

Statistical process control part 2: using statistical process control to measure process improvement in patient flow

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THE FIRST ARTICLE in this series, “Statistical process control part 1: a primer for using statistical process control in health care process improvement”¹ (in this issue of the Journal), introduced the basic concepts of statistical process control (SPC) and its main tool, the control chart. While this set of techniques was originally developed in the manufacturing sector, there is growing realisation in recent years that SPC (and also other quality improvement techniques, such as Six Sigma and lean thinking) can be successfully applied to health care quality improvement.² The reason for this is that SPC is a potent and powerful, yet simple tool for tracking, and detecting any variation in, process performance over time; which creates the opportunity for health professionals to promptly respond to any improvement or deterioration in the process. Perhaps the most valuable feature of SPC techniques however, is the ability to place a change in the outcome of a process in close temporal proximity to the redesign and improvement of the process. This means SPC can reliably evaluate the effectiveness of quality improvement initiatives implemented at the front line of health service delivery, despite the complexities of the hospital system and the challenges this often poses for health services research (for example, the inability to use robust research designs).

The purpose of this companion article is to therefore demonstrate the practical application of SPC in a health care organisation. Specifically, the

technique of control charting was used to track the impact of patient flow process improvement interventions in a public hospital, in the hope that this will exemplify to health care professionals the value and simplicity in applying SPC as part of their daily work.

Patient flow — the problem

The problem of poor patient flow stems from the fact that no two patients are the same. Put in the context of a complex health care system where multiple departments, services, and staff interact during a patient's journey throughout the whole system, some variations (which inevitably translate into waits, delays, and cancellations) are unavoidable. But the situation will only continue to worsen as hospitals nationwide face an increasing number of emergency and acute patient presentations. In the past, the solution has been the addition of resources; more beds, more buildings, more staff.³ However, few hospitals are capable of funding additional resources, and there is also growing evidence that improving patient flow, and not simply adding resources, is the answer.³ Improving patient flow therefore lies in hospitals prioritising the redesign of processes related to patient flow, so that the sources of variation are reduced,³ and the bottlenecks which flow on to delays throughout the system avoided.

Methods

Project development

In April 2006, Queensland Health's Clinical Practice Improvement Centre approved and funded a major public hospital (providing secondary services to the regional metropolitan and rural population) to carry out a process redesign

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I Details of the four process redesign interventions

Intervention	Description and purpose
Improve transit lounge utilisation (October 2006)	Extend transit lounge hours (7am to 6pm) and develop a model for pulling patients awaiting discharge into the transit lounge, to increase the early discharge of patients from the medical wards. Using the "pull" model, patients ready for discharge, but awaiting discharge medications, summaries, or transport are flagged at the morning bed management meeting and pulled from the ward into the transit lounge.
Establish and record EDDs in the medical wards	<i>Baseline phase (December 2006).</i> Discuss patient EDDs at the daily medical ward multidisciplinary meeting and record on the medical unit's patient journey whiteboard, to facilitate discharge planning and to improve communication about bed availability.* <i>Post-intervention phase (October 2007).</i> Integrate collection of EDD indicator (number of medical ward patients with an EDD recorded on the whiteboard) into routine data collection activities, to improve compliance with using the new process.
Redesign bed management meetings (January 2007)	Redesign existing daily bed management meetings so that they provide an avenue for each ward to identify outlier patients (ie, patients admitted to a ward not catering to their requirements for specialist care) to be pulled back to the home ward for specialist care, reducing the need for extended ward rounds and potentially improving these patients' quality of care and length of stay.†
Introduce long stay patient meetings (October 2007)	Introduce long stay patient meetings to assist medical wards in coordinating care for non-acute patients (ie, patients with a hospital length of stay greater than seven days). The medical wards use the weekly meetings to identify non-acute patients to be transferred to a step-down facility within the district for ongoing care, and to facilitate communication relating to such transfers.

EDD = estimated discharge date. * Before the commencement of the project the hospital had no formal process for recording a patient's EDD. The baseline phase data therefore provides baseline measurement of the process. † During the planning stages, the hospital identified an excessive number of outlier patients, whose quality of care and length of stay was potentially impacted by their physical location.

project for improving patient flow within the emergency department and medical inpatient wards. The project ran for a period of 18 months, commencing July 2006. Applying Langley and colleagues' model for improvement,⁴ the project team undertook mapping and tracking of hospital processes during the diagnostic phase to identify variances and queues in the patient journey, from presentation at the emergency department through to hospital discharge. From the information documented, the steering committee approved an intervention plan that would address the areas of highest priority and improve clinical processes within the patient journey.

