The Impact of Laboratory Automation on Performance Improvement

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With a plethora of challenges facing today's laboratories—including increasing work volume, labor shortages, and curbed budgets—full or partial automation systems could be a tremendous asset. These authors explored the effects of test automation systems in two VA laboratories.

For modern pathology laboratories, the goal of reducing costs while providing accurate and timely test results is a challenging one. Despite laboratories' budget constraints, the volume of their work is growing—due, in part, to the aging U.S. population and the increasing diversity of available laboratory tests. Laboratories also face a shortage of key personnel; the U.S. Department of Labor projects that 13,200 medical laboratory professionals will be needed annually through the year 2010, while only 5,000 such professionals complete their training each year.[1]

Many laboratories have used automation to relieve workflow problems and use valuable personnel more effectively. The degree of automation varies from one laboratory to another, with some opting for total automation, while others implement automation on a smaller scale using modular automation systems or automated diagnostic tests.

In this report, we briefly discuss the evolution of laboratory automation. We then explore the impact of modular automation and automated molecular diagnostic testing on performance at two VA laboratories: those located at the James A. Haley Veterans' Hospital (JAHVH) in Tampa, FL and the Orlando VA Medical Center (VAMC) in Orlando, FL. We describe how automation affected the laboratories' turnaround times, space constraints, use of personnel, and cost benefits.

EVOLUTION OF THE AUTOMATED LABORATORY

Laboratory mechanization began in 1956, with the introduction of automated analyzers to detect urea in serum.[2,3] The development of multitest analyzers linked to computer-based laboratory information systems (LIS) increased productivity in the 1970s, and in the 1990s, a belt system was developed to transport specimens for automated analysis.[2,4]

Today's system of total laboratory automation involves the combination and consolidation of multiple instruments that can perform specimen sorting, routing, centrifugation, preparation, analysis, storage, retrieval, and integration into the LIS for chemistry, coagulation, endocrinology, hematology, immunology, serology, and urinalysis tests.[2,4,5] Costs and other constraints, however, make total laboratory automation impractical for all but an estimated 7% of U.S. laboratories.[4–8]

For many laboratories, therefore, modular automation systems can be a more cost-effective option. These systems incorporate several areas into a single modular unit or "workcell" connected by a specimen manager and transportation system.[4–8] The modular unit most commonly consolidates testing for clinical chemistries (such as electrolytes and creatinine) and immunoassays or antibody-based assays (such as those that establish hormone levels).

Automated molecular diagnostic tests offer another alternative to traditional laboratory testing. These tests typically utilize polymerase chain reaction (PCR) methods, which allow small quantities of DNA or RNA in samples to be amplified exponentially for easy detection. For example, two strands of DNA can be amplified to over one million strands in about 20 cycles. PCR techniques gained widespread use in the laboratory only after they became automated.[9]

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THE FACILITIES

The JAHVH is among the nation's busiest VA hospitals. Until being designated as a separate medical center in October 2006, the Orlando facility served as the JAHVH's largest multispecialty outpatient clinic. Together, the facilities include two nursing homes, a spinal cord injury and polytruama rehabilitation center, three multispecialty outpatient clinics with attached laboratories, and six community-based outpatient clinics.

The JAHVH has 503 beds and serves 116,031 unique veterans, who generate about 941,000 outpatient visits annually. The facility's core laboratory performs 7.1 million tests per year, including three million chemistry assays and 600,000 immunoassays. Volume of testing has increased an average of 22% annually over the past five years.

The Orlando VAMC has 178 beds and serves 90,000 veterans, who generate 573,485 outpatient visits annually. The facility processes one million chemistry assays and 250,000 immunoassays each year, with an average volume increase of 15% annually.

AUTOMATION AT THE JAHVH AND ORLANDO LABORATORIES

Prior to implementation of the automation systems described in this article, the JAHVH's laboratory monitoring program identified workload increases due to rising test volumes and broader menus of tests. These increases led to physical space constraints, as they necessitated the use of more equipment, and they limited the amount of time that technologists could devote to performing tests and tracking specimens.

