Excel-based Tools for Lean Six Sigma: Crystal Ball and QI Macros

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Faced with global competition, businesses worldwide are applying process improvement methodologies to drive productivity and profitability. Large and small companies are turning to Lean Six Sigma (LSS), a blend of Six Sigma for quality and Lean Speed for waste reduction, to help reduce the defects, delay, and deviation that devour profits and alienate customers.

Experience has shown that as little as 4% of any business produces over half of the waste, rework and delay. Finding and fixing these pockets of dysfunction can dramatically reduce costs and boost profits. According to Authors Stalk and Hout in *Competing Against Time*, a 25% reduction in delay will double productivity and increase profits by 20%. It doesn't matter if you're a manufacturer producing components or a healthcare provider producing a service; Lean Six Sigma can help you fire up your profits by plugging the leaks in your cash flow.

As with any new methodology, much of the upfront time is spent learning the basics and proving the value of the business investment. World-class Lean Six Sigma programs combine a tight focus with the right people and the best software tools, tools that are easy to learn and use and streamline the journey to profitability. Most businesses use Microsoft Office as their documentation suite, and because employees are often too busy to learn new software packages outside of the Office environment, Excel-based analysis tools are increasingly popular.

Two such Excel-based tools are QI Macros and Crystal Ball® software. Using the methods of Lean Six Sigma and QI Macros, you can quickly diagnose the root causes of delay, defects and deviation. This analysis helps build models of how things work. Then, with Crystal Ball software, you can quickly analyze and optimize the solutions required to reduce or eliminate the root causes. This paper covers the basic features of both software tools and discusses their use in Lean Six Sigma through a case study of a Level 1 hospital Emergency Department.

Lean Six Sigma Statistics and Charts with QI Macros Software

While an excellent analytical tool, Microsoft Excel is not programmed to produce the charts and statistics required for LSS projects. QI Macros adds these tools to Excel through a pull down menu (or a 2007-style ribbon). QI Macros users select the data and have the QI Macros do the math and draw the graphs for them.

QI Macros has four key components:

- **Macros that create visual tools such as control charts, histograms, pareto charts, fishbone diagrams, and more**. A Control Chart Wizard even helps you to choose the right control chart.
- **Statistical Tools**. An easy-to-use front-end for Excel's Analysis Toolpak that calculates Six Sigma metrics such as Cp, CpK, and Sigma.
- **Data Transformation Tools**. Used to change, restack or analyze data. A CrossTab-PivotTable Wizard quickly analyzes up to four columns of text or numbers.
- **Fill-in-the-blank templates** for many Lean Six Sigma tools and charts.

A Lean project often begins with no more than a few pads of Post-it™ notes to map the value stream of a process. Using the QI Macros Value Stream Template, you can quickly capture a value stream map, such as a hospital's emergency room (Figure 1), into Excel, where it can be modified and improved as required. A Lean Six Sigma improvement story can be as simple as a line, pareto and fishbone diagram (Figure 2), all of which can be easily created with QI Macros.

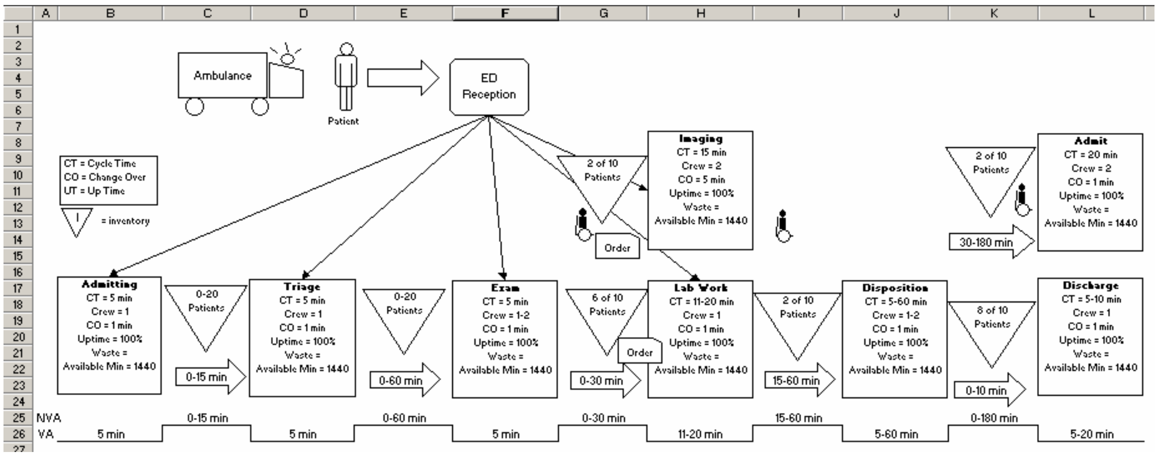


Figure 1 – Emergency Room Value Stream Map

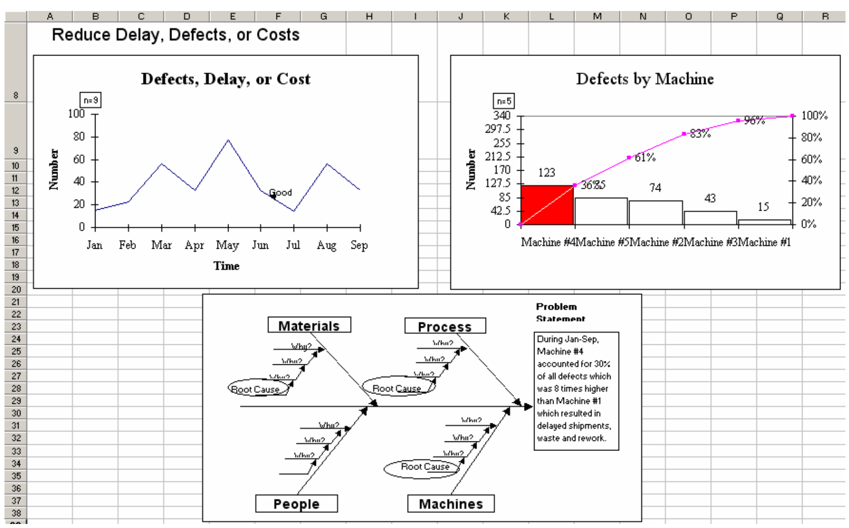


Figure 2 – A Lean Six Sigma Improvement Story

Simulation and Risk Analysis with Crystal Ball Software

Once you have some facts and figures about how your business, process or system works, you've got the essential data required to develop a computer model that represents the business, process, and system. A computer model can establish a baseline (the current or "as-is" state) against which you can measure the effects of potential improvements (the future or "to-be" state). Models are especially handy when data is estimated, limited in size, expensive to collect, or difficult to measure in a reasonable amount of time.