Interventions and study design

The design was a before and after study of the impact of the following four quality improvement interventions (as described in Box 1): improving transit lounge utilisation; establishing and recording estimated discharge dates (EDDs) in the

medical wards; redesigning bed management meetings; and introducing long stay patient meetings. The indicators for measuring process performance, and therefore the effect of each intervention, are shown in Box 2.

Data collection

Data for each of the indicators were sourced from hospital records or from data collection activities initiated as part of the project. The EDD data were initially collected daily by a project officer over a 2-month period between December 2006 and February 2007. Collection of the EDD indicator recommenced in October 2007 when the indicator (captured as a snapshot at the start of each week) was integrated as part of the hospital's routine data collection activities. Transit Lounge utilisation was an existing measure recorded by Transit Lounge staff each day and entered to a spreadsheet each month. Medical ward data (number of outlier and non-acute patients) were retrospectively extracted from Queensland

2 Clinical indicator and appropriate statistical process control chart for each intervention

Intervention	Clinical indicator	Control chart
Improve transit lounge utilisation	Number of patients in the transit lounge awaiting discharge	I-chart and MR-chart [†]
Establish and record EDDs in the medical wards	Proportion of medical ward patients with an EDD recorded on the whiteboard	P-chart
Redesign bed management meetings	Proportion of medical ward patients outlying* from the home ward	P-chart
Introduce long stay patient meetings	Average number of non-acute patients in the hospital	X-bar-chart and S-chart [†]

* An outlying patient is defined as any patient admitted to a ward that does not correspond to the admitting doctor's unit. † The MR-chart and S-chart (used to calculate the control limits of the I-chart and X-bar-chart, respectively) are not presented, so that the reader's focus is not taken away from the main messages in the I-chart and X-bar-chart.

Health's current state-wide patient information system.

Statistical analyses

All control charts used for SPC analysis were created using MINITAB software (Minitab Inc., <http://www.minitab.com>). The indicators were charted, either weekly or monthly, using the appropriate control chart (Box 2). Control charts created in MINITAB display each measurement of process performance, along with a centre line and upper and lower control limit (UCL and LCL, respectively).

The centre line represents the mean value for the indicator. The UCL and LCL represent three standard deviations (SDs) around the spread of data (the mean), and define the range of natural variation in performance expected when the process is in "statistical control". The three SD limits, termed "three-sigma control limits" in SPC jargon, are based on statistical theory which dictates that 99.73% of all data points are expected to fall within this range when a process is stable and unchanged,^{5,6} and the performance of the process normally distributed. Any values falling within these control limits are therefore likely to represent common cause variation.

The likelihood of a value falling outside the three-sigma control limits when a process is

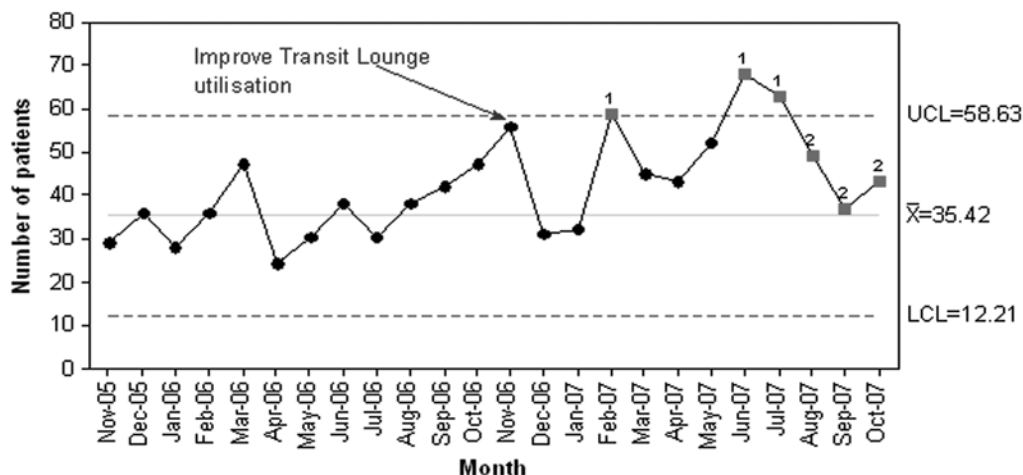
unchanged and performing as expected is 0.27%.⁶ Consequently, an outlying value is unlikely to result purely from random fluctuations in the process. Any values beyond the control limits can therefore be interpreted with high confidence as departing from the regular rhythm of the process. These outlying values represent special cause variation, and are clinically relevant because they flag when the process is being influenced by a non-random event extrinsic to the process, causing it to perform outside of what is typical for the process.

