# Health care quality: reducing the length of stay at a hospital

Bisgaard, S.; Does, R.J.M.M.

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# Quality Quandaries*: Health Care Quality—Reducing the Length of Stay at a Hospital

**Søren Bisgaard[1], Ronald J. M. M. Does[2]**

[1]Eugene M. Isenberg School of Management, University of Massachusetts Amherst and Institute for Business and Industrial Statistics, University of Amsterdam, The Netherlands
[2]Institute for Business and Industrial Statistics, University of Amsterdam, The Netherlands

## INTRODUCTION

The medical profession has made great strides in improving the science of health care. The report card on the management of health care is less glorious. The drastic increases over the past decades in the cost of health care in the United States and Europe justify the latter claim. As the (now former) U.S. Comptroller General David M. Walker recently said, "unless we fix our health care system—in both the public and private sectors—rising health care costs will have severe, adverse consequences for the federal budget as well as the U.S. economy in the future." Similar dire projections can be made for Europe. (http://www.gao.gov/highlights/d071155sphigh.pdf)

Some of these cost increases can obviously be attributed to the use of more advanced health care methods; today we can do a lot more than we could 50 years ago. This obviously costs money. However, another significant part of the cost increases can be attributed to health care organizations generally lagging behind in terms of implementing modern management principles. Health care organizations are rife with waste and inefficiencies. The problem with health care is therefore not the science of health care. It is with the management of health care. Unless we get better at managing health care, the benefits of the advances in the science of health care will be offset by inefficiencies in management. In fact, the marvels of modern health care science may soon only be affordable by a small minority of the population and may need to be rationed in some form or another for the rest.

Fortunately, the quality profession can help alleviate some of these problems. An important new application area for quality engineering concepts and methods is health care. Applications are both on the clinical and the operational side. As important as it clearly is to focus on reducing medication errors and other clinical quality problems, we need to take a broader view. Quality problems are abound! As in industry where the focus initially was only on factory floor problems, focusing only on clinical quality problems is a "Little q" focus. Progressive health care quality initiatives instead adopt a "Total Quality" or "Big Q" approach; see Juran (1989).

*Edited by Søren Bisgaard

Address correspondence to Søren Bisgaard, Eugene M. Isenberg School of Management, University of Massachusetts, 121 Presidents Drive, Amherst, MA 01003. E-mail: bisgaard@som.umass.edu

Moreover, progressive health care quality applications go far beyond using only quality control charts and performing process monitoring.

In this "Quality Quandaries" column we provide an example of the application of Lean Six Sigma to health care. The specific case study was about reducing the length of stay of patients with chronic obstructive pulmonary disease (COPD). First, we provide a brief background for the case study. We then highlight some of the statistical aspects. This study is interesting because, unlike the common assumption, it shows that there are no trade-offs between quality and cost; we can improve quality while at the same time reducing costs.

## BACKGROUND

The Red Cross Hospital in Beverwijk in The Netherlands is a 384-bed, medium-size general hospital employing a staff of 966. In 2004, the year the case study was conducted, the Red Cross Hospital had 12,669 admissions, performed 11,064 outpatient treatments, and received 198,591 visits to its outpatient clinics, of which 78,832 were first contacts.

In the late 1990s, the Red Cross Hospital's management introduced a basic quality assurance system and obtained an ISO 9002 certification in 2000 and an ISO 9001 certification in 2003. Confronted with escalating costs, quality problems, and limited budgets, it was decided in 2002 to initiate a Six Sigma program. Prior to the Six Sigma initiative, management had deployed a number of teams to work on specific quality improvement projects. Management at the time believed that these projects worked well. Indeed, a number of them yielded good results. However, over time, management increasingly began to feel the needed for a better organizational framework, in particular programs for managing projects and coordinating, tracking, and supporting improvement teams. This frustration became the impetus to look for help and eventually to experiment with implementing Six Sigma; see Van den Heuvel (2007).

