Design a Lean laboratory layout

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February 2006

With a review by Dr. Jeffrey Liker, noted lean management expert and best-selling author:

“I believe there is a real need for papers like yours... ...The methodology you illustrate through value stream mapping, re-layout, and planning overall flow is the right approach and labs need to see the real example you describe to understand what is possible.”

Jeffrey K. Liker
Professor of Industrial and Operations Engineering
Director, Japan Technology Management Program

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Design a Lean laboratory layout

By Thomas P. Joseph, MBA, MT (ASCP)

The Lean principles that revolutionized manufacturing are now bringing dramatic changes to the service sector, including healthcare. Laboratories considering significant renovations or construction of a new facility have an exceptional opportunity to design space using Lean operations from start to finish. Rather than working within limitations of existing structures to develop “pockets of Lean” in the form of work cells, these laboratories can optimize the entire value stream.

Based on the Toyota Production System, Lean manufacturing is a defined methodology with a focus on elimination of waste. Toyota — consistently benchmarked as best in class for high quality, productivity, manufacturing speed, and flexibility — has the fastest product-development process in the world.1 Seven wastes identified by its founder Taiichi Ohno were systematically identified and eliminated, dramatically improving the time from customer order to delivery and cash collection.2 Four wastes are our focus: waiting for work, unnecessary transport, unnecessary movement by staff, and excessive inventory. The methodology described here can achieve a 49% to 81% reduction in overall worker travel and specimen transport compared to traditional laboratory designs.

The importance of developing an effective facility layout has long been recognized; this is a key aspect of Lean design principles. Between 20% and 50% of total operating expenses in a variety of production and manufacturing settings are attributed to materials handling. Studies have demonstrated that efficient facility design can reduce these costs by 10% to 30%,2 and provide an excellent return on investment over the life of the facility.3 The objectives of optimal facility layout include:

1. obtaining smooth flow;
2. minimizing handling distances/costs;
3. reducing (a) walking distances and (b) work in progress. In the laboratory setting, this translates to specimens in process (i.e., samples sitting in racks waiting for processing and analysis, or test results waiting for review and release); and
4. improving (a) visibility for effective management of operations; (b) the work environment; and (c) inventory management.

Development of a Lean facility design

In order to develop the most comprehensive Lean design and derive the maximum benefit over the life of the facility, planning should include:

1. assessment of current operations and development of a Lean future state (the planned sequence of processes for a product that identifies opportunities for improvement from the current state);
2. development of a long-range growth model;
3. development of space requirements by functional area using the growth model, Lean tools, and metrics;
4. employment of optimization methods that generate a high-level layout; and translation of design into detailed drawings.

Assessment of current operations and development of Lean future state. Development of a Lean laboratory design begins with a thorough understanding of the current operations — including test capabilities, specimen arrival from various business segments, and customer turnaround time (TAT) requirements — using Lean methodologies and tools. The importance of this review cannot be overstated. This assessment provides much of the information required to properly design, measure process/instrument capacity, and identify opportunities for improvement. This evaluation begins with:

- understanding the workflow from process to process through the entire operation;
- measurement of cycle times, lead times, and turnaround times; and
- analysis of specimen arrival times and workload by hour of day.

Workflow assessment often takes the form of a value stream map. (A graphical depiction of the sequence of processes for a product and key characteristics of each process.) A process includes analytical equipment that performs testing as well as manual functions, such as specimen receipt verification, distribution, and result reporting. Value stream mapping can aid in evaluation of operations and identify waste in the process, thereby improving the overall efficiency of the lab. The key characteristics of each process should be measured, including cycle times (the number of specimens processed per unit of time) and lead times (the time it takes a specimen to move through a process). For example, a particular analyzer may turn out a result every 30 seconds (cycle time), but it may take 10 minutes for the first result to be produced (lead time) once a run is initiated.

The described methodology results in significant improvements in operating efficiency vs. traditional laboratory designs, achieving a reduction in the Weighted Workflow ranging from 49% to 81%.

Examination of customer TAT expectations and daily demand for different assays can be translated into a takt time (available work time divided by customer demand), which — in conjunction with measures of process cycle times — indicate where bottlenecks are occurring in the value stream. In order to meet TAT expectations, each process must have a cycle time that is less than the takt time. (Takt is a German term for a precise time interval, as in a metronome beat.)