In accordance with other statistical tests for special cause variation recommended in the literature,^{5,7,8} the following four tests were selected when the control charts for this study were constructed in MINITAB: one point more than three SDs from the centre line; a run of seven or more consecutive points on one side of the centre line; seven or more consecutive points in a continual ascending or descending trend; and 14 consecutive points in a repeated up and down pattern. In MINITAB, labels on the control chart indicate which test was violated for each value where special cause variation is detected.

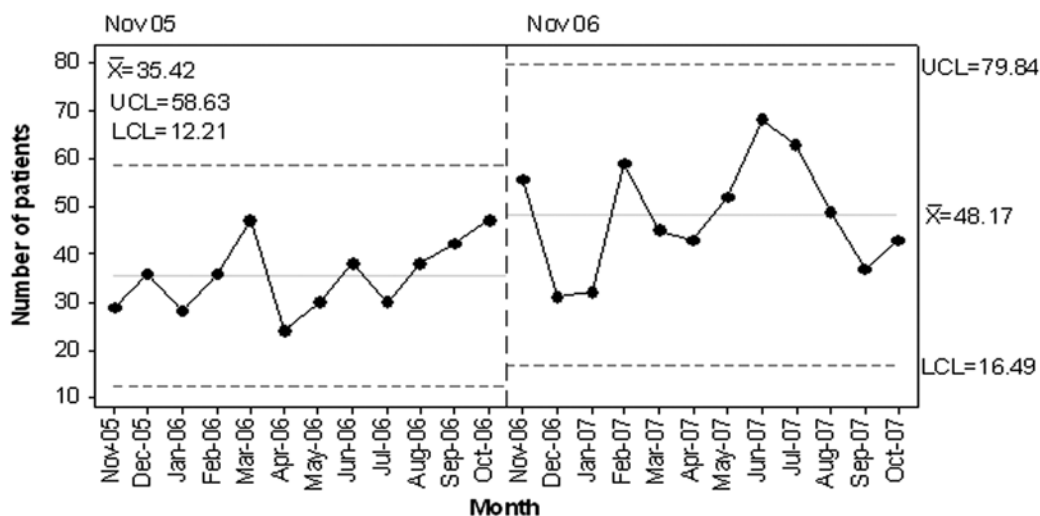
There are two control charts for each indicator being studied. The first shows the data for the entire measurement period (baseline and post-intervention) with the mean and control limits

3 Statistical process control chart for the “improve transit lounge utilisation” intervention

(a) Data with mean and control limits frozen after November 2006



(b) Data separated into two phases; baseline and post-intervention



\bar{X} = mean. UCL = upper control limit. LCL = lower control limit.

