



## Guidance for Analyzing Quality Improvement Data Using Time Series Charts

### I. WHY USE A TIME SERIES CHART?

The crux of quality improvement is answering the question, how will we know that a change yields improvement? Without data, or the skills to graph and interpret them, we are unable to know. The key to answering this question is the time series chart, a line or run chart that displays a key indicator over a regular unit of time.

Time series charts help us understand if the changes we are making are leading to a change in improving the quality of care from some initial level to a consistently sustained higher level. They are a simple yet effective tool to track the performance of a process over time and document the story of improvement work.

We use time series charts to portray and analyze our indicator data over time because they provide a dynamic follow-up of indicators over time. While most graphs are like a photo that captures a point of time, the time series chart is like video rolling over time. This ongoing monitoring of an indicator through a time series chart is particularly valuable in quality improvement as it allows us to track when specific changes were introduced, see their impact on a process, and tell whether improvement is sustained over time. The time series is a simple and effective tool that can be completed as easily using paper and pencil as with a computer. (See Appendix I for detailed instructions on constructing a time series chart.)

#### Box 1: What is a time series chart?

The time interval is displayed on the X (horizontal) axis and can be any interval of time (e.g., minute, hourly, daily, weekly, monthly, quarterly, yearly, etc.). The indicator being tracked is plotted on the Y (vertical) axis. Common types of indicators plotted on the Y axis are percentages (e.g., percent of patients receiving care according to standards), rates (e.g., patient satisfaction rates), time (e.g., waiting time), quantities (e.g., stock levels), or numbers (e.g., weight).

Using this guidance regularly will allow you to:

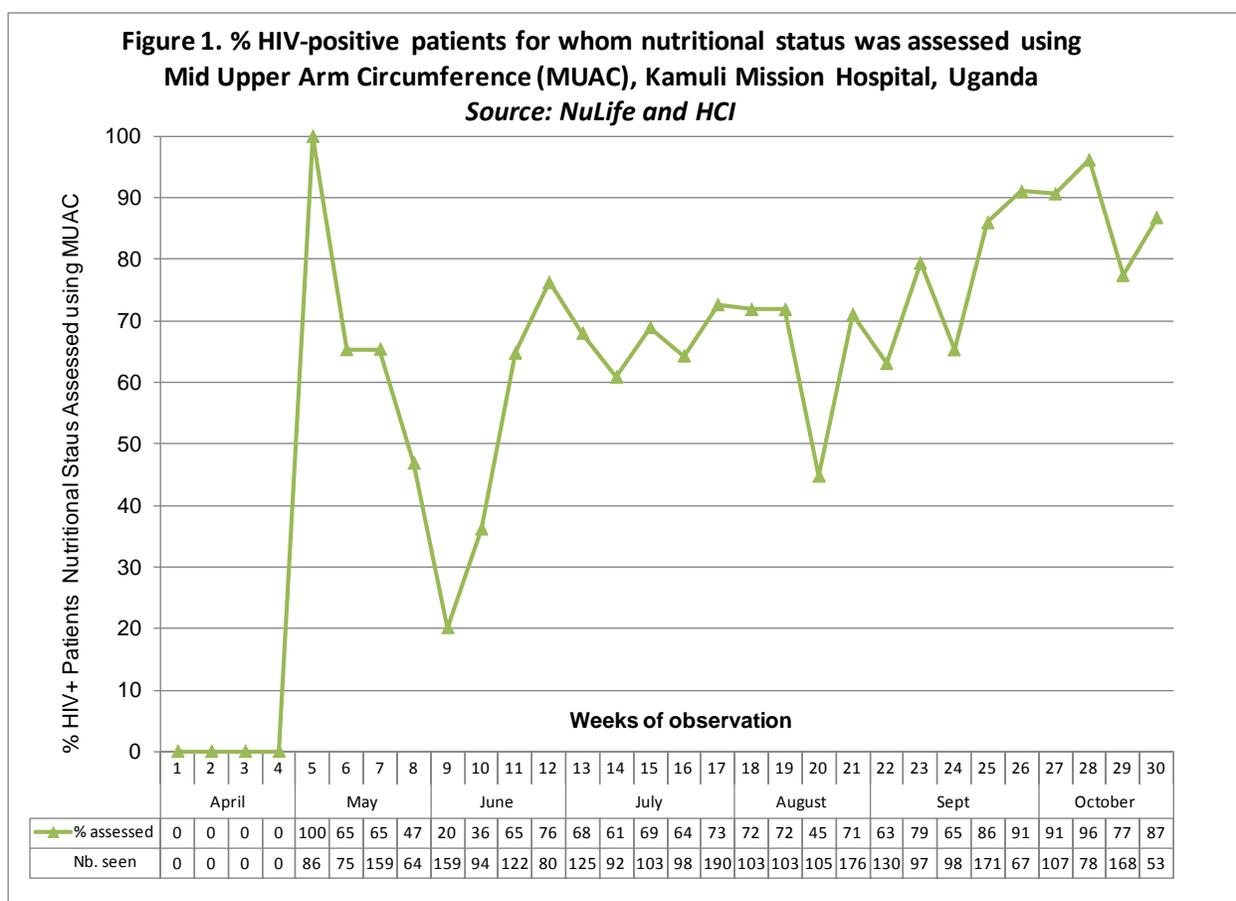
- Analyze data without complicated formulas or computers, but with statistical rigor if enough data points are available
- Identify and react to statistically significant change in a process as quickly as possible
- Develop aims by identifying which processes are consistently underperforming over time
- Determine if improvements are sustained over time

Figure I presents a time series chart illustrating the work of one quality improvement (QI) team at Kamuli Mission Hospital in Uganda. This team, assisted by the Food and Nutrition Interventions for Uganda (NuLife) and HCI projects, sought to increase the percent of HIV-positive patients assessed for nutritional status using mid-upper arm circumference (MUAC) for the purpose of identifying those needing therapeutic food. Graphing the data over time like this helps the team track their progress and demonstrates that improvement is not always linear.

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Time series charts can also be used to plot results across multiple health facilities (such as those participating in a collaborative) by pooling and plotting their data collectively. Although the chart may be labeled to reflect this pooling of data, the rules for interpretation would remain the same.