Crystal Ball software uses Monte Carlo simulation (often referred to as "What-If" analysis) to forecast the behavior of a spreadsheet model. In a spreadsheet, a model consists of a set of inputs (X's) and at least one output (a formula). Simply put, Monte Carlo simulation is a random sampling technique that uses probability distributions (e.g., the normal distribution) as process inputs rather than a single or averaged value. For each Monte Carlo trial, Crystal Ball randomly samples from the defined distributions, enters each new sampled value into the appropriate spreadsheet cell, recalculates the entire spreadsheet, and records the output results for later analysis. In this way, Monte Carlo simulation virtually creates hundreds or thousands of new scenarios for each process, engineering design, or financial forecast. You can use the resulting charts and statistics to assess the risk involved with the project and to provide support to critical business decisions.

For example, in a fairly linear order process (Figure 3), Monte Carlo simulation is used to move thousands of virtual orders through the system in a period of seconds. The variable inputs are the green colored process steps and delays, and the key output is blue colored cycle time. After the simulation, you can review the descriptive statistics about the process (e.g., mean, standard deviation) and capability metrics for the order process (e.g., Cpk, Sigma).

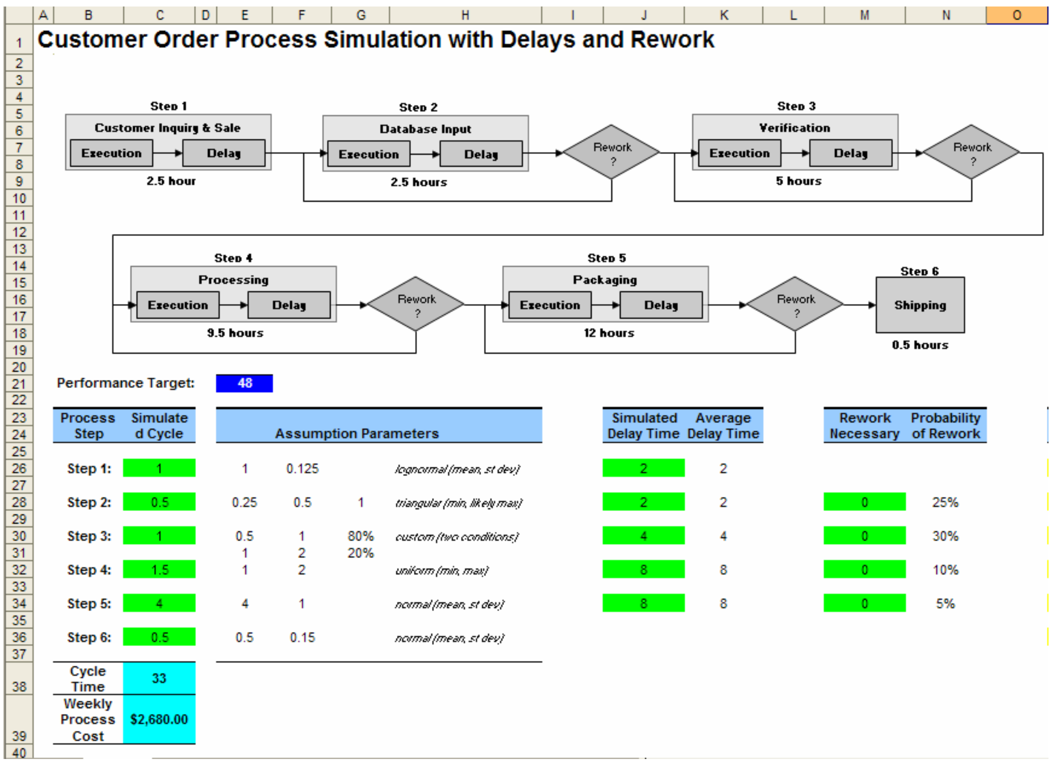


Figure 3 – Order Process Model in Excel with Crystal Ball

When Crystal Ball runs a simulation, it also analyzes the relationships between the inputs and outputs to determine which inputs have the greatest relative impact on performance. This sensitivity analysis tool can help you to determine, for example, which process steps are most critical to quality (CTQs – cycle time and defects) and which steps have little impact. Sensitivity analysis is especially helpful when input distributions are non-normal, when output formulas are nonlinear, and when the model contains large numbers of input distributions. You can then forecast the effects of proposed process improvements by updating the model, simulating the new version, and comparing the results.

Hospital Emergency Department Case Study

With few exceptions, most hospital emergency departments (ED) struggle with patient management and flow. While the ED's motto is "treat 'em and street 'em," the process can be far slower than necessary. Failure to turn patients around can result in an overcrowded ED, which in turn can cause the ED to go on *diversion*, when ambulances are turned away from a hospital. It also forces ambulances to drive farther, which may impact patient safety.

To understand the current challenges facing many EDs, here are some revealing statistics:

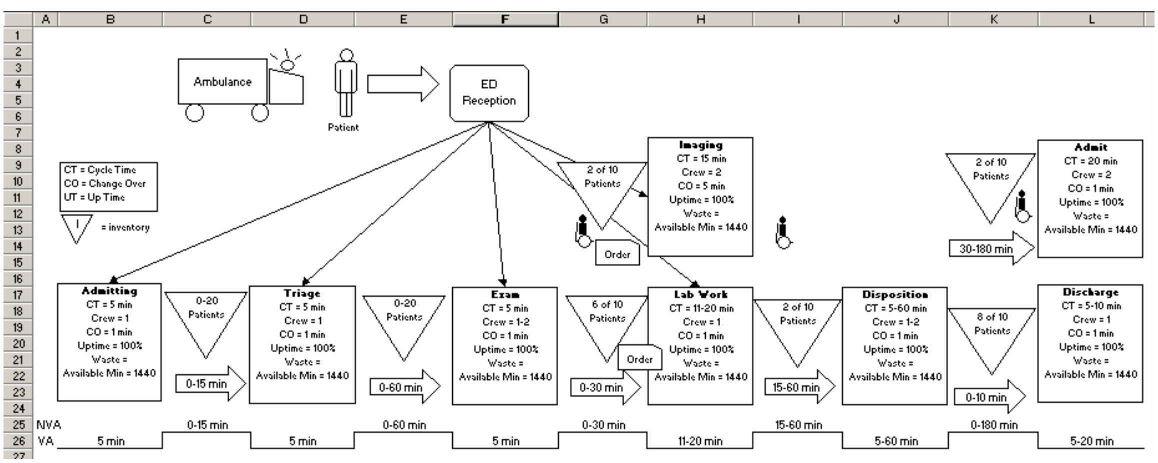
- 6 of 10 hospitals and 9 of 10 trauma centers are operating at or over capacity.
- One-third of all EDs experience diversion (turning away ambulances) the entire year.
- EDs average two ambulances an hour.
- Each patient who arrives by ambulance is worth about $7,000 on average. So every hour on diversion can cost the hospital an average of $14,000. Most hospitals experience 2-20 hours of diversion a week.
- In cardiac hospitals, 1 in 5 ambulances bring a heart bypass patient worth over $100,000. So, every 2.5 hours on diversion may cost these hospitals six figures of income.