At the time, the JAHVH's clinical chemistries equipment consisted of 12 chemistry/immunoanalyzers with eight workstations. Technologists were spending up to 17% of their time performing manual tasks, including specimen preparation, loading and unloading, storage, and relocation for repeat or add-on testing. Both hepatitis C virus (HCV) and HIV testing required laboratory staff to perform labor-intensive specimen preparation and purification manually. To help solve these problems, a team of senior medical technologists and pathologists evaluated various options for automation and sought feedback from laboratories that were already using automation.

In December 2002, the JAHVH laboratory responded to the evaluation by replacing its old clinical chemistry system with a modular automation system called the ADVIA WorkCell CDX Automation Solution (Siemens Healthcare Diagnostics Inc, Deerfield, IL) (Figure 1). A similar workcell was implemented the same month at the Orlando laboratory.

Initial evaluation of the JAHVH laboratory's needs indicated that the benefits from fully automated front-end processing (known as task-

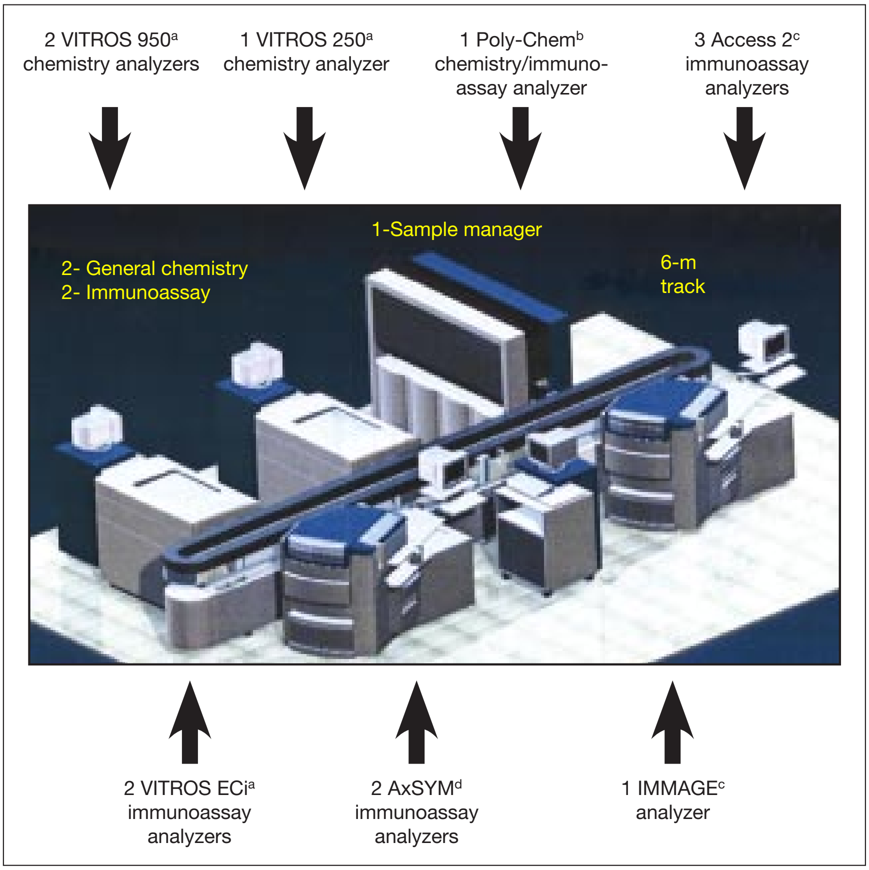

Figure 1. James A. Haley Veterans' Hospital's replacement of 12 chemistry and immunoassay analyzers with a modular automation system (ADVIA WorkCell CDX Automation Solution, Siemens Healthcare Diagnostics, Inc, Deerfield, IL) consisting of two chemistry and two immunoassay analyzers, one sample manager, and a 6-m track. Image provided courtesy of Siemens Medical Solutions Diagnostics, East Walpole, MA. Used by permission. [a]Ortho-Clinical Diagnostics, Rochester, NY. [b]Polymedco, Inc, Cortlandt Manor, NY. [c]Beckman Coulter, Inc, Fullerton, CA. [d]Abbott Diagnostics, Abbott Park, IL.

targeted automation) would be limited.[6] Therefore, certain tasks—such as order entry into the Veterans Health Information Systems and Technology Architecture (VistA), which serves as the VA's LIS; bar code labeling; centrifugation; and semiautomated decapping of specimen tubes—are performed manually.