This guidance is divided into sections. If you are new to time series charts, please read Section 2 carefully, which lays out the essential features of time series charts and explains how to calculate the median value. Section 3 presents two important rules for analyzing time series charts, with examples. Section 4 outlines some important considerations for time series charts, and Section 5 summarizes how they can be used to detect effective changes. The appendix provides step-by-step instructions on how to make a time series chart by hand.

## 2. ESSENTIAL FEATURES OF TIME SERIES CHARTS FOR ANALYZING IF CHANGES YIELD IMPROVEMENTS

Time series charts can be used to track any indicator over regular time intervals. Good time series charts facilitate the analysis of whether changes yield improvements by including clear labeling and definitions, a median line, and annotation.

### a. Clear labeling and definitions

Time series charts should be easy to read and interpret, such that anyone could interpret the chart without explanation from the person who actually drew it. To accomplish this clarity, time series charts need to have clear titles, labels for X and Y axes, definitions of the numerator and denominator, denominator values, data sources, sampling strategy, and a legend (see Box 2). These are described in detail in the project’s *Norms for Presentation of Time Series Charts*, available at <http://www.hciproject.org/node/1523>.

## b. Annotation

Annotation is the process of adding commentary or explanatory notes to a time series chart. Annotating when changes were implemented on a time series chart connects the numerical results (the data displayed in the graph) with the changes introduced by quality improvement teams; it also can provide context about other possible explanations for the data. Annotating a time series chart involves simply drawing small text boxes (by hand or on a computer) next to a data point with a brief explanation of what change was introduced or key event occurred that may have affected results. Annotation allows you to see if variations in results are linked in time with changes made to the process. Though it seems simple, annotation is very important as it provides a succinct and easy way to document changes over time and communicate the story of improvement to internal and external stakeholders. Teams should annotate their time series charts each time that they plot new data points.

Referring back to Figure 1, we can see that use of MUAC seems to be improving over time, but this version of the chart does not tell us about what the quality improvement team did to achieve these results. It also does not help the team from Kamuli Mission Hospital determine which changes are most effective, nor does it convey learning to other interested stakeholders. In contrast, Figure 2 shows the same time series chart but with annotation about specific changes introduced. This annotated version is more helpful than the version in Figure 1, as it clearly documents what and when the team tried different interventions.

## c. Calculating the median

The median represents the middle value in a set of data. Drawing a horizontal line through the median of a data set (see Box 3) allows you to detect shifts or changes in the tendency of the indicator on a time series chart. You will need a minimum of ten data points to plot the median<sup>1</sup> of your data.

### Box 2: Appropriate labeling of a time series chart

Time series charts should include:

- A title that describes the indicator charted
- Labels on both the horizontal and vertical axes
- Definitions of the components of the indicator (e.g., numerator and denominator)
- Data table; if data are pooled, the data table should also show the number of sites contributing to the pooled values

### Box 3: Calculating the median

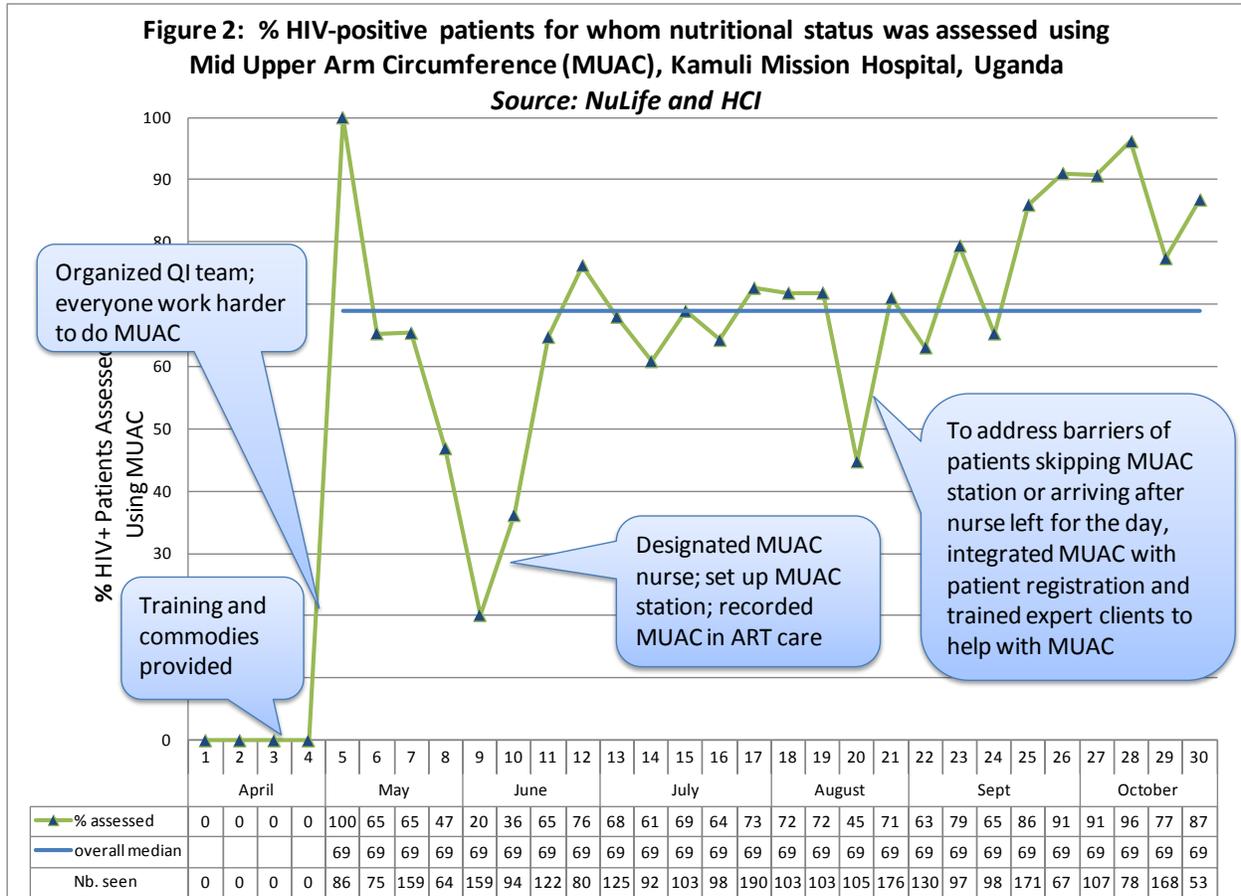
#### By hand:

1. List the numbers in order from smallest to largest.
2. If there is an odd number of data points in the set, take the number in the middle. For example, the mean (or middle value) of the following set of 15 data points is 11:  
3, 4, 6, 7, 9, 10, 10, 11, 13, 14, 17, 17, 18, 20, 22
3. If the data set has an even number of data points, add the middle pair of numbers together and divide by two. For example, the median in the following set of 16 data points is 12:  
3, 4, 6, 7, 9, 10, 10, 11, 13, 14, 17, 17, 18, 20, 22, 24  
(median =  $(11 + 13) / 2$ )

#### Using a computer (in Excel):

1. Select a cell next to the set of numbers for which you are calculating the median.
2. Type: =MEDIAN(
3. Select the numbers in the data set
4. Type the end parenthesis symbol: )  
For example, the formula to calculate the median of the data set A3 through A12, the formula would be: =MEDIAN(a3:a12)

<sup>1</sup> For time series charts, the median is the preferred measure of central tendency, as it is not as sensitive to extreme values as is the mean, which is more affected by extreme values.



If you have fewer than ten data points, it is still useful to plot the data even without the median. It is possible to detect a trend without a median line. The more data points you have, the better understanding you can gain about your process over time. If you would like to draw conclusions sooner about your process, consider collecting data more frequently (e.g., daily or weekly instead of monthly).

Figure 2 includes this median line (shown in blue). The median line enables you to apply the rules discussed below to assess the effectiveness of interventions. The version of the chart in Figure 2 gives enough information to apply the rules discussed in the next section to determine if the changes have resulted in significant improvement.

### 3. RULES FOR DETECTING TRENDS AND SHIFTS IN TIME SERIES CHARTS

This section of the guidance will provide you with information to detect the two most commonly used rules for analyzing time series chart data: 1) *trends* (at least five consecutive points moving in the same direction, discussed in section 3a), and 2) *shifts* (at least six points on one side of the median line, discussed in section 3b). These rules have been published in the quality improvement literature (please see the references for the most applicable literature specific to health care) and are commonly applied. There are additional rules, but these two are the easiest to understand and the best suited for determining if a change is yielding improvement or not.

Using these rules will help you avoid drawing any premature conclusions about your results while helping to identify significant changes, even when they are not immediately obvious. These rules are based on probability theory, which means that the likelihood of meeting the criteria for any one of these rules is less than 5% without any significant change made to the process (Provost and Murray 2007). In other words, if any of the following rules are detected in your data, it is 95% likely that there was

statistically significant change to the process you are studying. This means that the patterns you are seeing in your data are not due to chance, but something real happening. You need apply only one rule to determine if a significant change has occurred in the process that you are studying, however, it is possible that both of these rules will appear in the same data set.

### a. Trends

A trend is continued movement in a single direction, either up or down (see Box 4). When examining if a change is yielding improvement, we are looking for movement in our data. Identification of a trend requires at least five consecutive data points moving in the same direction. The median is not required to detect trends. If you have more than ten data points, it is recommended that you still calculate the median to provide greater perspective on the data.

When counting the number of consecutive points for determining a trend, if two or more consecutive data points in the series are the same, only one of these points is counted (and the others ignored) to determine if there are enough (i.e., at least five) consecutive points to detect the presence of a trend. Table 1 provides the exact requirements for the number of data points required to determine a trend, based on the total number of data points available.

#### Box 4: Trends at a glance

- No median required
- A minimum of five data points continuously increasing or decreasing (see Table 1)
- If more consecutive data points are equal, only one counts towards the trend

**Table 1: Number of points required to identify a trend**

Number of data points available	Number consecutively increasing or decreasing points required for a trend
≤8 data points	5 data points
9-20 data points	6+ data points
21+ data points	7+ data points

Source: Lloyd R. 2004.

Figure 3 demonstrates this rule applied to data from Uganda. Unlike the data in Figures 1 and 2, which represent a single site, data in Figure 3 are pooled across multiple sites working together in a collaborative. These sites were able to identify a trend (six points which are progressively increasing) after only 10 data points. These six data points in a row, each one higher than the previous point, indicate that this pattern is not due solely to chance. This time series chart also has a median line, as there were ten data points; although it is helpful, the median is not necessary to see this trend.

### b. Shifts

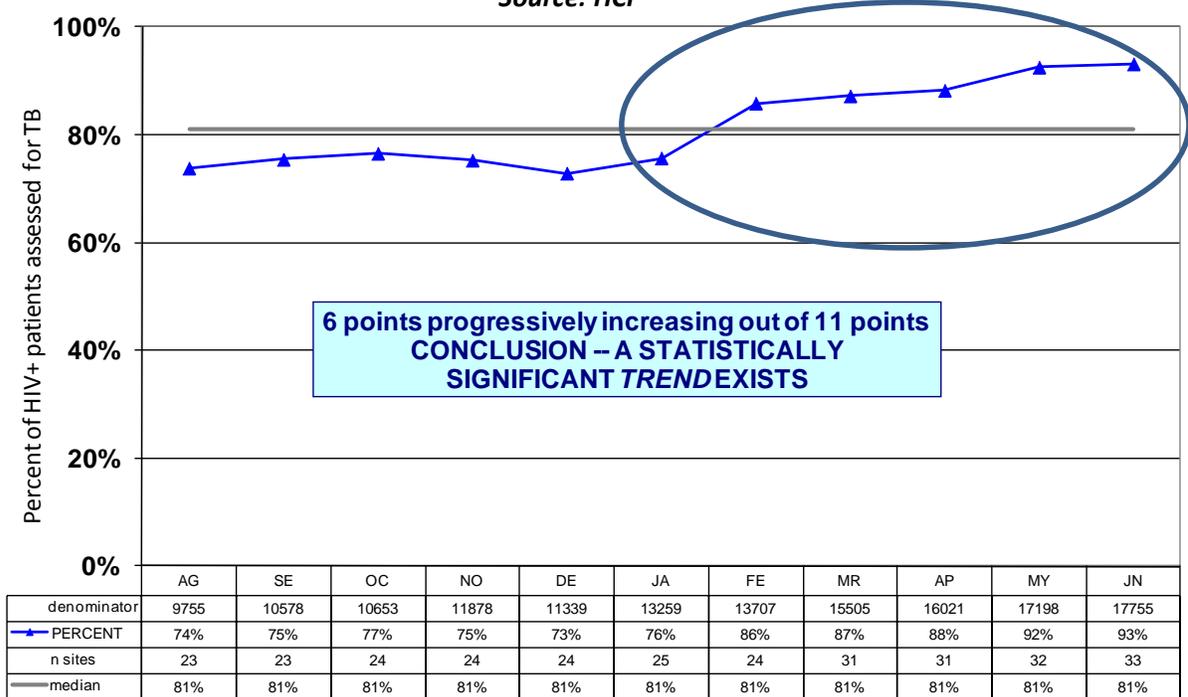
A shift is a pattern indicating that a process or outcome measure in question has now moved to a different level, and that this shift is statistically significant. In fact, in quality improvement, this pattern is what we are hoping to achieve when we make changes in the process of how we do our work. The median for all available data points is necessary to identify a pattern as a shift, and a shift requires at least six points on one side (above or below) the median line (see Box 5).