According to the JCAHO (Joint Commission for Accreditation of Healthcare Organizations), there were 107,500,000 emergency department visits in 2001. Patients who are discharged from the ED should spend no more than 90 minutes. Admitted patients should spend no more than 120 minutes before being moved to a nursing unit.

In 2004, The Robert Wood Johnson University Hospital won the National Baldridge award for quality. The average time for discharged patient in this ED was 38 minutes. Admitted patients ran less than 90. They even offer a guarantee that you will see an ED nurse within 15 minutes and a physician in 30 minutes or less. This offers a baseline for what is possible to achieve using Lean Six Sigma in an ED.

The Level 1 Trauma ED Process

In this particular project, a Six Sigma Black Belt was assigned to improve the flow through a 19-bed Level 1 Trauma ED. A typical ED looks similar to the Lean Six Sigma value stream map shown in Figure 1 (repeated below), which is available as a template in QI Macros. The process runs as follows:



1. A patient signs in and then waits.
2. A patient is “registered,” so that the hospital can bill the insured, and then waits.
3. A triage nurse checks the patient’s vital signs, makes an initial assessment, and moves the patient to an exam room where he or she waits for the doctor.
4. The doctor examines the patient and may order lab tests or imaging (x-rays). About 66% of patients require lab work, 33% require imaging, and some may require both.
5. The lab sample is taken and given to the clerk to send to the lab, or the patient is transported to imaging where the image is taken and forwarded to a radiologist for review.
6. The patient waits for a lab or radiologist to complete their analysis.

7. The patient waits for the doctor to read the results.
8. Based on the test results, the doctor may recommend that the patient be admitted, request a consultation with a specialist (less than 20% of patients), or prescribe treatment and sign the release to discharge the patient. The patient then waits for a bed, specialist or discharge.
9. The patient is admitted, or the discharge nurse spends some time “teaching” the discharged patient what she needs to do when she goes home.

The Black Belt then used the value stream map to divide these activities into two distinct time categories: Value Added (VA) and Non-Value Added (NVA). The VA time (registration, triage, exam, lab, imaging, and discharge) represented activities that were valuable to the customer, were done right the first time, and somehow changed (positively) the product or service (e.g., the lab tests came back negative, eliminating possible causes). NVA time in this process occurred primarily when the patient was waiting.

The easiest way to accelerate an ED is to start to reduce or eliminate the patient’s wait time between steps in the process. However, Lean Six Sigma methodology dictates that a Black Belt must first measure understand the character and timing of the current state of a process prior to making changes in the process. An analysis of the existing performance may often reveal hidden rework or non-intuitive relationships that dramatically impact patient flow through the ED.

Some hospitals keep manual records and ED log books that can be analyzed to determine the timing for process steps. Other hospitals use electronic medical records, which make it even easier to analyze performance. In this project, the Black Belt had electronic data, which he then moved to Microsoft Excel and QI Macros for analysis.

Analyzing the Historic ED Data

Using the hospital’s data and QI Macros, the Black Belt developed several XmR control charts and histograms to highlight the EDs past performance. Based on staff interviews, he focused his studies on three areas: the time for sign-in to triage, the time required for lab/imaging, and the time from when a bed is ordered until it is occupied by an admitted patient.

His first control chart displayed the average time for sign-in to triage (Figure 4). Notice that at 17.4 minutes, it’s only slightly longer than the aforementioned Baldridge hospital’s standard of 15 minutes. The software statistically and automatically highlighted in red all unstable conditions and improbable behavior (out of control points and points hugging the center line). Out of control points were analyzed for special causes. Periods like the one below where the times were tightly clustered around the center line were studied to determine how to minimize variation.

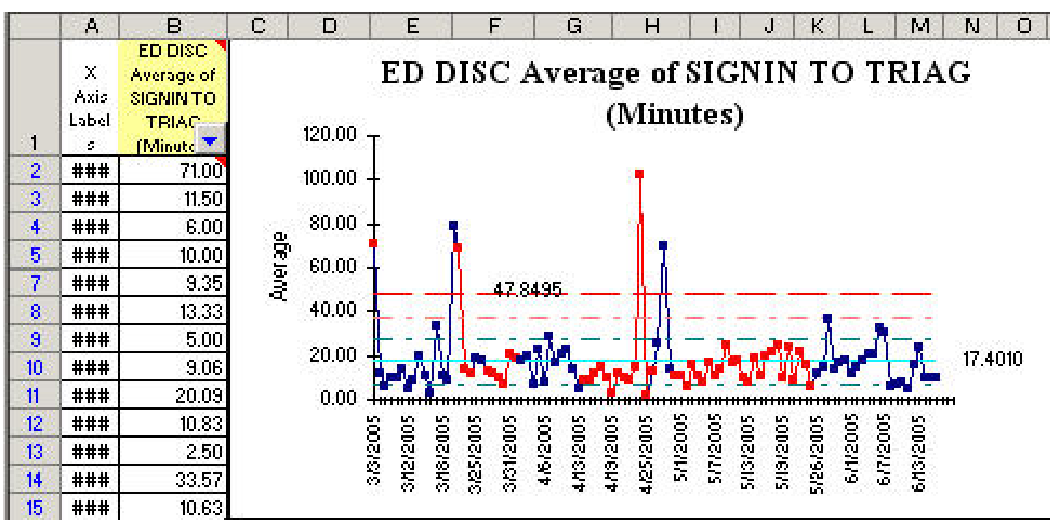


Figure 4 – Sign in to Triage

A histogram of the same data (Figure 5) showed the average time, 17.4 minutes, and the range of times from sign-in to exam for a discharged patient. When the Black Belt specified an upper limit of 15 minutes for waiting for triage, QI Macros calculated capability metrics (Figure 5, left side) that were far below the desired capability of Cp=Cpk=1.0. A Cp/Cpk of 1.0 means the process is at 3 sigma. 1.33 is 4 sigma. 1.66 is 5 sigma. And 2.0 is 6 sigma.