Following these tasks, the specimens are placed into the workcell, which consists of a single modular unit and two workstations. A 6-m track equipped with barcode readers and robotics delivers the specimens to three devices: the ADVIA 1650 chemistry analyzer, the ADVIA Centaur chemiluminescent immunoanalyzer, and a sample manager that sorts and archives specimens. The workcell system also is linked to VistA. The JAHVH laboratory determined that two ADVIA 1650s and two ADVIA Centaurs would be adequate to meet the current and projected future needs of the laboratory.

The JAHVH laboratory also implemented automated molecular diagnostic testing for HCV and HIV in December 2005. It began to use the MagNA Pure LC Instrument (Roche Applied Science, Indianapolis, IN) for HCV testing and the Cobas AmpliPrep Instrument (Roche Molecular Systems, Branchburg, NJ) for HIV testing. Both of these systems, which are still in use at the JAHVH laboratory, have been described previously.[9–12]

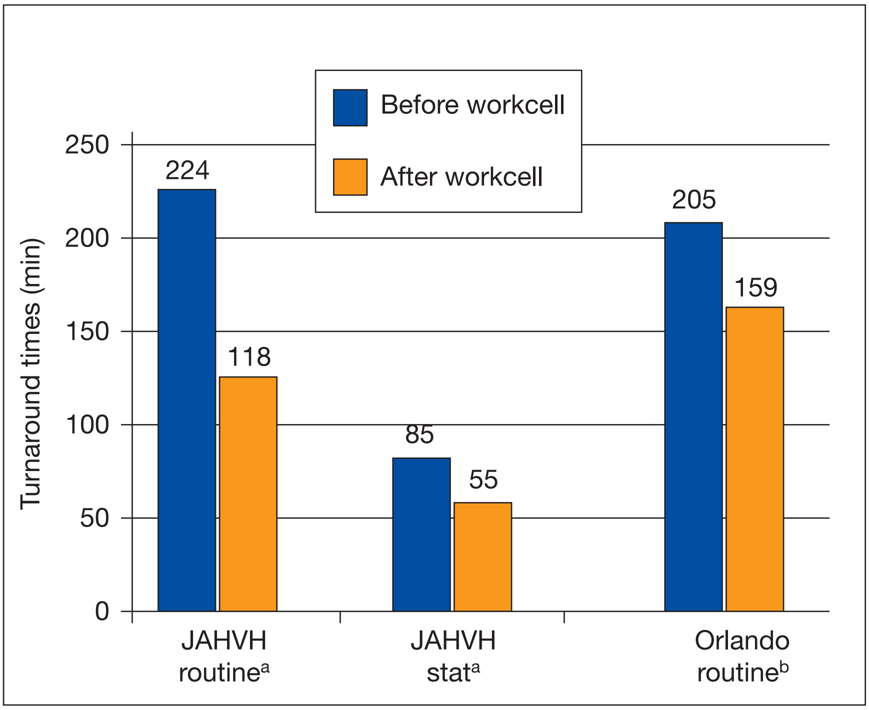

Figure 2. Laboratory tests turnaround times before and after implementation of the modular automation system (workcell) at James A. Haley Veterans' Hospital (JAHVH) and Orlando VA Medical Center. [a]Randomly selected days in November 2002 and November 2006. [b]All days in November 2002 and November 2006.