#### Box 5: Shifts at a glance

- A median is necessary
- At least six data points above or below the median
- Data points that fall on the median are not counted

**Figure 3: Uganda - Percent of HIV-positive patients assessed for active TB, August 2005-June 2006**

Source: HCI



If there are points which fall on the median line, these cannot be counted as part of the six points needed to detect a shift. It should be noted that it is possible to find a trend embedded in a shift, if five consecutive points of these six are ascending or descending and fall consistently above or below the median.

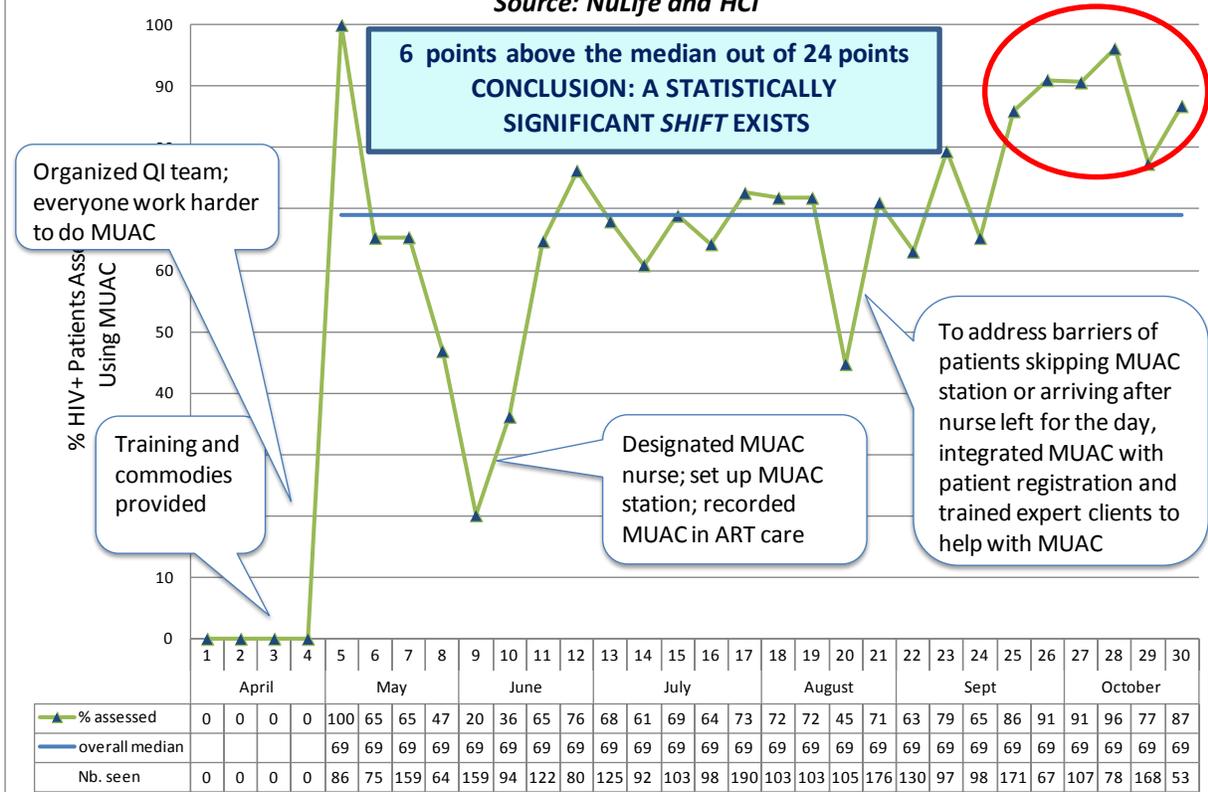
Figure 4 is a continuation of the data set displayed in Figures 1 and 2, with enough information on the time series chart, we can now interpret the chart using the rules. The last six data points are clearly above the median, constituting a shift; with the annotated chart, we can see that this shift indicates that the nurse’s new schedule and use of a trained expert resulted in a significant increase in the percent of HIV-positive patients assessed using MUAC.

Going back to Figure 3 for active screening for TB among HIV-positive patients in Uganda, no shift was yet evident in the data, but there was a trend. Figure 5 shows this same data set, except with an additional seven months of data. With this additional data, we are able to identify a shift. At this point, the upward trend of HIV-positive patients screened for TB (from Figure 3) has now developed into a shift, showing a statistically significant increase in the level of compliance with this standard.

Figure 6 provides another example of a shift with data from Ecuador on the management of pre-eclampsia. This graph displays a clear shift in the management of patients with pre-eclampsia after only 12 data points.