Application of several of these principles is illustrated with the following example. A sequential analysis of CBC TAT in
Figure 1 indicates that the lab is generally meeting desired TAT of less than 30 minutes only during the period after 7:30 a.m. Between 2:30 a.m. and 7:30 a.m., the TAT averages 44 minutes and misses the target 64% of the time (see Table 1).

Table 1. Turnaround-time summary.

<table>
<thead>
<tr>
<th></th>
<th>All Spec</th>
<th>2:30a - 7:30a</th>
<th>7:30a - 12:00a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (minutes)</td>
<td>31.0</td>
<td>28.7</td>
<td>13.0</td>
</tr>
<tr>
<td>Median (minutes)</td>
<td>28.0</td>
<td>28.0</td>
<td>14.5</td>
</tr>
<tr>
<td>Minimum (minutes)</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Maximum (minutes)</td>
<td>4.0</td>
<td>14.5</td>
<td>110.0</td>
</tr>
<tr>
<td>Target (minutes)</td>
<td>30.0</td>
<td>30.0</td>
<td>30.0</td>
</tr>
<tr>
<td># Spec Above Target</td>
<td>34</td>
<td>75</td>
<td>15</td>
</tr>
<tr>
<td>Total Spec</td>
<td>244</td>
<td>114</td>
<td>100</td>
</tr>
<tr>
<td>% Spec Above Target</td>
<td>40.2%</td>
<td>54.1%</td>
<td>15.0%</td>
</tr>
</tbody>
</table>

Data on specimen arrival time can shed light on the cause of the excessive TAT and lead to various strategies for improved performance. Figure 2 illustrates the typical arrival of specimens in the lab by hour of the day. The early morning workload peak combined with the TAT chart indicates that a bottleneck process is likely causing the increase in TAT. For example, Figure 2 shows peak specimen arrival during the third, fourth, and fifth hours with specimens arriving at a rate of 100 or more per hour. This is the exact time period where Figure 1 shows TAT beginning to exceed the target of 30 minutes (red line). Observation of operations suggests that the bottleneck occurs in specimen processing. An analysis of takt and cycle times will validate this hypothesis.

The takt time during this peak period is calculated as the available time (six peak-period hours) divided by customer demand (of 800 specimens) = 45 seconds. The purpose of takt time is to match the rate of production to demand. Operations must complete one CBC sample every 45 seconds to meet customer expectations. In this illustration, a single Beckman Coulter cell counter produces a result every 37 seconds. In other words, a CBC is entering the analytical process every 45 seconds (takt time) on average. The cell counter has the processing capacity to turn out a result every 37 seconds (cycle time) and, therefore, is able to keep up with demand during this peak period. Figure 3 shows the cycle times for each process from receipt to verification for a CBC for an individual workstation and for all workstations available in the current state.

Figure 3 confirms that the bottleneck in specimen processing, where there is insufficient capacity to meet takt time. After a while, specimen inventory waiting to be processed will build up, resulting in an increase in TAT. Cycle times for CBC processes are below takt time for analytical and reporting ones, which have sufficient capacity.

The specimen-processing bottleneck could be addressed by leveling morning workload by moving non-timed and non-fasting specimen collection to evening shift or delivering morning draws to the lab in small batches. Only after exhausting leveling strategies should a manager consider adding additional workstations in specimen processing. In other situations with excessive TAT, there may be sufficient capacity for each process but poor transfer of work between them. This might be because of poor coupling of processes due to lack of proximity or visual obstructions. In other cases, a bottleneck may be the result of insufficient capacity in the analytical process and may require additional analytical equipment.

Prior to developing a final space plan, other Lean strategies should also be examined. A key strategy includes development of work cells (an adjacent series of processes to promote continuous flow, typically with a U-shape design to minimize operator walking).