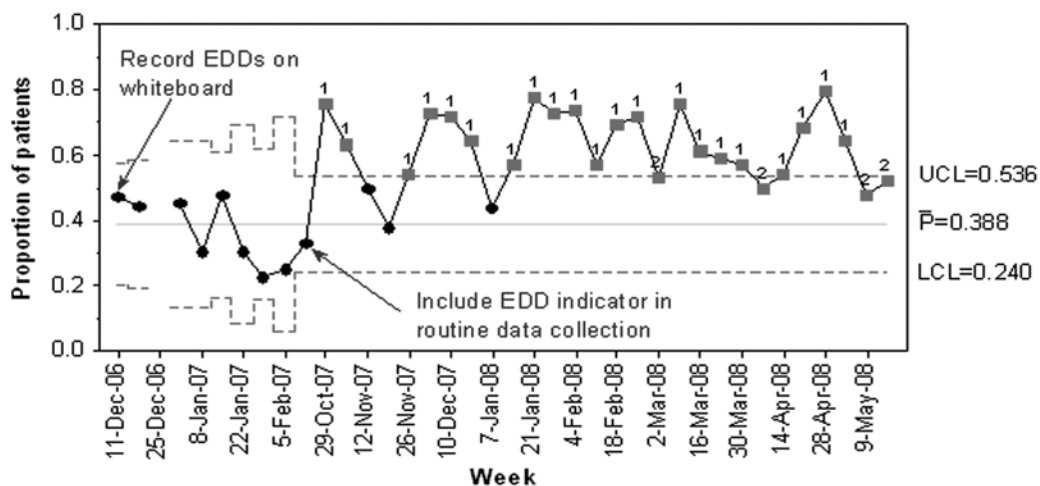
Datapoints shown with a square symbol are signalling special cause. The numeric annotation indicates the test violated: 1 = data point is 3 SDs from the centre line; 2 = run of 7 or more consecutive data points on one side of the centre line; 3 = 7 or more consecutive points in a continuing ascending or descending trend; 4 = 14 consecutive data points in a repeated up and down pattern.

frozen from the date the respective intervention was implemented, to measure the impact of the quality improvement intervention when the baseline process is in control. This is because a stable

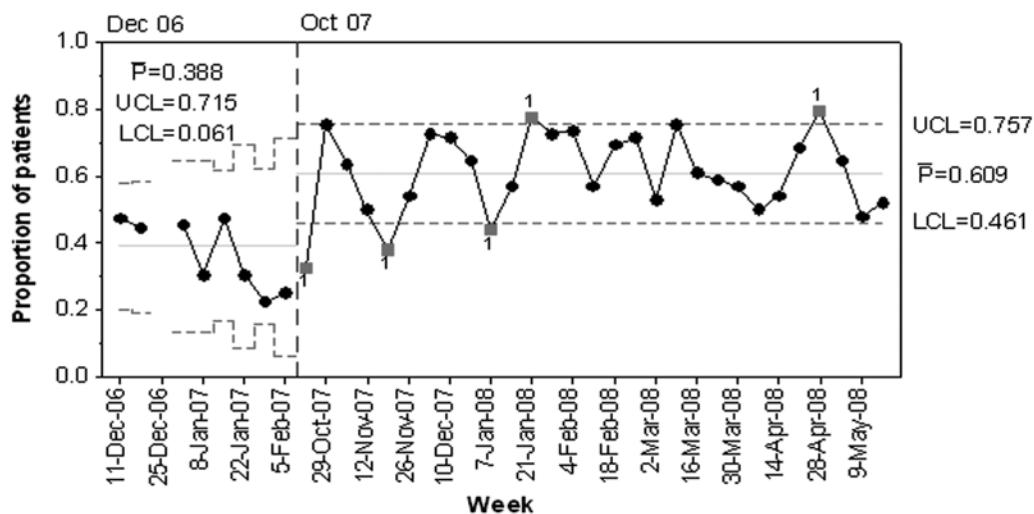
process will continue to perform as it has in the past, and therefore the control limits from the baseline phase estimate with confidence the projected performance boundaries of the process if

4 Statistical process control chart for the “establish and record EDDs in the medical wards” intervention

(a) Data with mean and control limits frozen after October 2007



(b) Data separated into two phases; baseline and post-intervention



EDD=estimated discharge date. P=mean proportion. UCL=upper control limit. LCL=lower control limit.