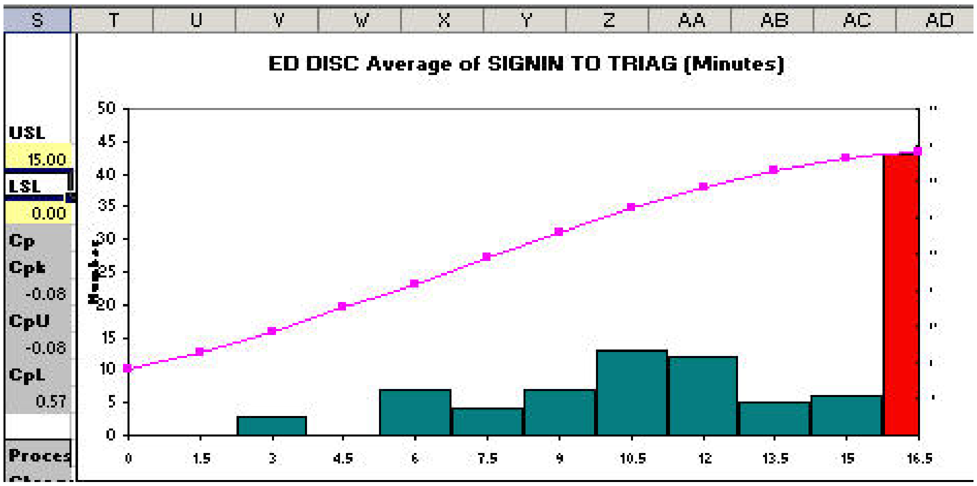


Figure 5 – Sign-in to Triage Histogram

Next, he looked at the data for sign-in-to-exam. He surmised that, if the lab/imaging time took 40-60 minutes, then to get the patient in and out in less than 90 minutes meant that the upper limit of time from sign-in to exam should be no more than 30 minutes.

The histogram for the data (Figure 6) proved that most of the patients were outside of a 30-minute specification and that it was virtually impossible for a patient to get in and out of this ED in less than 90 minutes. The XmR chart (Figure 7) showed that the average time was 49.6 minutes from sign-in-to-exam, almost 20 minutes more than the 30-minute target achieved by the Baldridge-award winning hospital.

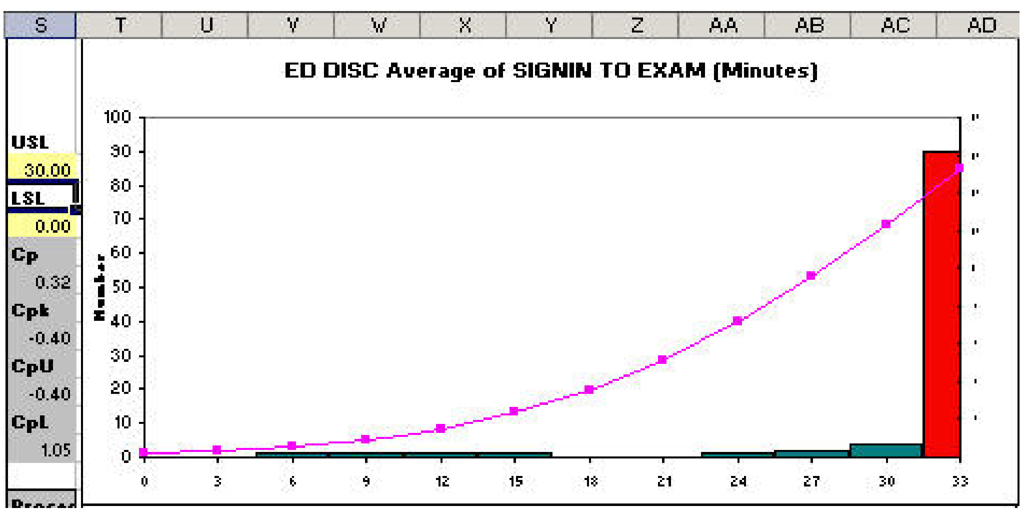


Figure65 – Histogram for Sign-in to Exam time

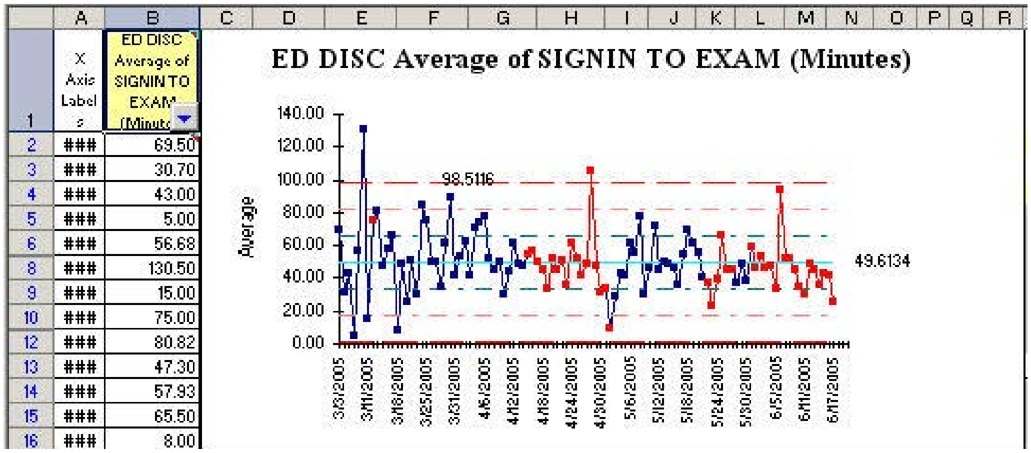


Figure 7 – Control Chart for Sign-in to Exam

Finally, he examined the data for the time interval between when a bed was requested and then occupied by an admitted patient. The delays were far worse! A QI Macros XmR control chart showed how ordered-to-bed times were running 199 minutes, or 3 hours and 19 minutes (Figure 8). The chart also revealed a stair-step shape where a recent project in the hospital reduced the average bed ordered time to 167 minutes, a clear process improvement, yet one that still had not reduced the bed wait to acceptable levels.

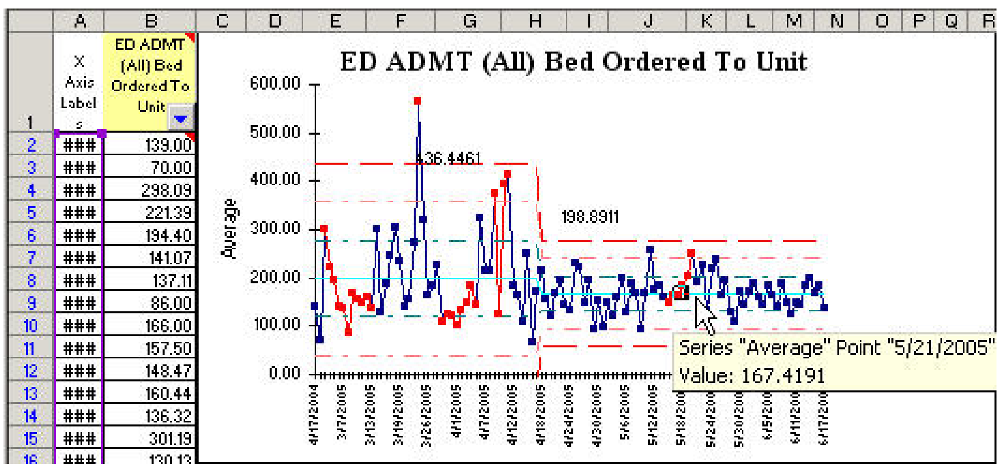


Figure 8 – Bed Ordered to Unit Times

Assuming that there was one patient admitted every hour and that admitted patients had to wait almost three hours for a bed, he found it reasonable to conclude that three patients were "boarded" in the ED while waiting transfer to a nursing unit. So, a 19-bed ED was quickly reduced to a 16-bed ED with three boarders. He analyzed the distribution of the data using the QI Macros Probability Plot (Figure 9), which showed that the order-to-bed times were non-normal.