While a full treatment of Lean strategies and methods is beyond the scope of this article, Lean methods do provide a very effective tool set for evaluating operations and eliminating waste. There are many excellent Lean resources available for the interested reader, including the following:

Continues on page 26
Planing for growth: activity projections. Once current operations have been evaluated and reviewed for operational improvements, a long-term space plan can be developed. A carefully developed facility plan will be optimized not just for today’s operations, but also give proper consideration to changing requirements that arise from growth and test mix changes. Mix changes are often the result of developing new business segments (e.g., outreach) or new areas of testing.

A growth plan should begin with test activity projections and consider historical trends, an institution’s strategic plan, and the planned development of other business segments. Each of these items will provide key assumptions toward development of a long-term growth model. These inputs may differ in test mix, utilization, and specimen arrival times. For example, outreach specimens typically arrive at the lab after the morning surge of inpatient testing and, therefore, may not require additional analytical capacity.

While a long-term growth model will not perfectly predict the future, it provides a sound basis for assessment of capacity. If desired, key assumptions with a high degree of uncertainty can be further modeled using risk analysis and Monte Carlo simulation.4 (Monte Carlo simulation is a method of determining likely outcomes for an analysis by evaluating key assumptions with a probability distribution rather than using the traditional best-estimate/best-case/worst-case approach.)

The growth model should be able to provide projections for overall growth and growth by business segment, department, or workstation (see Figure 4). A comprehensive model will also allow activity projections to be translated into projections of workload by workstations and by hour of the day (see Figure 5).

Developing space requirements by functional area. A critical component in the development of space requirements entails an examination of the capacity of key processes, both manual and automated. A comparison of cycle and takt times provides the picture of capacity of each process (see Figure 3). This information is useful in determining which processes will require additional capacity and in allowing appropriate space for future growth (e.g., equipment footprint projections).

Figure 5 shows the projected utilization of a single analyzer based on measured cycle times. Growth projections indicate that anticipated demand will not exceed capacity during the next 15 years. This analysis by hour of the day illustrates how outreach growth uses excess instrument capacity available during the afternoon shift. The potential early morning bottleneck anticipated in later years can be addressed in any of several ways:

- leveling workload as discussed above, which requires no capital investment and improves flow for all downstream processes;
- adding capacity with duplicate analytical instruments; and
- eventual selection of replacement equipment with reduced cycle times.

All key processes should be evaluated. Some will necessarily increase directly as a function of volume, while others may have considerable excess capacity to accommodate anticipated growth. Systematic evaluation of process capacity will allow translation of activity projection into space requirements for each process.

The end result of the activity-based growth model and capacity measurement is a projection of space requirements for each area over the long-term planning horizon (see Figure 6).

If the laboratory is relocating to a new facility, the space requirements model will provide overall space requirements as well as requirements by area for a long-term plan. In situations with limited space availability, the projections will provide an assessment of how long a particular space will be adequate and the relative requirements for each functional area. This model of space requirements provides key input into the overall space-optimization plan.
Development of a high-level layout using optimization methods. The next stage of the space planning process employs methods to develop a general layout with optimal arrangement of lab areas to produce the best overall workflow. There are four steps in this process:

1. Quantify all workflows including specimen flow, materials flow, storage/retrieval of specimens and information flow.
2. Assign weights to workflows.
3. Develop a flow or interaction matrix.
4. Perform the optimization using linear programming that will generate a layout that maximizes the efficiency of operations.

Quantification of workflows. Once the workflows for specimens, supplies, and information are identified, these workflows must be converted into quantified activity that occurs among processes or functional areas of the lab. The most apparent type of flow is specimens. It is a relatively simple matter to determine the flow to each department or area. A count of specimens as they move from specimen processing to each technical area and then to storage areas can be readily developed from activity reports. Other flows can be considered as well, including movement of supplies, information, and staff. Including this data will allow the space plan to be optimized for support functions and areas as well as the technical workspace.

Workflow weights. Different weights can be assigned to reflect the relative importance of the flow. For example, the different types of flows: specimen testing, specimen storage/retrieval, and restocking supplies could be assigned relative weights of 1.0, 0.5, and 0.2, respectively. This weight becomes a factor in the objective to maximize the efficiency of operations and will give appropriate weight to aspects of operations most critical to customer satisfaction. (In the author’s view, flows that directly relate to achieving turnaround time should have a greater weighting than flows such as specimen archiving.)

