the critical business processes.

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• **Six Sigma:** This approach strives to improve quality by identifying and removing the causes of errors and minimizing variability in processes. This methodology uses quality control and statistical methods. A six sigma process is one in which 99.99966% of all items are statistically expected to be free of defects (3.4 defects per million). The DMAIC project methodology has five phases: Define the problem and the project goals, Measure key aspects of the current process and collect important data, Analyze the data to explore and determine relationships, Improve the current process based on previous steps, and Control the sustainability of the improved process to make certain variations from the target are corrected in time to prevent errors.

3.3 Pairwise Comparisons

It is imperative for the ANP model that human judgments are provided when performing the evaluations. Therefore, a pairwise comparison scale is used which is shown in Table 1. The judgment of an expert was solicited to develop the pairwise comparisons for this study. The expert has approximately 20 years of experience managing hospital laboratories. The decision on the weight of the evaluating criteria and the alternatives has a direct impact on which stage is selected. For that reason, the judgment used had to reflect that of an expert in the laboratory medicine field. Several meetings were arranged with the expert to gain feedback and judgments regarding this study.

Table 1
Pairwise Comparison Scale (Saaty, 1977, 1980; Kumar, 2006; Maheshwarkar & Sohani, 2013)

The fundamental scale for pairwise comparisons		
Intensity of importannce	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another,its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affinmation
Intensities of 2, 4, 6 and & can be used to express intemediate values. Intensities 1.1, 1.2, 1.3, etc., can be used of elements that are very close in importance.		

The ANP model for this study has been formulated to demonstrate how the best features of the four improvement methodologies mentioned previously: Theory of Constraints, Lean, Critical Business Process, and Six Sigma, could be used together to develop an approach for prioritizing and selecting the stage for improvement in the hospital laboratory of a healthcare delivery facility. The success of the ANP has been seen in applications where the results produced corresponded with identified answers in the real world or from predicted outcomes. Therefore, this technique is a trustworthy methodology for making decisions based on priorities and significance. The initial step of the ANP model is the development of the control network. In the control network you determine the overall goal for the model, which in this study is to select the most critical stage to optimize in the hospital laboratory. Then the sub-networks of the model are developed and the relationship between the control network and the sub-networks is identified. The four improvement techniques: Theory of Constraints, Lean, Critical Business Process, and Six Sigma each represents a sub-network for the model. Once the control network and sub-networks have been developed, the next step involves developing the clusters within each sub-network. There are two clusters in each sub-network. The alternatives are included in one cluster and the attributes of the improvement technique are included in the other cluster. The alternatives cluster for all of the sub-networks include: preanalytical stage, analytical stage, and postanalytical stage. The software used for the ANP modeling was Super Decisions. The Super Decisions software is used for decision-making with dependence and feedback. This software uses a vital prioritization method based on deriving priorities through judgments on pairs of factors or from direct measurements.

4. RESULTS AND DISCUSSION

The priorities of the three alternatives (preanalytical, analytical, and postanalytical) with respect to the lean sub-network, six sigma sub-network, theory of constraints sub-network, and critical business process sub-network are shown in Table 2. These priorities, as the result of doing pairwise comparisons, are referred to as local priorities. The preanalytical stage has the highest priority in each of the sub-networks. The overall priorities for the control network are shown in the last column of Table 2 and are the final priorities for the ANP model. The preanalytical stage has the highest priority with a value of 0.6079; the postanalytical stage has the second highest priority with a value of 0.2076, and lastly is the analytical stage with a value of 0.1845. Therefore, based on the results of the ANP model, the optimal stage to select to improve laboratory performance in the healthcare delivery system is the preanalytical stage.

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Table 2
Priority Values for Alternatives With Respect to Sub-Networks

		Sub-networks for improvement methods				
		Lean	Six sigma	Theory of constraints	Critical business process	Overall
Alternatives	Preanalytical Stage	0.5066	0.5585	0.6352	0.6370	0.6079
	Analytical Stage	0.1537	0.2374	0.2039	0.1047	0.1845
	Postanalytical Stage	0.3397	0.2041	0.1609	0.2583	0.2076

CONCLUSION

As the healthcare industry continues to grow rapidly, obtaining both efficiency and effectiveness within healthcare delivery systems has become a major priority. In order to increase patient satisfaction and patient safety, hospital laboratories must improve their overall performance. The objective of this study was to determine of the three stages in the laboratory process, which stage was the most critical for improvement purposes. The results from the ANP model indicate the preanalytical stage is the most critical stage in the laboratory process, which confirms what has been stated in the literature. Previous studies have indicated, from a qualitative perspective, that the most critical stage is the preanalytical stage. The study presented in this paper uses ANP modeling to provide a quantitative approach to identifying the most critical stage in the laboratory process.

The limitation of this study is that only the stage selected from the ANP model will be improved. This is due to the assumption that improving the stage selected will have an indirect positive effect on improving the remaining two stages. Although, many decision problems are best studied through the ANP technique, one should compare the ANP results obtained to those obtained using the AHP or any other decision making approach with respect to the relevance and accuracy of the results (Saaty & Vargas, 2006) . Future work will include developing an AHP or other decision making models to compare with the results from the ANP model to validate and ensure the most critical stage has been selected for improving laboratory performance in healthcare delivery systems.

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