By changing the type of trendline, the Black Belt found a well fitted distribution and formula for the data (shown on the top chart of Figure 9). With a strong visual understanding of the historic data, he was now ready to begin to analyze the effect of potential process changes.

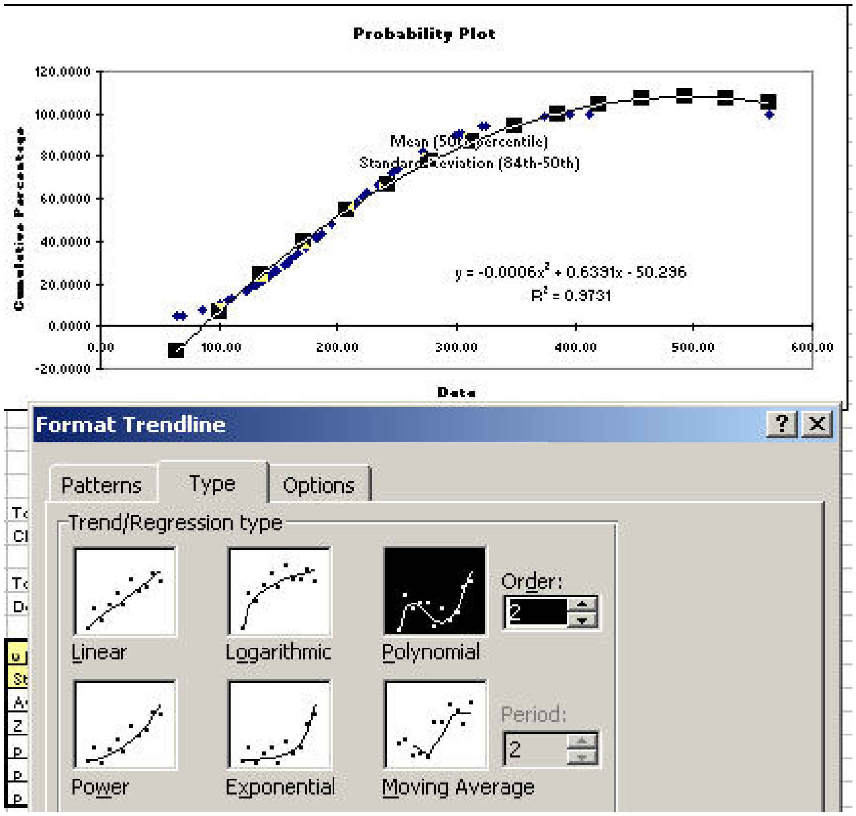


Figure 9 – Probability Plot

Applying Simulation to Analyze and Improve the ED Process

There are many ways to speed up an ED, including card readers for registration, portable X-ray equipment, on-site phlebotomists during peak hours, point-of-care lab testing, and transporters to move patients to nursing units. Each solution impacts a different activity or delay and has its own level of practicality and cost effectiveness.

In most projects, one or more these improvements is applied, and then the Lean Six Sigma team waits for a period of time while they measure the (hopefully positive) effects of the process improvements, tweak the process again, measure again, and so on. An increasingly popular alternative to the "implement and wait" practice is to create a computer model that mirrors the current process state and then simulate the effects of proposed process improvements.

In this project, the Black Belt enhanced the existing ED value stream map from QI Macros (Figure 1) with Crystal Ball software to create a valid process model below the map (Figure 10). He first added several new rows of information below the existing map that represented the inputs and outputs of the simulation model and separated the VA and NVA activities for additional analysis. For each of the inputs, he entered the mean or median values for each activity, values determined through the electronic data analysis.

He then used Crystal Ball to define probability distributions for each of the activities and delays that displayed time variation. For example, the previous statistical analysis proved that time of delay between the Triage and Exam was lognormally distributed, with a mean of 15 minutes and a standard deviation of 8 minutes. Through Crystal Ball, he added this Lognormal distribution (Figure 11) into the process model to represent this NVA activity. He also used Crystal Ball's fitting function to create probability distributions based on the measured hospital data.

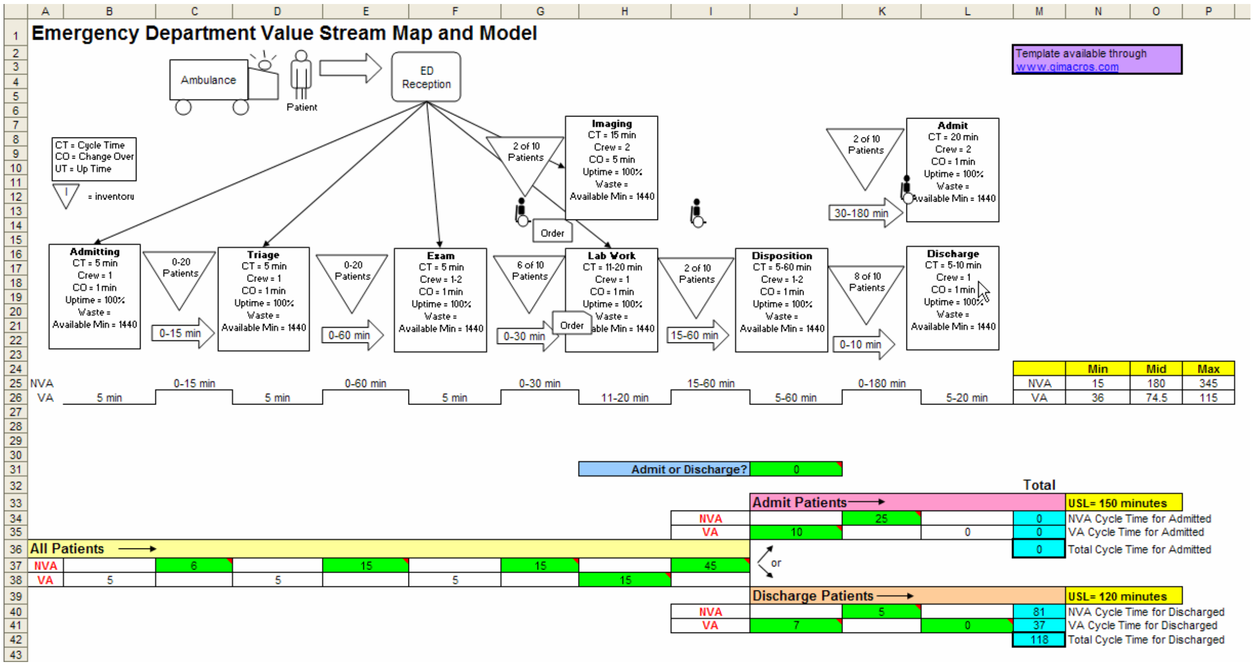


Figure 10 - Emergency Room Value Stream Map Enhanced with Crystal Ball

At the end of the ED process, the model split into two separate end paths for each patient: patients were either discharged (3 of 4 patients) or admitted (1 of 4 patients). The Black Belt defined a new cell as a simple Yes-No distribution (Figure 12), where 75% of simulation trials would result in a 0 (discharge) and 25% would result in a 1 (admission).