EVALUATING THE NEW SYSTEMS

To evaluate the impact of these automation systems, we looked at several kinds of data from before and after the systems' implementation. We collected data on turnaround times for all tests at the JAHVH laboratory during two randomly selected days in November 2002 and November 2006, as well as data on turnaround times for 15 selected routine tests at the Orlando laboratory during the entire months of November 2002 and November 2006. In addition, we collected data on turnaround times for HCV and HIV tests at JAHVH during the entire months of November 2004 and November 2006. These data were used to conduct real-time workflow analyses and time-in-motion studies. We also looked at data on the amount of equipment used at the laboratories, the volume of specimens, and the amount of technologists' time that was devoted to performing manual tasks.

Results

Our data indicated that after the workcell implementations, turnaround times for all tests studied decreased substantially at both the JAHVH and the Orlando laboratories. While test volumes at the JAHVH laboratory increased 20% between November 2002 and November 2006, the laboratory's turnaround times decreased 47% for routine tests and 35% for "stat" laboratory tests (those that must be completed within one hour) (Figure 2). At the Orlando laboratory, volume increased 60% while turnaround times decreased by 22% from the first to the second period.

We also found that after automated molecular diagnostic testing was implemented at the JAHVH, turnaround times for HCV and HIV tests decreased substantially. HCV viral load test volumes increased 119%, from 420 cases to 918 cases, between the data collection periods of November 2004 and November 2006. Yet turnaround times for HCV tests decreased 86%, from 14 days to

1.9 days, between the same periods. Similarly, HIV viral load test volumes increased 47%, from 288 cases to 396 cases, while turnaround times for HIV tests decreased 73%, from 15.3 days to 4.1 days.

Our other data indicated similarly positive results from the automation systems. The workcell system reduced the number of analyzers by 67% and the number of workstations by 75% at the JAHVH laboratory, and it reduced the number of workstations by 40% at the Orlando laboratory. By allowing staff to perform chemistry and immunochemistry testing with one primary tube, without aliquoting samples to multiple workstations, the workcells decreased specimen volumes by one third at both laboratories. And after the workcell implementation, JAHVH technologists' time spent on specimen handling decreased from 17% to 4%. No additional staffing was required at either laboratory during our study period, despite a steady increase in test volume at both sites.

THE BROADER BENEFITS

Turnaround times

The automation systems' success at reducing turnaround times for both laboratories has a number of positive implications. The reduction of laboratory test turnaround times has been shown to decrease overall length of stay in emergency departments and hospitals.[13] Some authors have proposed that automation has the potential to eliminate the need for stat testing.[8,13] At the JAHVH laboratory, turnaround times for routine tests after automation approached those of stat tests before automation. The dramatic improvements in stat turnaround times after automation, however, suggest that stat processing still has a role at the laboratory.

The reduction of turnaround times offered the additional benefits of allowing entire workloads to be completed in a single day and eliminating batch testing. Prior to the workcell implementation, only 66% of tests at the JAHVH laboratory were completed during regular operating hours. For example, specimens for high-density lipoprotein and low-density lipoprotein cholesterol testing that arrived at the laboratory on a given day often were held until the following day, which meant that staff on the already busy morning shift had additional specimen retrieval and sorting to complete to set up the day's run. Since the workcell implementation, however, the laboratory's tests have been run continuously, 24 hours a day. As a result, the laboratory often is able to collect an outpatient's laboratory test on the day of his or her appointment and make the test results available to the physician during the appointment.

While some of the benefits in turnaround times for HCV and HIV tests that we found may have been due to the fact that molecular diagnostics was transferred from nuclear medicine to the pathology and laboratory medicine section during the study period, staffing remained the same and much of the dramatic success is attributable to the impact of increased automation.

The improvement contributed strongly to patient care at the JAHVH. It is estimated that over 10% of all veterans—a rate five times higher than that of the general population—are HCV positive.[14,15] Molecular quantitative determination of the viral load, or amount of virus in the patient's serum, has become the standard of care in guiding the treatment of both HCV and HIV infections.[9–12,16] Therefore, rapid determination of these levels is important to patient care. It has been stated that current automation for microbiology is at the stage of clinical chemistry in the 1960s and 1970s.[9] As the success of our system demonstrates, however, developments are being made at a rapid pace.