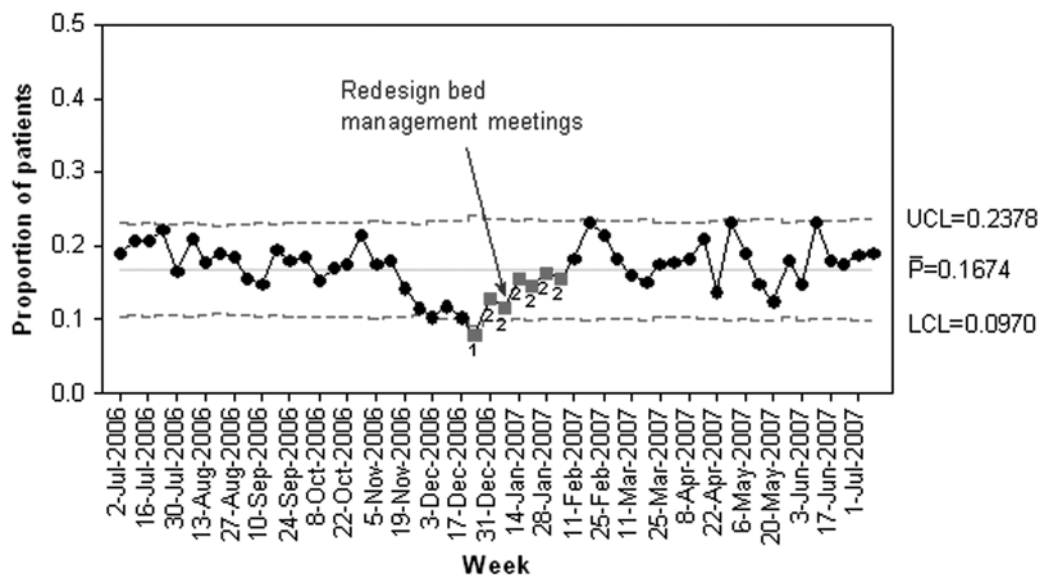
Datapoints shown with a square symbol are signalling special cause. The numeric annotation indicates the test violated: 1 = data point is 3 SDs from the centre line; 2 = run of 7 or more consecutive data points on one side of the centre line; 3 = 7 or more consecutive points in a continuing ascending or descending trend; 4 = 14 consecutive data points in a repeated up and down pattern.

nothing had changed. By freezing the mean and control limits, each new measurement of process performance can be plotted against these projected performance boundaries, to determine if

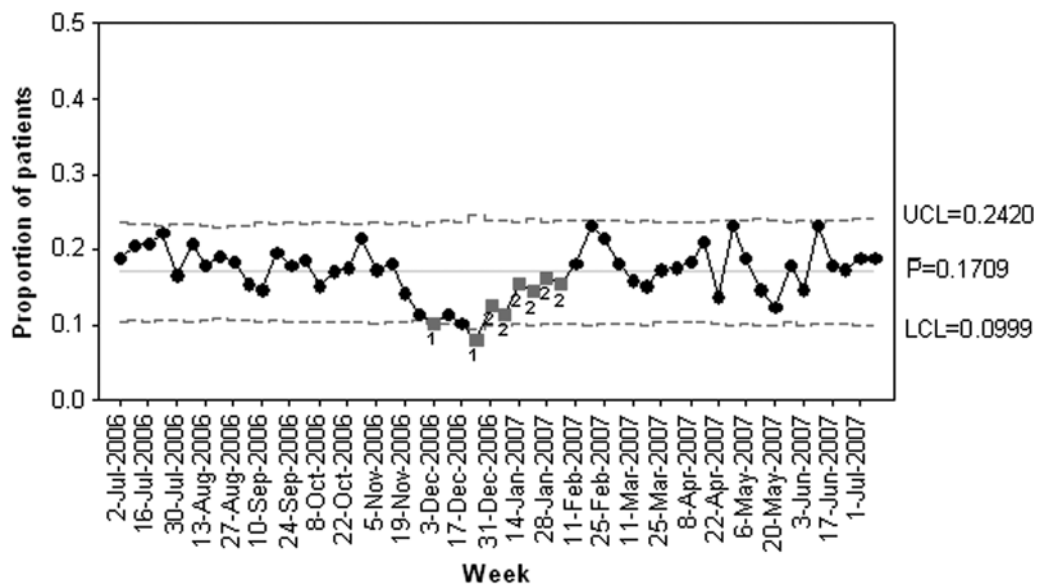
they are part of the original process or not. In line with SPC theory, whereby quality improvements deliberately attempt to introduce a special cause to the process, any new measurement that signals

5 Statistical process control chart for the “redesign bed management meetings” intervention

(a) Data with mean and control limits frozen after January 2007



(b) Data over the entire measurement period



P = mean proportion. UCL = upper control limit. LCL = lower control limit.