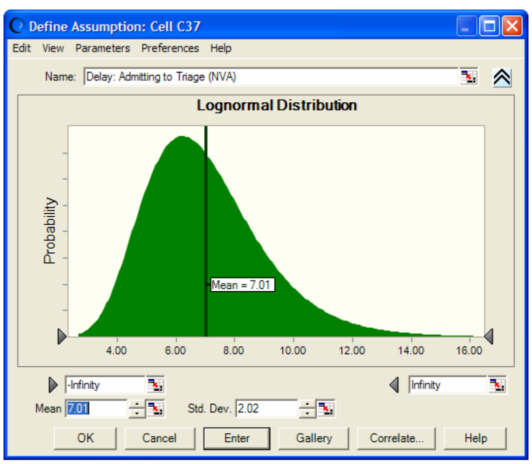


Figure 11 –Distribution for the Delay between the Triage and Exam

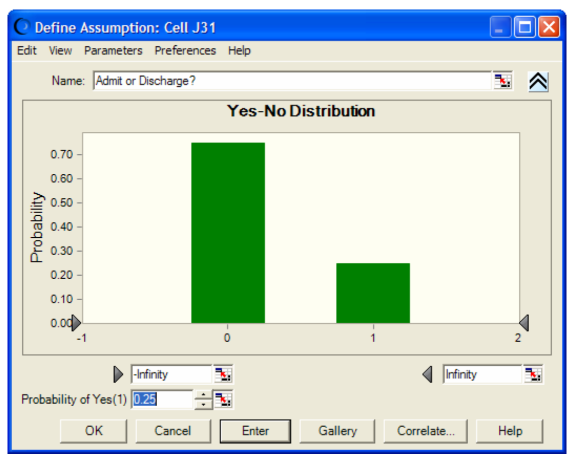


Figure 12 – Distribution for Whether to Discharge or Admit a Patient

The Black Belt's final task was to use Crystal Ball to identify the total cycle times for admitted patients and discharged patients as the "forecasts" (the outputs or Y's) of the simulation. The forecasts were defined such that the admitted patient's cycle time had an upper specification limit (USL) of 150 minutes, and the discharged patient's USL was 120 minutes. Any patients still in the ED process after those cycle time limits were considered "out of spec" (essentially, dissatisfied customers).

He ran Crystal Ball for 5,000 simulation trials to develop an analysis of the current (as-is) process state. The 5000 trials were the virtual equivalent of 5000 patients, but the analysis was completed in seconds rather than in days or weeks.

Examining the Simulation Results

Using the simulation charts and statistics, the Black Belt analyzed the ED's performance and validated that the model closely reflected the known process (as seen in the statistical analysis). The results for both discharged and admitted patients reinforced that the ED process cycles times were poor at best. For admitted patients the model accurately predicted that the turnaround times (TAT) were closer to 180 minutes and were only in spec 14.1% of the time (Figure 13). For discharged patients, only 36.3% of discharged patients were released within the specified 120 minutes (Figure 14).