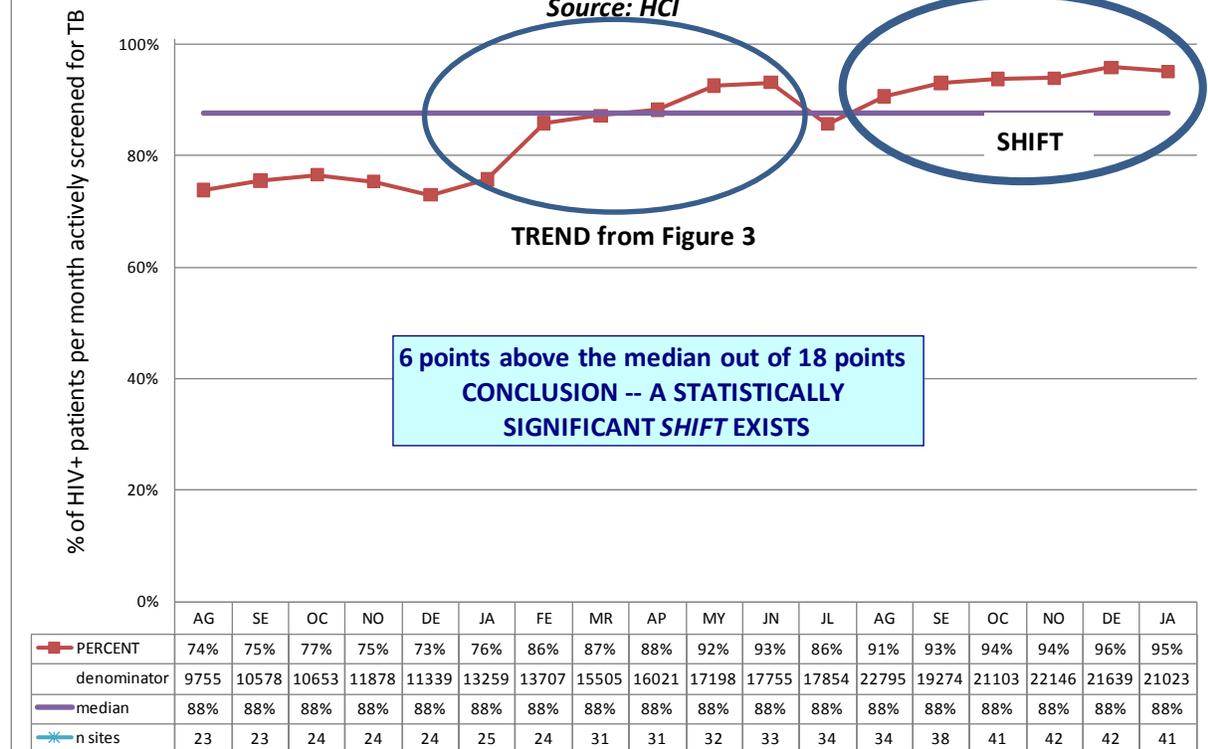
**Figure 4: % of HIV-positive patients for whom nutritional status was assessed using Mid Upper Arm Circumference (MUAC), Kamuli Mission Hospital, Uganda**

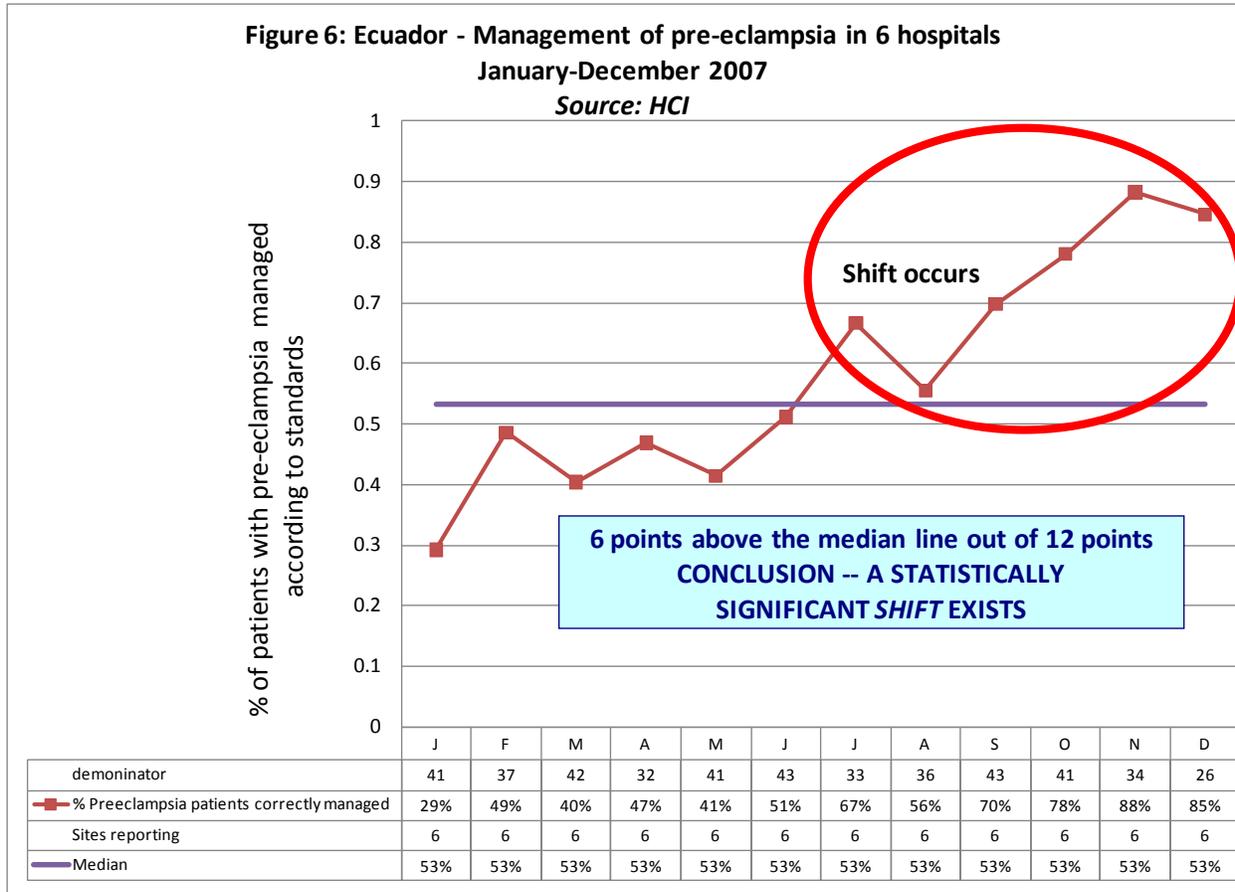
Source: NuLife and HCI



**Figure 5: Uganda - Percent of HIV-positive patients assessed for active TB, August 2005-January 2007**

Source: HCI





**c. Calculating a new median after a shift**

Once your process is generating results at a new level (after you have detected a shift), it is often useful to analyze results at that new level to see how your process is performing. When you have at least 10 data points after a shift has occurred, you can recalculate the median. Figure 7 shows an example of two medians calculated using the data from Uganda on active TB screening. With more data available, it appears that the curve is stabilizing at a new level. By calculating a new median line based on values at that new level, we can see that the pattern has stabilized and does not appear (at least as of yet) to be experiencing further significant improvements. The first median line (at 81%) includes the data points that identified the trend, while the second median line (at 94%) includes the data points starting at the shift.