With the assistance from the Institute for Business and Industrial Statistics at the University of Amsterdam, Six Sigma was kicked off in earnest at the Red Cross Hospital in September of 2002 with a first wave of Green Belt (GB) training. The training was provided in two separate blocks of 3 days, 2 months apart. Each GB was required to complete a project as an integral part of the training. The financial threshold for initiating a project was a projected minimum savings of $30,000. GBs typically worked one or 2 days a week on their projects. As part of the project management system, teams were carefully monitored and only allowed to proceed to the following phase of the define, measure, analyze, improve, and control (DMAIC) sequence after presenting the projects' champion with interim reports providing evidence that they had completed the preceding phase. For a summary of the typical steps of a Six Sigma project, see Figure 1. Teams were required to present their results twice in front of the class. The second presentation served as the GB's graduation exam.

**Phase 0: Define**
- Define project scope and boundaries
- Select Champion and GBs
- Develop team charter
- Estimate $ impact
- Get leadership approval

**Phase 1: Measure**
- Define CTQ's
- Map the process and identify inputs and outputs
- Develop measurement plan
- Validate the measurement system
- Establish measurement system capabilities

**Phase 2: Analyze**
- Make cause-and-effects matrix
- Establish process capability baselines
- Perform multi-vari analysis
- Develop input-output relations
- Identify critical process inputs
- Develop FMEA
- Re-estimate financial benefits

**Phase 3: Improve**
- Verify critical process inputs
- Optimize critical process inputs
- Reduce variability

**Phase 4: Control**
- Develop control plan
- Implement control plan
- Verify long term capability
- Transfer to operations
- Verify financial benefits
- Continuously improve the process
- Complete documentation of the study

**FIGURE 1** Summary of the steps of the define, measure, analyze, improve, and control cycle used in Six Sigma.

The first wave was followed by additional GB training waves scheduled every 6 months. In general, the Six Sigma approach was well received. The GBs felt that the training and project management system supported them well. Importantly, the data-driven approach seemed helpful in establishing management support and in minimizing resistance to change. However, the original curriculum was more or less a standard Six Sigma program and not necessarily tailored to health care. With the experience gained from the projects, the instructors increasingly began to feel the need for updating the materials and for tailoring them to the specific needs in health care. Some tools and methods were not relevant in health care, whereas others typically not included were needed or needed more emphasis.

After completing the training of the fourth wave of GBs it was decided to fundamentally revamp the training materials. The experience from the previous waves of GB training indicated that many health care problems involved various forms of waste. Lean concepts were therefore added to the revised Six Sigma program. For example, they added materials on time value maps, value stream maps, and the eight standard forms of waste to the curriculum in the analysis phase; see, e.g., Liker (2004). Further, the curriculum for the improve phase was expanded to include complexity reduction, cellular production, pull systems, line balancing, and the 5 S method to reduce inefficiencies due to clutter and poor organization; see, e.g., George et al. (2005). The revised training program was expanded to eight days, divided up into two periods of three days and an additional section of two days. The Lean Six Sigma GB training program was kicked off in September 2004 with 18 participants distributed on teams of two or three GBs.

The Red Cross Hospital experience illustrates four key elements of the Lean Six Sigma approach: (a) the Red Cross Hospital applied the organizational infrastructure typical of Six Sigma; (b) they used a project-by-project approach; (c) rather than having external consultants taking the lead, they focused on developing internal organizational competency for innovation by training a dedicated workforce as project leaders (GBs); (d) in project selection they maintained a strategic focus. In the present case, the Dutch Ministry of Welfare and Health had imposed severe budget cuts on the Red Cross Hospital. This necessitated a keen focus on cost reductions while maintaining or possibly improving quality. Potential projects were suggested by champions, who were all department heads. The final project go-ahead was made by the general manager based on an evaluation of the projects strategic relevance.

Over the years the Red Cross Hospital carried out a number of successful Lean Six Sigma projects. We now review one focused on reducing the length of hospitalization of patients with pulmonary diseases.