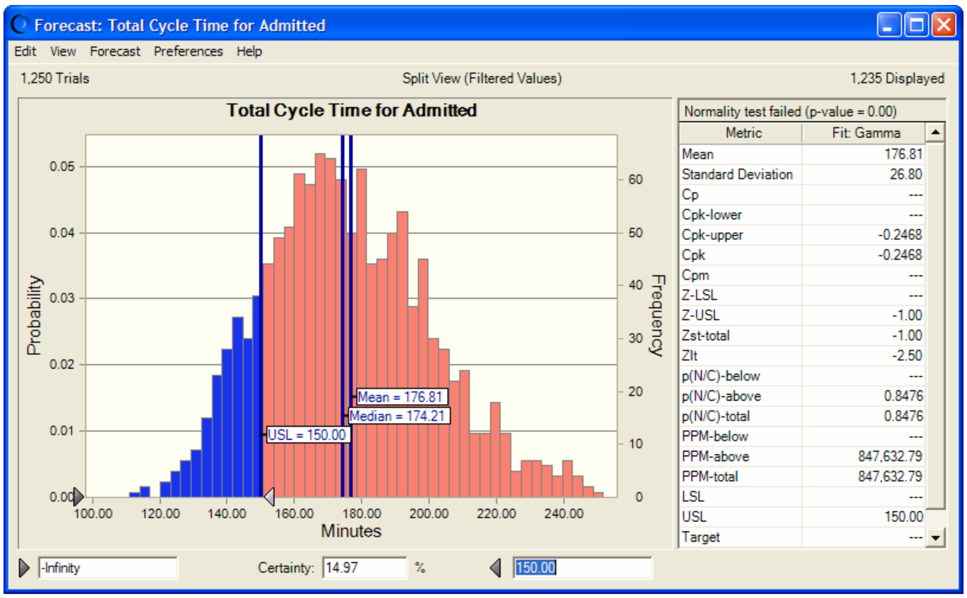


Figure 13 –Forecast for Total Cycle Time of Admitted Patients

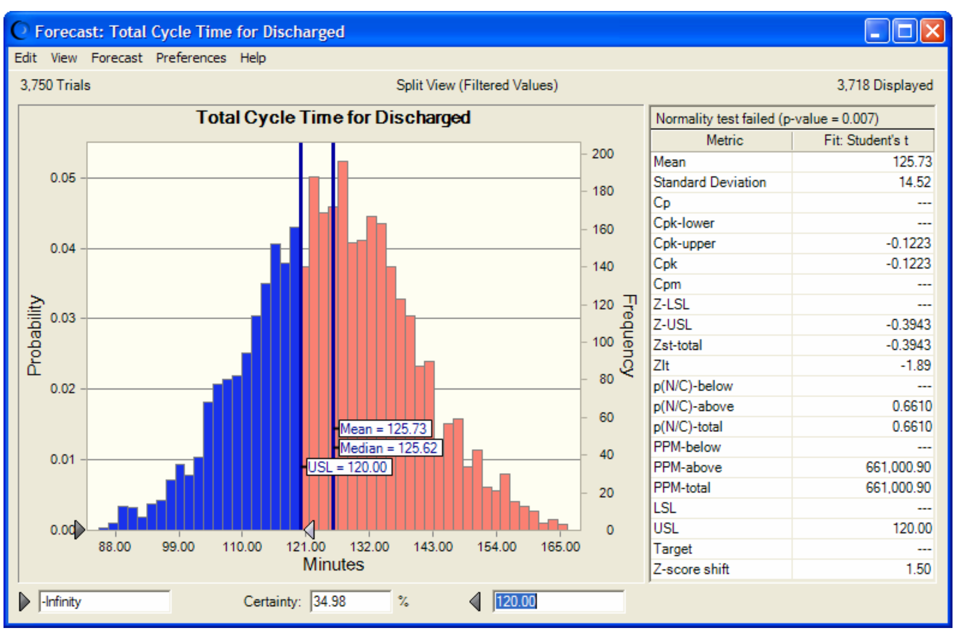


Figure 14 –Forecast for Total Cycle Time of Discharged Patients

Looking at the non-value added time for admitted patients, he learned that most of the total turnaround time was non-value added (mean and median of 136.0 minutes) with the greatest variation (a standard deviation of 27.6 minutes). The same was true for discharged ED Patients (NVA mean was 76 minutes, with a standard deviation of 14 minutes). The overlay chart between the Total Cycle Times of the two types of patients helped lend a visual perspective to the problem and pathways differences (Figure 15). The long, low profile of the admitted patients' cycle time indicated that the current process, was far from predictable for this set of critical patients.

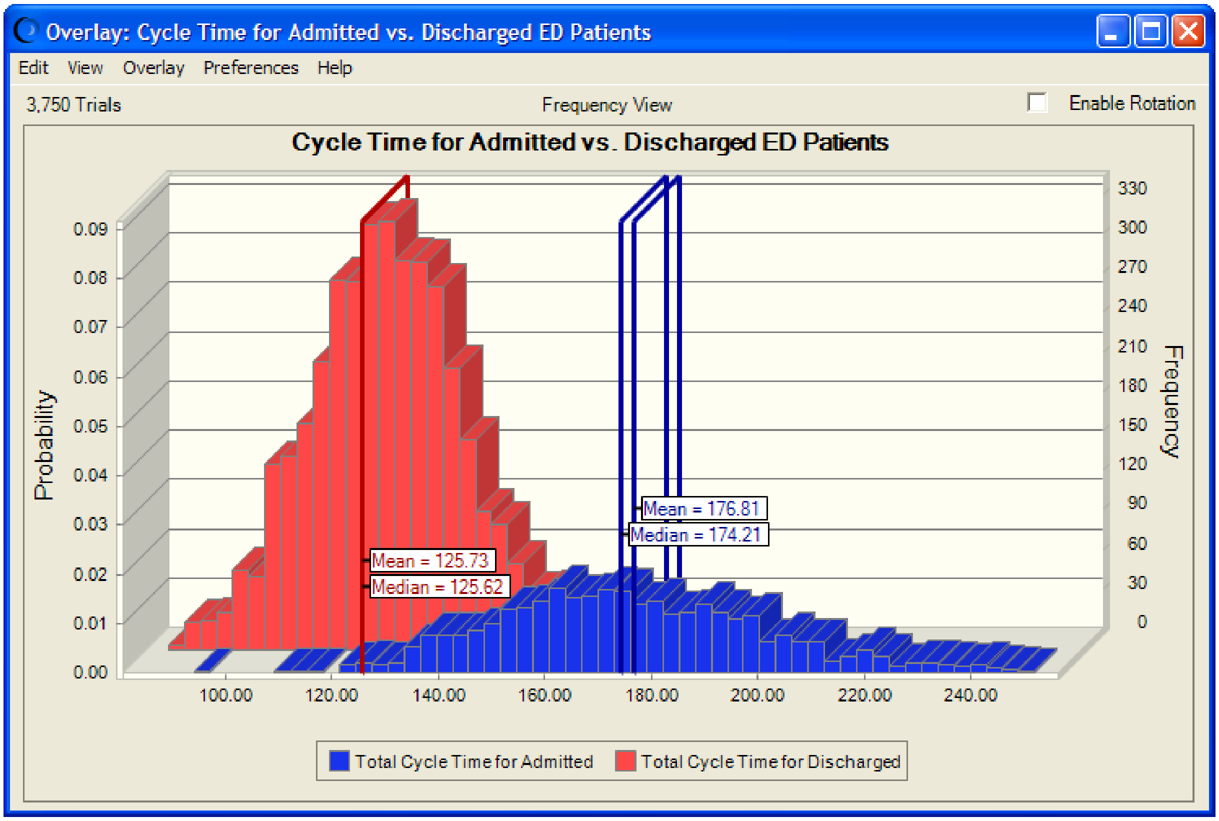


Figure 15 –Comparison of Simulated Total Cycle Times of Admitted vs. Discharged Patients

The Opportunities for Process Improvements

After simulation validated the Excel model of the current process, Crystal Ball's sensitivity analysis helped the Black Belt to understand which of the variable activities (X's) contributed to most to the variation in the patient cycle times (Y's). For discharged patients (Figure 16), the biggest problem (44.2%) was the delay between lab draws and results. The delays between triage to exam (25.8%) and exam to lab/imaging (18.3%) were also important contributors to cycle time variation.

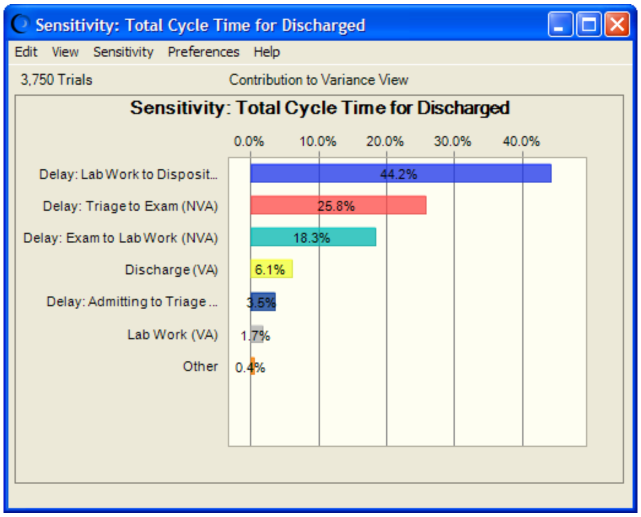


Figure 16 – Sensitivity Chart for Total Cycle Time for Discharged Patients

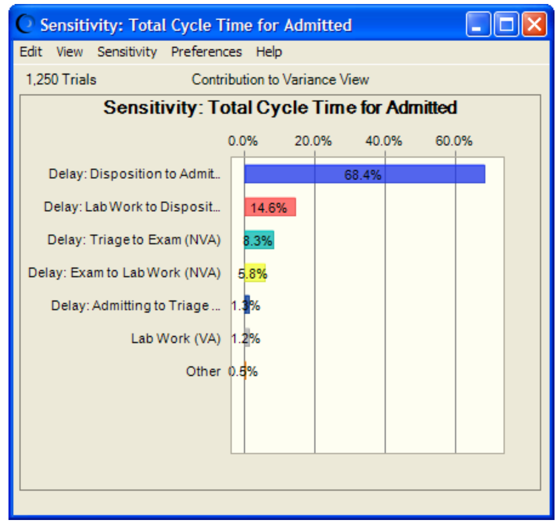


Figure 17 – Sensitivity Chart for Total Cycle Time for Admitted Patients

For admitted patients (Figure 17), sensitivity analysis described a different situation. The sensitivity chart showed that most of the problem (68.4% of delay) lay in getting patients into a hospital bed, with the delay from lab work to disposition as a lesser issue. No matter how fast they could make the ED, the cycle time problem for admitted patients would still rely on bed cleaning, staffing and patient transportation.