To determine when to recalculate the median, examine your graph and see when a new pattern appears to be taking shape, after the shift has started. Use the rules for analyzing time series charts with this new median to see if a new, stable pattern has emerged (that is, with no significant trends or shifts). You will need at least ten points for calculating each of the medians, so at least 20 data points in all. To recalculate the median values, cluster your data into the two groups (before the shift and at least ten data points after the shift), and using the instructions in Box 3, calculate the median for each group separately.

**Figure 7: Uganda - Percent of HIV-positive patients assessed for active TB, August 2005-June 2007**

Source: HCI

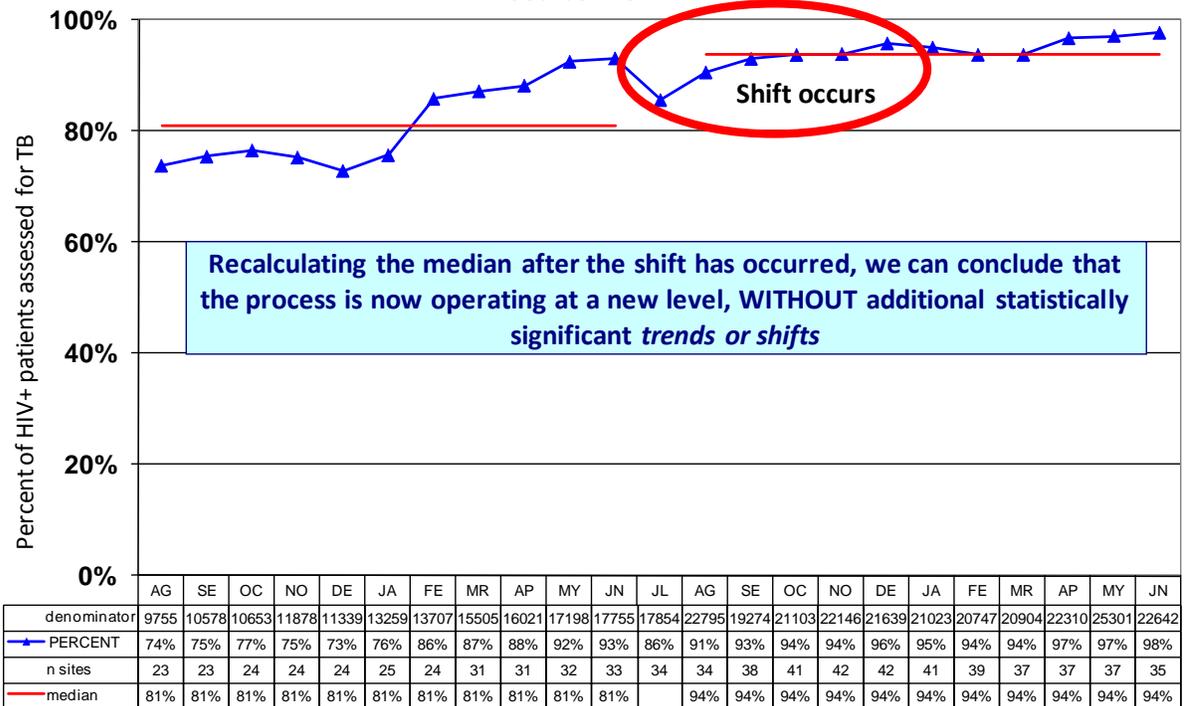


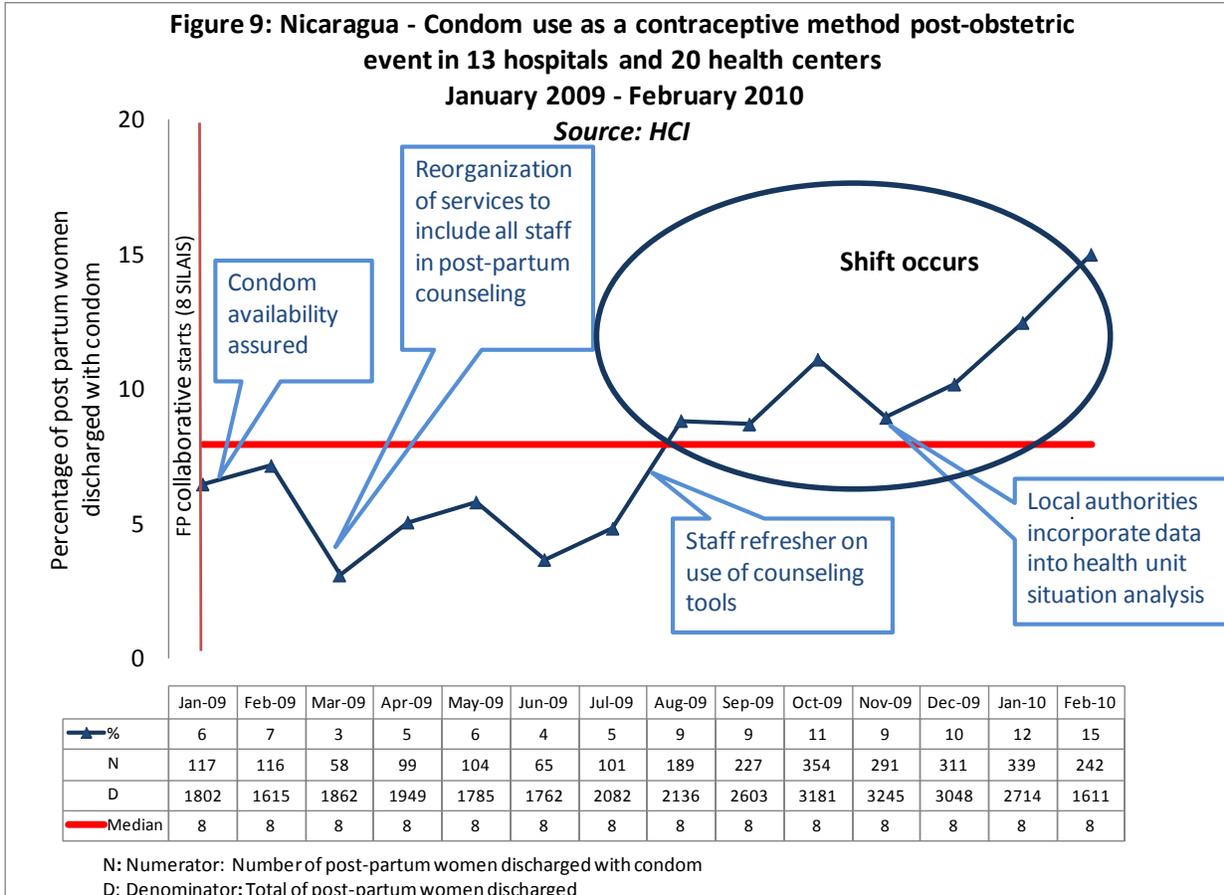
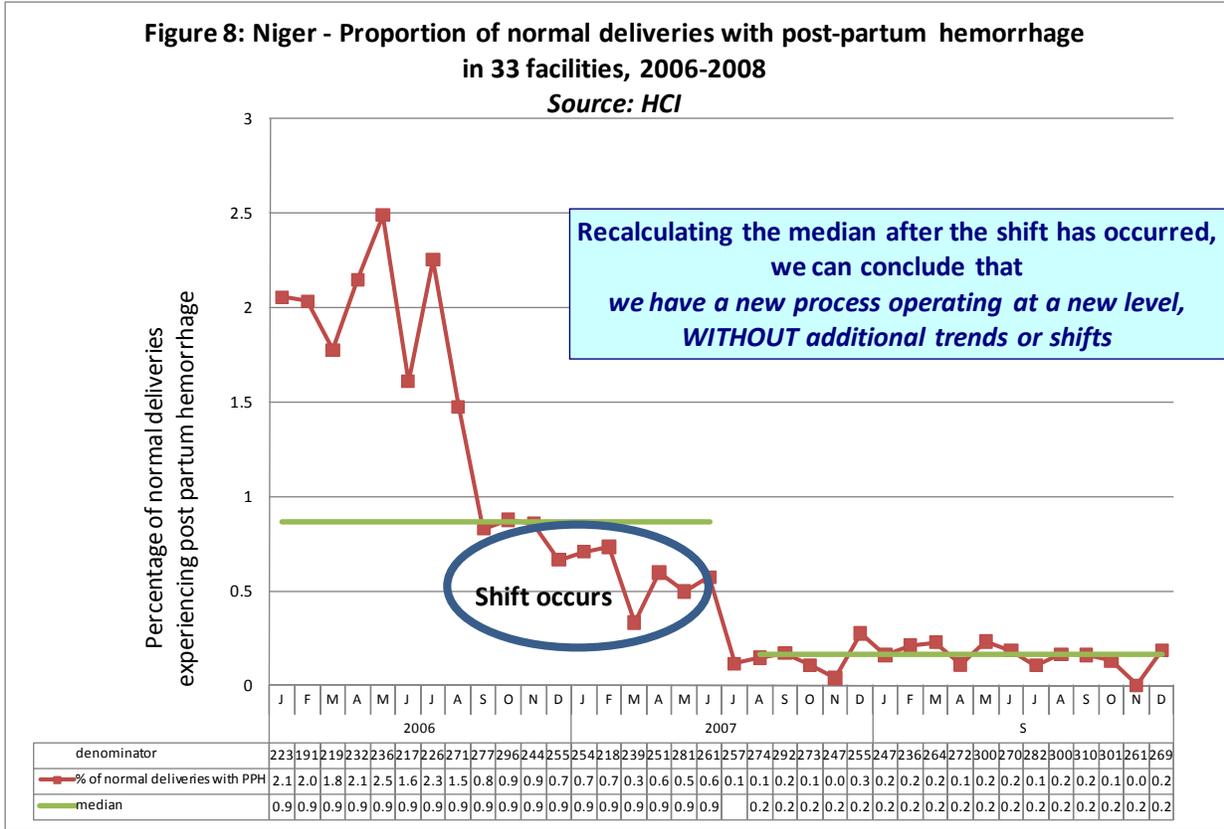
Figure 8 presents another example of shifting medians for post-partum hemorrhage data from Niger. This example shows how these rules also apply to negative trends or shifts. In this case, a dramatic downward shift in the percent of post-partum hemorrhage among women with normal deliveries was apparent after 17 months of data. When more data had been collected (another 18 months), two median lines were calculated. In this case, the new pattern emerging started after the shift, and the new median was calculated well after the shift was detected. From this analysis, we can see that the process is now consistently operating at a new, lower level.

#### 4. IMPORTANT CONSIDERATIONS FOR TIME SERIES CHARTS

This section discuss two additional considerations for time series charts: 1) how annotation also applies to grouped data (such as collaborative databases), and 2) the importance of comparable denominators across time periods.

##### a. Annotation of time series charts

Annotation is useful for all time series charts, whether they are charts for individual health facilities or pooled table from multiple health facilities (such as collaborative level databases). Annotating time series charts for pooled data creates some challenges, as not all sites will be implementing changes at the same time. However, indications of changes that were broadly implemented helps explain the patterns in results seen. Figure 9 is an example from Nicaragua of interventions introduced throughout the course of a collaborative in the 33 participating health facilities and demonstrates a shift following certain changes. The annotation on this time series not only shows the specific interventions, but also useful contextual information about missing data at the baseline. Other examples of useful contextual information include other events that explain the results (positive or negative), such as strikes, movement of personnel, or stock-outs.



## b. Comparable data points

When interpreting data points, the variation in the denominator can influence patterns and conclusions. Two common sources of variation in denominator size are: 1) changes in service utilization by clients, and 2) for pooled data, variations in the number of sites contributing (reporting) data. When this variation is greater than 25% of the median value for the denominator, you will need to think about what this may mean.