Space constraints and rising test volume

The workcell system helped to alleviate the JAHVH laboratory's space constraints considerably by reducing its numbers of analyzers and workstations. Despite this reduction, the duplication of equipment built into the workcell design met the laboratory's current and anticipated future volume requirements. It also ensured that the laboratory would have a backup system if one machine were to malfunction.

At a time when test volumes were increasing, the workcell decreased specimen volumes substantially. As a result, such preanalytical processing work as labeling, centrifugation, decapping, aliquoting, and sorting also decreased. As the workcell gives every tube a unique identifier that is recognized throughout the hospital network and tracks each specimen from entry until storage, it eliminated such tasks as searching for specimens, diluting samples, and performing repeat tests. Finally, fewer tubes mean less patient discomfort from unnecessarily large blood draws and fewer specimen handling errors.

Cost containment and personnel shortages

No capital outlay was required for equipment with our system. Rates negotiated for reagents and maintenance contracts essentially made our system cost neutral. Our laboratory cost efficiency compares very favorably to similar hospitals in the VA system (Figure 3).[17] Among the highest complexity grouping of VA health

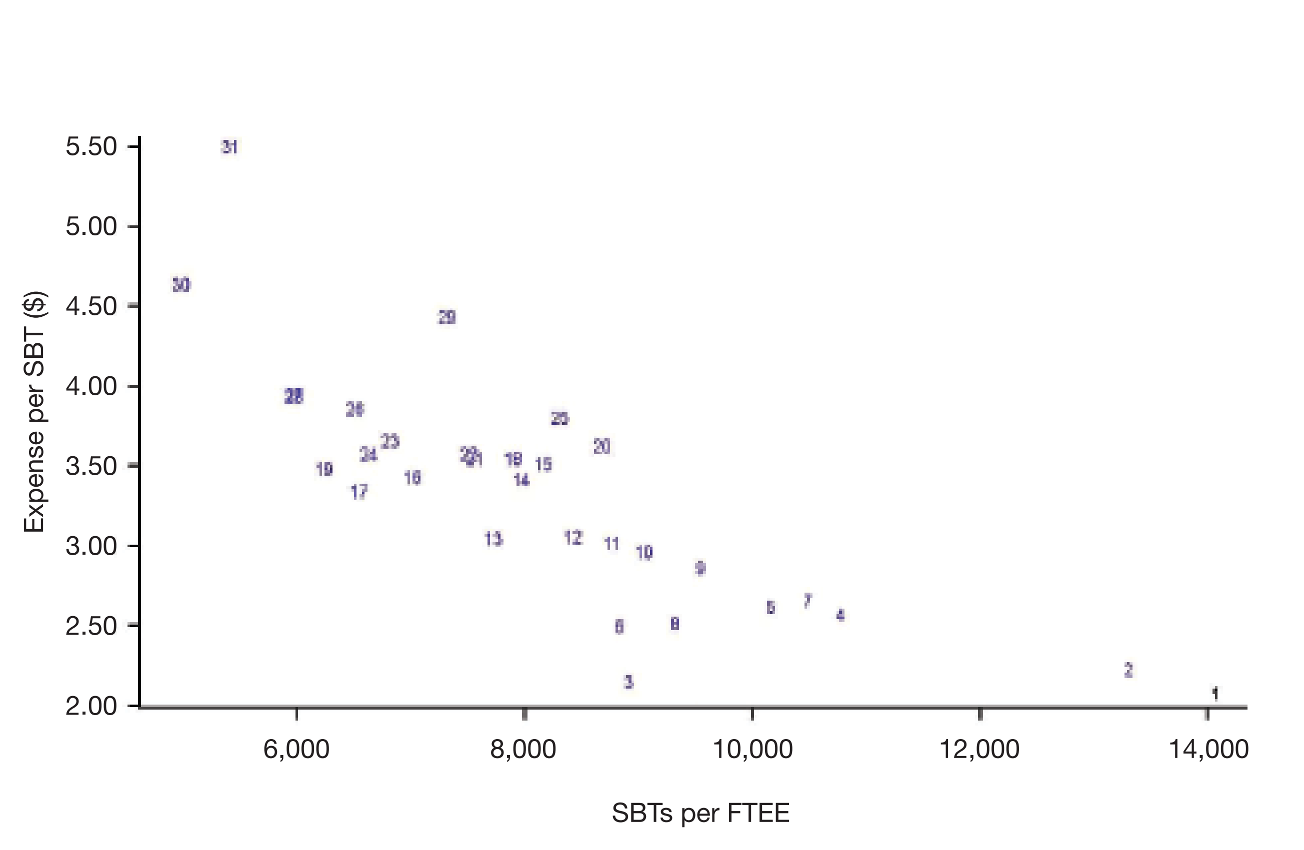

Figure 3. On-site clinical laboratory performance—expense per standard billable test (SBT) and SBTs per full-time equivalent employee (FTEE)—for the highest complexity grouping of VA health care facilities (CI Group 1a, n = 31).[17] Facility Ranking: 1–VA Medical Center (VAMC) Tampa; 2–San Juan VAMC; 3–VA Salt Lake City Health Care System (HCS); 4–Louis Stokes VAMC, Cleveland; 5–Dallas VAMC; 6–Memphis VAMC; 7–VAMC Gainesville; 8–Miami VAMC; 9–VA HCS Baltimore; 10–VA Pittsburgh HCS; 11–Atlanta VAMC; 12–VAMC Portland; 13–Houston VAMC; 14–VA San Diego HCS; 15–South Texas Veterans HCS, San Antonio; 16–VA Tennessee Valley HCS, Nashville; 17–Chicago HCS; 18–Brooklyn VAMC; 19–VA Ann Arbor HCS; 20–Greater Los Angeles HCS; 21–San Francisco VAMC; 22–VA Palo Alto HCS; 23–New York VAMC; 24–Central Arkansas Veterans HCS, Little Rock; 25–Hines VA Hospital; 26–VAMC Washington, DC; 27–Durham VAMC; 28–Minneapolis VAMC; 29–Cincinnati VAMC; 30–VA Puget Sound HCS, Seattle; 31–VA Boston HCS.