Datapoints shown with a square symbol are signalling special cause. The numeric annotation indicates the test violated: 1 = data point is 3 SDs from the centre line; 2 = run of 7 or more consecutive data points on one side of the centre line; 3 = 7 or more consecutive points in a continuing ascending or descending trend; 4 = 14 consecutive data points in a repeated up and down pattern.

special cause variation indicates that the intervention may have changed the process,^{9,10} for better or worse.

The second chart shows either: the data separated into baseline and post-intervention phases with the mean and control limits calculated separately for each phase, to assess the new post-intervention process; or the data with the mean and control limits calculated from the entire measurement period (both baseline and post-intervention phases).

Results

The control charts in Box 3 through Box 6 show the time-ordered charting of each indicator, and demonstrate the capacity of this SPC technique to track process variability over time and identify special causes of variation.

“Improve transit lounge utilisation” intervention

The control chart in Box 3, (a) shows that, before the hospital intervened, the transit lounge accommodated, on average, 35 patients awaiting discharge each month. Following the extending of opening hours and implementing the model for pulling patients into the transit lounge, there were 6 months signalling special cause. These special causes indicate a non-random shift in the number of patients pulled into the transit lounge, most likely due to the intervention.

Box 3, (b) separates the data into baseline and post-intervention phases, and shows an improvement in the average number of patients awaiting discharge in the transit lounge each month, from 35 to 48. The post-intervention phase shows that the improved process for pulling patients into the transit lounge is in control, meaning that chance only is responsible for monthly fluctuations. As the improved process is exhibiting only common cause variation, the hospital can predict from the control limits that the transit lounge will accommodate between 16 to 80 patients awaiting discharge each month; this range reflects the variation resulting from normal or common causes. It is interesting to note however, that the

transit lounge intervention has inadvertently increased the range of month-to-month variation, as evidenced by the wider control limits after the intervention. While some of this variation may be attributed to predictable seasonal causes (for example, decreased activity during the December/January holiday period, or increased activity during the June/July “flu season”), the hospital should identify each source of variation in transit lounge activity, with the intention of reducing any variation due to causes that are within their control.

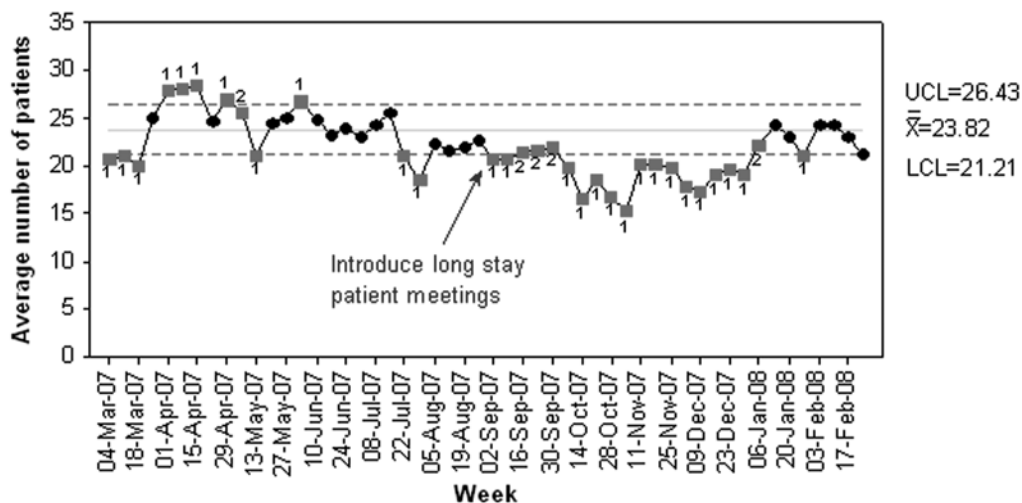
“Establish and record EDDs in the medical wards” intervention

As shown in Box 4, (a), when the process for establishing and recording medical ward patients’ EDD on the whiteboard was first implemented (baseline phase), it was in control. Yet even though the process was stable, there was clearly room for improvement given that, on average, only 38.8% of patients had an EDD recorded. After including the EDD indicator in routine data collection activities (post-intervention phase), 25 of the 29 subsequent data points signalled special cause; there had been a shift in the process. It is necessary to note however, that the control limits may not be fully representative of the actual baseline process because they are calculated from only eight data points, and therefore should be interpreted with caution. Ideally the hospital should have collected the baseline data for a longer period, yielding at least 12 to 15 (preferably 25 or more)⁵ data points.