**Variations related to client population:** The rules described above for analyzing time series charts for trends and shifts are based on an assumption that denominator values are roughly consistent within a range of  $\pm 25\%$  across time periods. For example, a hospital working on loss to follow-up rates needs to examine the indicator's denominator—the number of HIV-positive patients enrolled in care and treatment—over time. For example, this denominator may typically be an average of 500 patients per month, but some months it may be 375 (25% lower) and others months it could be 625 (25% higher). If the denominator value goes beyond this 25% range and is not due to a data collection error, this should be annotated on the chart so that the chart can be interpreted within this context. For example, if there are changes in performance levels corresponding to variations in denominator size, it would be important to understand if this might be related to having a smaller or larger number of patients to manage.

**Consistency in reporting sites for group data:** When denominators from multiple health facilities are pooled together into a single database (as in collaborative databases), a common source of variation in denominators is the number of sites reporting. As with case load, the key question is whether this change in the number of sites reporting is influencing the results seen. For example, if sites that are doing poorly are not reporting in a specific month, the indicator value may appear higher than it should. In this case, one can limit the analysis of data to those sites for which data are available for the whole period, or wait to interpret the data until data are available from more sites. Again, it is important to annotate this information on the chart, not only for external stakeholders that view your time series charts, but also for your own team to keep an accurate record for future reference.

## 5. CONCLUSION

A time series chart is a simple tool for quality improvement requiring only a pencil, paper, and accurate data. Yet, with the consistent application of some simple rules and best practices (see Box 6), these charts provide rigorous evidence of the effect of improvement efforts, with the ability to detect changes in a process within 95% statistical probability. Interpreting time series charts is an essential skill for managers, coaches, quality improvement teams, and stakeholders to understand improvement data and properly interpret the results of their work. Teams applying these simple rules can detect significant trends and shifts. The rules can also be applied at different times to determine how patterns in their data are changing.

### Box 6: Best practices for using time series charts

- ✓ Do not wait to create the chart: start plotting and annotating with your first data point.
- ✓ Plot and annotate the data on an ongoing basis to build the habit of using data regularly and enable the data to drive your improvement effort.
- ✓ Remember to calculate the median after 10 data points and clearly define and label the key elements of the chart.
- ✓ Seeing a trend or shift by itself does not tell you *why* it occurred. Annotating the time series charts with interventions and/or contextual information could explain the trend or shift.

## 6. REFERENCES

- Institute for Healthcare Improvement (IHI). 2004. *Process Analysis Tools: Run Chart*. Boston, MA. Available at <http://www.ihl.org/IHI/Topics/Improvement/ImprovementMethods/Tools/Run+Chart.htm>
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## Appendix I: How to make a time series chart

Making a time series chart is simple and can be completed using paper and pencil as easily as with a computer. Making a time series charts can be broken down into four major steps:

1. Organize your data.
2. Draw and label your chart.
3. Plot and annotate your data.
4. Analyze your chart.

If you have access to a computer, the USAID Health Care Improvement Project has a template that will plot your chart with a median line as you enter your data; you can download this template at: <http://www.hciproject.org/node/1274>. Whether making your chart by hand or on the computer, please refer to the USAID Health Care Improvement Project's *Norms for Presentation of Time Series Charts*, available at <http://www.hciproject.org/node/1523>, for more complete guidance on constructing time series charts.

### 1. Organize your data.

The first step is to figure out the indicator that you will be tracking and clarify if this is a chart of a single facility, or pooled results across a number of health facilities (e.g., will the chart show the work of a single hospital, or data grouped from 10 hospitals?). If you don't have the data yet, you will need to make a plan to start collecting the data. If you already have some data points for the indicator, organize the data chronologically (e.g., Week 1, Week 2, Week 3, etc.).

Once you have your data, start by writing some basic information:

- A brief but descriptive title at the top of the page
- The data source
- A brief description of how sampling was done (if applicable)
- A legend if there is more than one indicator or group on a single chart

### 2. Draw and label your chart.

Now you will set up the basic structure for your chart (see the *HCI Norms for Presentation of Time Series Charts*):

- Draw a straight horizontal line for the X axis and a straight vertical line on the left side of the page for the Y axis.
- Create a data table underneath the X axis (horizontal) that lists the data points together chronologically. If you are tracking a percent, include the numerator and denominator for each measurement point. If the time series chart will show grouped data from multiple health facilities, make sure to include in the data table the number of sites reporting for each data point.
- Divide and clearly label the X axis into equal time intervals based on how often your team is collecting and plotting the data (e.g., daily, weekly, monthly, etc.). Make sure to leave enough room to plot future data.
- Create the scale for the Y axis (vertical).
  - If you are just starting to collect data, you can start with a scale from 0 to 100% to encompass all values.

- If you already have at least 15 data points, you can customize the scale by subtracting 20% of the smallest value and adding 20% to the largest value in the data set (IHI 2004).

*Example:* Let's use the example of a team tracking infection rates, where the range of values in the data is between 1% and 5%. To figure out the upper end of the scale, you would take 20% of 5, which is 1; therefore, upper range of the scale would be 6% (5+1). To figure out the lower end of the scale, you would subtract 20% from the smallest value in the data set, 1%. Since 20% of 1 is .2, the lower end of the range would be 0.8% (1-0.2).

- Divide the axis into equal intervals.
- Label the Y-axis with a descriptive name of what is being measured (e.g., percent of women tested for HIV in antenatal care, minutes clients wait until receiving care). If the measure is a percentage, include a definition for the numerator and denominator with criteria for what was counted.

### **Plot and annotate your data.**

Now that you have the structure for your chart, you can start to plot and annotate your data points.

- Plot the actual values on the chart according to when they occurred in time (horizontal X axis). Connect the dots together with a line.
- Annotate the time series chart with additional useful information that will help tell the story over time, such as:
  - Quality improvement interventions (changes implemented)
  - Any other key events that occurred during the time period that would explain changes in the results over time (e.g., stock-outs of drugs, loss of staff, strikes, changes in other government policies that affect the facility, etc.)
  - The aim for the quality improvement work

### **Analyze your chart.**

For this stage in developing your time series chart, refer to the text in Section 3 of this document.

- If you have at least 10 data points, calculate the median and plot it on the chart. If you have fewer than 10 data points, do not add the median yet. Please see Box 3 for instructions on calculating the median.
- Use the rules to look for trends and shifts on your chart.
- Pay attention to any variation in denominator values or number of sites reporting that need to be taken into account in your interpretation of results.