## SHORTENING THE LENGTH OF STAY OF COPD PATIENTS

At the Red Cross Hospital, patients with chronic obstructive pulmonary disease (COPD) were primarily admitted to the pulmonary department (PD). However, in case of bed shortage, the internal medicine department (IMD) also admitted COPD patients. Based on anecdotal evidence, it was suggested that there might be a difference between the lengths of stay of patients admitted to the two different departments. But rightly so, there were also skeptical voices objecting to this hypothesis and warnings made about jumping to rash conclusions. For example, if there was a difference, perhaps it could be explained by differences in the patient populations admitted to the two departments. The patients could be different in a number of ways, including severity of the illness, age, and sex. It was decided to put together a Lean Six Sigma team to evaluate the situation. Team members included the head of the nursing staff of the PD, a lung specialist, and two senior nurses from each of the two departments. The general manager of the hospital assumed the role of champion for the project.

During the define stage of the DMAIC cycle, the team, in cooperation with team's champion, developed a charter statement. It stated that the primary objective was to discover factors influencing the length of stay of COPD patients. In particular, the team needed to determine whether patients admitted to the PD or the IMD showed any differences not explained by demographic factors or severity of illness. In other words, the critical to quality (CTQ) metric was length of stay in the hospital for COPD patients. In what follows, we discuss some of the statistical issues that confronted the team. Due to space limitations we do not provide a full discussion of all the steps of this Lean Six Sigma project.

## PRELIMINARY STEPS

After developing a detailed process map (or flowchart) of the process from admission to discharge, the team created a cause-and-effect matrix, mapping all potential factors that might impact the length of stay for COPD patients. Subsequently, the cause-and-effect matrix helped the team develop a list of factors (*X*s) that potentially could influence the length of stay (*Y*). Many of these were demographic factors.

It was decided to study 146 COPD cases for a period of twelve months. Note that patients who died while hospitalized were not included. This period was considered long enough to provide a reasonable representative sample of the process. Table 1 provides a list and short description of the 25 input variables. These variables were already being recorded by the hospital but needed to be assembled into a comprehensive spreadsheet for further analysis. To collect and clean the data the team received valuable help from the IT department. An abbreviated list of the data is provided in Table A1 in the Appendix.

## Initial Data Analysis

Any data analysis ought to start with a comprehensive graphical investigation to get a "feel" for the data and to clean up abnormalities and outliers. Of course, many of the graphs produced in such an investigation may not make it to the final report. Those that survive typically go through several iterations before they tell the "right" story.

Figure 2 is an example of one of the graphs that was considered helpful in getting a comprehensive first overview of the data. It shows a plot of the

**TABLE 1** Variables Collected for the Study and Short Descriptions

| Variable | Description |
|---|---|
| Patient number | A number assigned to the patient at admission |
| Main diagnosis | Main diagnosis of patients made at admission to hospital |
| Length of stay (days) | Days for treatment or in-bed days |
| Pre-admission (days) | No. of days admitted for pre-operative research |
| Pre-operative research (min.) | Time for pre-operative research |
| Waiting time for tests (days) | Number of days a patient has to wait for the results of the pre-operative tests |
| Research in OR (hours) | Research time in operating room (OR) |
| Recovery 1 (days) | Number of days a patient recovers on the ward from the tests before the doctor visits the patient |
| Doctor's visit (minutes) | Amount of time the doctor exams the patient to see how the patient is doing |
| Recovery 2 (days) | Number of days a patient recovers on the ward after the visit of the doctor |
| Time between discharge and departure (days) | Number of days between the moment of discharge of the patient and the actual moment the patient leaves |
| Specialty | Specialty |
| Specs name | Name of the specialist |
| Department | Department where the patient is being treated |
| Admission ward (Y/N) | Is the ward where the patient is treated the same as where the patient was admitted |
| Discharge ward (Y/N) | Is the ward where the patient is treated the same as where the patient will be discharged |
| Day of admission | Day of the week on which the patient was admitted |
| Hour of admission | Hour of the day on which the patient was admitted |
| Urgency | Whether a patient was admitted electively (planned) or urgently (urgent) |
| Age | Age of the patient |
| Gender | Gender of the patient |
| Day of discharge | Day of the week on which the patient was discharged |
| Year of registration | Year of admittance |
| Year & day of week of discharge | Year of discharge and day of the week |
| Destination code | Code describing the destination to where the patient was discharged: 0 = own home; 1 = assisted living; 2 = other institution (other hospital, nursing home, etc.); 3 = diseased; 4 = left against advice |