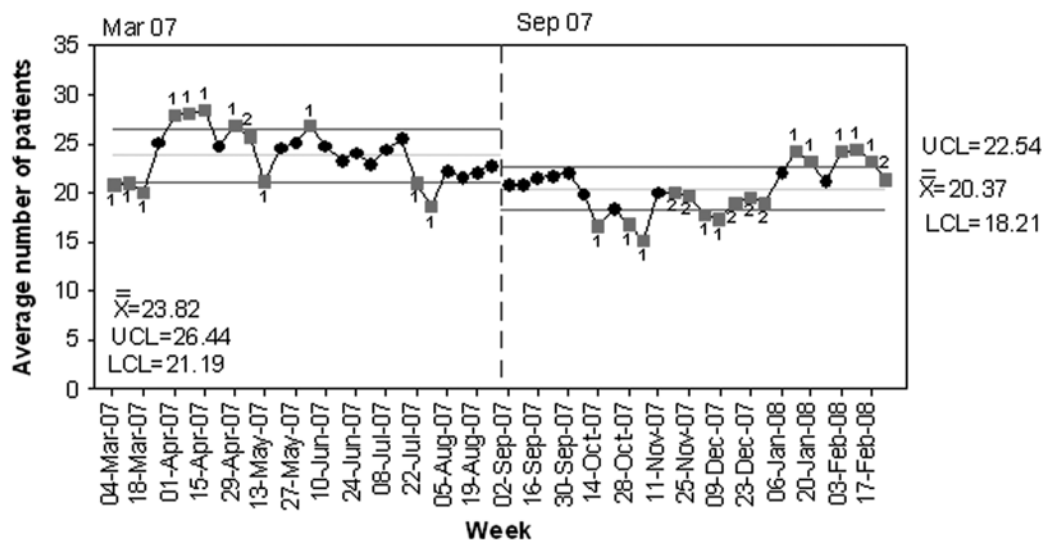
Box 4, (b) shows that although including the indicator into routine data collection activities shifted the process in the desired direction, this improvement was not consistent throughout the entire post-intervention phase. The new (post-intervention phase) process was statistically unstable, with five points outside the control limits, signalling special cause variation. The weekly figures are so unstable that the mean does not accurately represent the performance of the process, nor can the hospital predict what to expect in upcoming weeks. This instability would not have been noticed if the project team had

6 Statistical process control chart for the “introduce long stay patient meetings” intervention

(a) Data with mean and control limits frozen from September 2007



(b) Data separated into two phases; baseline and post-intervention



X = mean. UCL = upper control limit. LCL = lower control limit.

Datapoints shown with a square symbol are signalling special cause. The numeric annotation indicates the test violated: 1 = data point is 3 SDs from the centre line; 2 = run of 7 or more consecutive data points on one side of the centre line; 3 = 7 or more consecutive points in a continuing ascending or descending trend; 4 = 14 consecutive data points in a repeated up and down pattern.

compared only average scores of performance for the two phases. Because the new process is unstable, further work is needed to bring the

process into statistical control, so that it is stable and predictable within accepted limits. The goal should be to investigate and identify the source of

each special cause (using the pyramid model of investigation¹¹), so that appropriate action can be taken to prevent each special cause from influencing the process.

“Redesign bed management meetings” intervention

In the 6-month period before the redesign of the bed management meetings, the percentage of medical ward patients outlying from their home ward was 16.74%, as shown in Box 5, (a). In the weeks immediately before the bed management meetings were redesigned, there was an apparent shift in the process for managing the number of outlier patients, with two points flagging special cause variation. The existing run of seven consecutive weeks below the baseline mean continued for another 5 weeks after the intervention was implemented; the process then returned to the stable state seen at the start of the measurement period. It is unlikely that the improvement was a result of the redesigned bed management meetings as the onset was before the intervention was implemented. Other significant factors may therefore have impacted upon patient placement, such as low occupancy rate or independent operational decisions determining ward utilisation.