These results afforded the Black Belt and his team several solutions to investigate and test. Clearly, if they wanted to solve the "boarding" problem for admitted patients, they needed to find and fix problems with hospital bed availability (probably a second Lean Six Sigma project). But to accelerate the time needed to move *all* patients through the ED process, they could focus on how to accelerate lab work and imaging (e.g., add portable X-ray equipment, CT scans, point-of-care testing, and removing the time waste in the lab process) or examine how to move patients more quickly and effectively through the triage and exam activities (e.g., implement a "fast track" physician dedicated to handling non-emergent treatment).

Four areas of improvement were suggested:

1. The ED could implement point-of-care testing for patients with chest pain, reducing the time to get key heart indicators from 40 minutes to 10 (reducing the triage to exam delay),
2. The hospital lab could switch from bucket to STAT centrifuges, saving seven minutes when processing blood samples, and (reducing the lab work)
3. The hospital could implement an overall "pull system" that encouraged floor nurses to "pull" admitted patients from the ED at peak periods, which meant that patients spent an average of 30 minutes less time in the ED (reducing the delay when admitted patients waited for beds).
4. The hospital can employ an effective Kanban (visual alert) system to let doctors know when all of the lab data has come in to the ED (reducing the lab work to disposition delay by an average of 15 minutes and to a maximum of 40 minutes).

The Black Belt used parallels and expert opinion to estimate the new activity and delay input parameters and then re-ran the Crystal Ball model. Additional simulations showed a much improved process, with twice as many admitted and discharged patients within specification (Figure 18). This built consensus of management and staff for specific initial improvements.

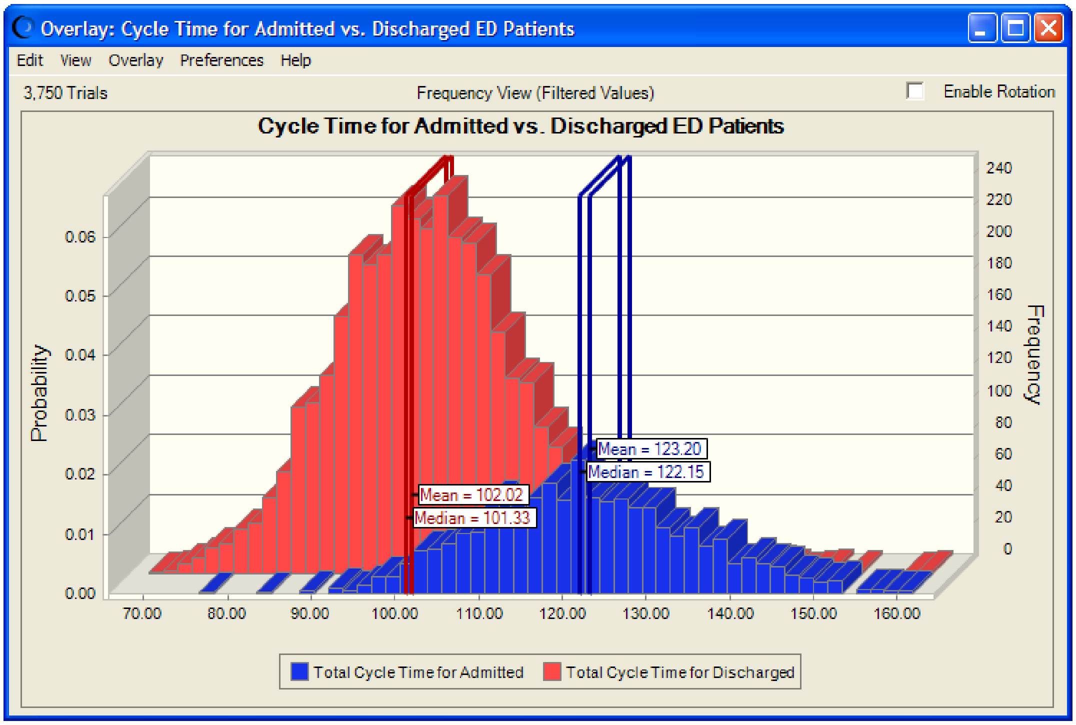


Figure 18 – Overlay Chart for Cycle Times with Proposed Process Improvements

Using Excel in the Control Phase

Too many people are willing to declare victory after implementing a change without actually measuring the impact. An ED would never release a patient unless their measurable test results improved. Black Belts shouldn't allow a process to be released without improvement either. Once changes are implemented, stair-step control charts like the one in Figure 8 can show how much improvement was obtained and how much work remains to be done. QI Macros control charts can be used by process owners to monitor that the ED process is in control and analyze the causes for out-of-control situations.

As the Robert Woods Johnson Hospital benchmark suggests, emergency departments can be a lot faster than they are. The biggest barrier to change, as always, is people. The ED's personnel have to want to serve the patient in new ways that eliminate delay and accelerate the patient's experience. To improve patient safety and reduce the chances of diversion, every ED and hospital will want to reduce patient length of stay (LOS). To reduce LOS, you don't need faster MDs or nurses, *you need faster patients*. The only way to speed up your patient is use techniques like Lean Six Sigma to reduce the non-value added delay *between* sign-in, registration, triage, exam, diagnosis, and treatment or admission.

Conclusion

The methods and tools of Lean Six Sigma can help quantify and pinpoint non-value added delay , and then teams can figure out how best to eliminate the delay. With the QI Macros for Excel to gather and analyze process performance data, and Crystal Ball to understand and predict performance, organizations dedicated to process improvement have new, easy-to-use tools to analyze and accelerate flow. It not only increases patient satisfaction, but also reduces errors and increases revenue.

Using the QI Macros, organizations can use existing data in Excel easily measure the stability and capability of current practices. Using Crystal Ball's prediction capabilities, they can then change any one of these parameters to reflect a potential process change, run the model, and evaluate the results. Best of all, testing improvement scenarios using Crystal Ball costs a fraction of what it would cost to implement any one of these solutions. When the benefits and consequences of the change have been analyzed, the team can make an intelligent choice about how to implement the change and later use the QI Macros to analyze the revised process and sustain the improvement.

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