care facilities, the JAHVH laboratory performs the most tests per employee with the least cost per test. While several authors have advocated the potential financial benefits of automation, accurate calculations are rarely reported and are not available for our review.[2–8,18] Most authors have emphasized decreased personnel costs and increased productivity without real analysis of costs and benefits.

At the JAHVH laboratory, the workcell helped to ensure no additional staffing was required during the study periods, despite an annual 22% increase in test volume and a more than 100% increase in HCV tests. By reducing the number of tubes and workstations, the system reduced the number of employees needed to handle specimens and the amount of staff hours required for equipment maintenance, calibration, and quality control testing. Limiting the need for additional staff helped to contain costs, as labor represents the largest laboratory expenditure. It also helped the laboratory deal with severe shortages of medical technologists and technicians. The number of accredited training programs for medical technologists has decreased by 30% over the past five years, and such large cities as Miami and Los Angeles currently have no accredited training programs. While Congress has considered legislation to help relieve the shortages,[1] laboratories must deal with the shortages immediately in order to continue their services. Our results indicate that automation can be an important tool in this regard.

Continued on page 23

Continued from page 18

A TIMELY TOOL

Modular laboratory automation allows small- and medium-sized laboratories access to automation that otherwise would be unavailable.[5,8] These systems address increasing test volumes and menus despite labor shortages. Turnaround times improve dramatically, and, in our case, the system was cost neutral.

Laboratory automation is rapidly expanding. It already has a major influence in the areas of clinical chemistries and hematology, and it is having a tremendous impact through molecular technologies in other areas, such as microbiology, phamacogenomics, and hematopathology. With implementation of these systems, our laboratories continue to provide state of the art care for our nation's veterans.●

Author disclosures

The authors report no actual or potential conflicts of interest with regard to this article.

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