Flow matrix. A flow or interaction matrix quantifies and maps the flows between two areas or processes. This matrix is also called a “from-to” matrix and is illustrated in Table 2. The matrix identifies each area of the lab to be studied and may include storage areas. It should include the entry points used to deliver specimens. For example, the specimens in this illustration first enter that laboratory at one of two areas: a lab “entrance” or a pneumatic tube station. When the actual optimization is performed, the former must lie on the lab perimeter, while the optimization process might place the pneumatic tube anywhere within the laboratory space, but most certainly in the specimen processing area. Flows should be defined as flow per time unit, as in specimens per day or month. The time unit should remain constant. In Table 2, the shaded cells indicate workflow from the initial entry into the lab or directly delivered to a particular department. The quantities shown are in terms of specimens per day. The other cells indicate subsequent specimen distribution to their final testing location or archiving of completed specimens. The weights have been assigned a value of 1.0 for most flows that relate to achieving turn around time, and 0.5 for specimen archiving. The blood bank has been assigned a weight of 3.0 to reflect its unique status in patient care.

Table 2. Flow (interaction) matrix

<table>
<thead>
<tr>
<th></th>
<th>Lab Entrance</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
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<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
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<td>0</td>
<td>1</td>
<td>0</td>
</tr>
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</table>

Layout optimization. Optimization methods are then employed which will produce a facility layout that achieves the greatest relative operational efficiency by minimizing the Weighted Workflow function:

\[
\sum_{i=1}^{m} \sum_{j=1}^{n} (f_{ij} \cdot w_{ij}) \cdot d_{ij}
\]

Where
- \( d_{ij} \) is the rectilinear distance from area i to area j
- \( f_{ij} \) is the flow per unit of time from area i to area j
- \( w_{ij} \) is the weight assigned to the flow

These calculations are illustrated in the following simplified example (see Figure 7). Approaches to developing solutions for this class of facility layout problems are based on linear and integer programming models described extensively by other authors.\(^5\) The optimization will produce a general layout that may require some modifications to conform to physical constraints in the facility. It does provide an objective layout that will provide a sound basis for detailed design work and can achieve a final design close to the ideal configuration.
The benefits of an optimized layout approach include the following:

- Multiple design alternatives can be evaluated quickly.
- The relative efficiency of alternative designs can be quantified.
- In the case of high growth settings, a parallel set of optimal designs can be developed for current and long-term space requirements, which will help achieve the least disruptive growth plan.

The diagram presented in Figure 8a is the optimized arrangement of laboratory areas based on the flows and weights shown in Table 2. This arrangement minimizes the workflow function presented earlier. Figure 8b is a slight modification of the optimal arrangement that yields a more compact layout with only a slight loss in efficiency (the workflow function is 3.5% greater in Figure 8b).

These diagrams provide a basic design for illustration purposes. A more detailed plan can be developed with separate areas for specialty testing. A comprehensive design will include other areas such as client services, supply storage, referral processing, administrative offices, and information systems. A design can also consider proximity to areas that may lie outside the laboratory perimeter, such as outpatient phlebotomy or various critical-care areas.

Optimal configurations will vary depending on a number of factors. These include:

- differences in workflow and weights;
- multiple entrances to the laboratory for receiving specimens, such as courier access for outreach;
- the shape of the laboratory perimeter;
- multiple floor designs; and other architectural constraints, such as internal hallways, stairwells, and elevators that cannot be relocated. Even in cases with significant architectural constraints, this methodology still provides the means of developing the most efficient layout possible.

Translation of high-level design into detailed drawings.

From the high-level block diagram plans, detailed schematic designs can then be developed that include instrument workstations, associated workspace, and support areas. Certain aspects of this detail design merit comment:

- Lean design planning will necessarily include adoption of a Lean culture including the 5Ss (a set of workplace practices that promote visual control and lean operations: sort, straighten, shine, standardize, sustain).
- In practical terms, 5S entails elimination of unnecessary clutter, development of standardized work processes, and minimal inventory at workstations. In general, a 5S initiative results in a more compact design with all necessary tools and supplies available to the operator.