With the redesigned bed management meetings not effective at reducing the number of outlier patients, the process over the entire measurement year is best viewed as a single process. The control chart in Box 5, (b) therefore shows the performance of the process over the entire period, without freezing the control limits or separating the data into baseline and post-intervention phases. Apart from the transient period of instability (not due to the intervention), the process was in a state of statistical control. Given the timing of the improved performance (19 Nov 2006 to 4 Feb 2007), this may reflect reduced patient numbers over the Christmas and New Year period. The hospital should investigate if this was in fact the case, or whether this was an example of good practice that can be integrated into the process.

“Introduce long stay patient meetings” intervention

Even before the hospital introduced the long stay patient meetings, the average number of non-acute patients in the hospital each week was unstable and unpredictable, with 12 weeks varying due to special causes (as shown in Box 6, [a]). After the hospital introduced the long stay patient meetings, the process for coordinating care for long stay patients was still out of control, with 16 weeks signalling special cause (as shown in the post-intervention phase of Box 6, [b]).

The presence of special cause variation both before and after the intervention has two important implications for the hospital. Firstly, the mean for each phase does not represent an accurate picture of the process and therefore should not be used to describe nor evaluate improvements in the process. This means that the frozen mean and control limits predicted from the baseline data (as shown in Box 6, [a]) do not estimate, with any amount of confidence, the future performance boundaries of the process. Without a valid comparison, it is not possible to determine whether the post-intervention measurements are part of the original process or not; that is, the hospital cannot evaluate the effect of introducing the long stay patient meetings.

Secondly, by not identifying and understanding the source of the non-random special causes of variation initially in the process, the hospital has not addressed nor removed these special causes. The process will continue to perform unpredictably until the hospital intervenes to eliminate the special causes of variation. Improvement efforts should have therefore focused on searching for and removing the special causes in the process before trying to action more fundamental process improvement and redesign.

Discussion

This case report illustrates the practical application of SPC charts at the local hospital level, and in doing so reveals the important features of the control chart that makes it a robust, yet simple and inexpensive tool for the real-time analysis of

health care process improvement. The key to this technique (and SPC methods in general) is the ability to detect and understand the sources of variation in a process over time. Differentiating common from special causes of variation reveals the stability (or instability) of a process, which informs local quality improvement decisions; specifically, how to best target improvement efforts (according to the sources of variation present in the process) and whether or not a process redesign has had the expected effect.

As was the case for the interventions for improving transit lounge utilisation and for establishing and recording EDDs in the medical wards, a baseline process in a state of statistical control is expected to perform as it has in the past if nothing has changed. This is important for two reasons: fundamental changes to the underlying processes were needed for improvements to occur; and the control limits from the baseline phases predicted future process performance, and therefore provided a comparison for investigating if each intervention was indeed effective at improving the process. In contrast, an out-of-control baseline process (in the examples herein, redesigning the bed management meetings and introducing the long stay patient meetings) indicates that the process is unstable. Improvement efforts should have instead focused on searching for and removing the special causes of variation before trying to action more fundamental process improvement and redesign.

These examples also illustrate the advantages of control charts that make them valuable tools for displaying data and providing regular feedback on local quality improvement initiatives implemented at the local hospital level. First is the ability to consistently track process performance over time. Because control charts account for the time-ordered sequence of observations, they observe the tendency of the process to vary (which provides the opportunity to identify special causes of variation that can be integrated into the process or eliminated, or to predict future performance of the process) and show

whether a change implemented at a particular local hospital has improved the process. Secondly, control charts measure process performance in real time by repeatedly testing the most recent dataset; essentially, a statistical test is recalibrated and applied for each new measurement of process performance. This facilitates timely attention to any special causes of variation that affect the quality of the process,¹² allowing prompt decision making and corrective action. Finally, control charts are well suited for reporting to non-statistical end-users due to their ease of design and ease of interpretation. They have been designed so that they can be easily plotted using SPC software applications or spreadsheet programs installed on most computers,⁵ and the visual nature of the control chart lends itself to easy interpretation, while also serving as a simple and straightforward communication method.

Conclusion

Control charts offer a valuable technique that complements and extends current quality improvement efforts in the health care sector. This study has shown the ease with which SPC charting can be applied and interpreted by health care professionals to manage process improvement and redesign, and the potential of this to enrich and improve the delivery of patient care.

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Competing interests

The author declares that she has no competing interests.

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