Detailed planning requires working closely with laboratory staff. Mock-ups are recommended for key areas of the lab, in particular any planned work cells. A mock-up can be developed that gives laboratory staff the opportunity to walk key areas to confirm

Table 3. Improvement in efficiency using recommended approach vs. traditional lab designs.

<table>
<thead>
<tr>
<th>Lab</th>
<th>Current</th>
<th>Lean Optimization</th>
<th>% Change</th>
</tr>
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<td>221,666</td>
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<tr>
<td>B</td>
<td>289,467</td>
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<td>-54.9%</td>
</tr>
<tr>
<td>C</td>
<td>184,481</td>
<td>85,000</td>
<td>-54.9%</td>
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<tr>
<td>D</td>
<td>427,524</td>
<td>121,679</td>
<td>-71.5%</td>
</tr>
<tr>
<td>Average</td>
<td>427,524</td>
<td>121,679</td>
<td>-64.2%</td>
</tr>
</tbody>
</table>

Continues on page 31
there is adequate space for the modified traffic patterns.

Finally, proper attention should be given to safety and environmental considerations. Egress and fire codes must be observed. Architects involved in the planning process will provide the necessary plan constraints.

Results of Lean design

What benefits can be expected from a comprehensive Lean design? The main benefit is an efficient design that optimizes specimen flow, increases staff productivity, and reduces waste over many years, throughout the life of the facility. The improvement in workflow will, of course, depend on the efficiency of the current laboratory design. Table 3 demonstrates significant improvements in operating efficiency for four traditional laboratory designs where a reduction in the Weighted Workflow ranged from 49% to 81%. This dramatic improvement translates, in practical ways, to improved operating performance, turnaround time, space utilization, and working conditions for employees.

Laboratories considering significant renovations or construction of a new facility have an exceptional opportunity to design space using Lean operations from start to finish

Laboratory management should seriously consider adoption of Lean management. Lean is not the “flavor-of-the-month” initiative; the Lean philosophy and tool set are here to stay. Countless success stories are available in both manufacturing and service sector. Those managers who implement Lean will continue to report success in crucial performance metrics and quality. They will also find Lean strategies a key to addressing the rapidly developing shortage of medical technologists. When significant renovation or construction of new laboratory facilities are being considered, the methods described here provide a comprehensive approach to achieving a highly efficient laboratory design. Such a design will support Lean operations in the immediate future while providing a plan for efficient operations for years to come.

Thomas P. Joseph, MBA, MT (ASCP), is managing member at Sprick, Stegall & Associates, LLC, in Ann Arbor, MI. Reach him at tpjoseph@umich.edu.

References

September 10, 2005

Dear Thomas Joseph:

Thank you for sending me your paper on “Layout Design for the Lean Laboratory.” I have communicated with many medical laboratories and the opportunity for improving through lean methods is tremendous.

I believe there is a real need for papers like yours. There is interest, there is waste, and there is opportunity. What labs are looking for are examples and methodologies. Many are starting with very small kaizen activities but without a plan for the system the results will be very limited. The methodology you illustrate through value stream mapping, re-layout, and planning overall flow is the right approach and labs need to see the real example you describe to understand what is possible.

The article is well written and a nice blend between the methodology and the case example.

Sincerely,

Jeffrey K. Liker
Professor of Industrial and Operations Engineering
Director, Japan Technology Management Program

Dr. Jeffrey K. Liker is internationally recognized for expertise in lean manufacturing. The following is a brief biography of Dr. Liker.

Dr. Jeffrey K. Liker is Professor of Industrial and Operations Engineering at the University of Michigan. He is the Director of the Japan Technology Management Program (JTMP) and co-Director of the lean manufacturing program at the University of Michigan.


He is active as a keynote speaker, speaker for executive retreats, and lean consultant, independently and through a company he cofounded --Optiprise, Inc. Recent clients include DaimlerChrysler, Metalsa, Danfoss, Rio Tinto Mining, Caterpillar Asia Pacific, Benteler Automotive, Amcor, Federal Mogul, PPG Industries, Johnson Controls, Tenneco Automotive, Framatome Technologies, Northrop Grumman Ship Systems, Jacksonville Naval Air Depot, and the U.S. Air Force material command.