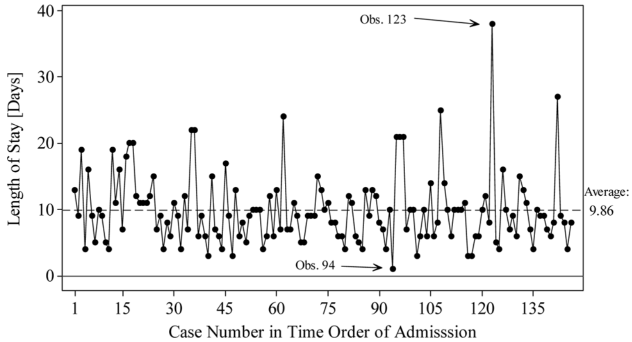


**FIGURE 2** **A plot of the length of stay versus case number for each of the 146 cases of COPD at the Red Cross Hospital for a period of 12 months.**

length of stay in days versus the case number in time order as the patients were admitted. We notice a tendency for the data to be mildly skewed toward longer stays. We also notice a few outliers. In particular, observation 94 is a patient admitted for only one day. After further scrutiny, it was found that the patient was a 64-year-old female admitted urgently on a Friday to the internal medicine department. Because her ailment turned out to be benign, she was sent home within one day to her own home.

The second outlier is observation number 123. In this case the patient was a 78-year-old male admitted urgently to the pulmonary department. Because of his age and the severity of his ailment, he had to be discharged to a nursing home, which took time to arrange. While social services were looking for a suitable nursing home, he was left in the care of the PD. Hence his stay ended up being 38 days.

## DATA TRANSFORMATION

Above, we suggested that the distribution of the length of stay data may be slightly skewed. To get a better feel for this, in Figure 3 we have made a dot plot of all 146 cases. We now see clearly that the distribution is skewed to the right. To a seasoned data analyst's eye, this should not be surprising; waiting times tend to be skewed to the right. This skewness can often be remedied by using a data transformation; see Box et al. (2005). For example, a log transformation will frequently help make waiting time data look more normally distributed. However, to verify this hunch, in Figure 4 we have provided a lognormal probability plot. From this plot we see again that observation number 94 is an outlier. As suspected, the rest of the distribution seems to be approximated well by a lognormal distribution. In other words, if we transform the data by taking the natural log of the length of stay data then the transformed data will appear to be approximately normally distributed. In the analysis below, we will take the natural logarithm of the data before using methods that assume approximately normal data

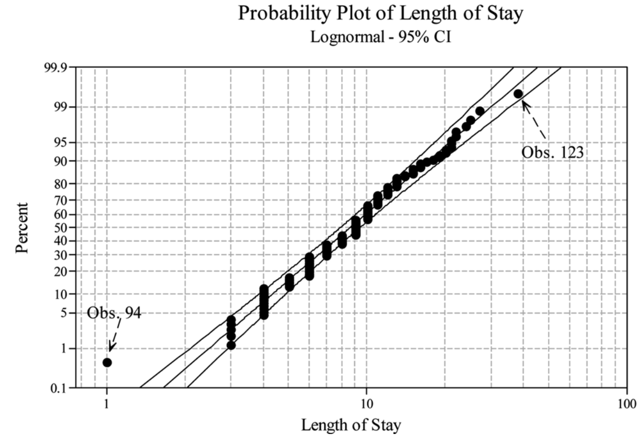


**FIGURE 4** **Lognormal probability plot of the length of stay data.**

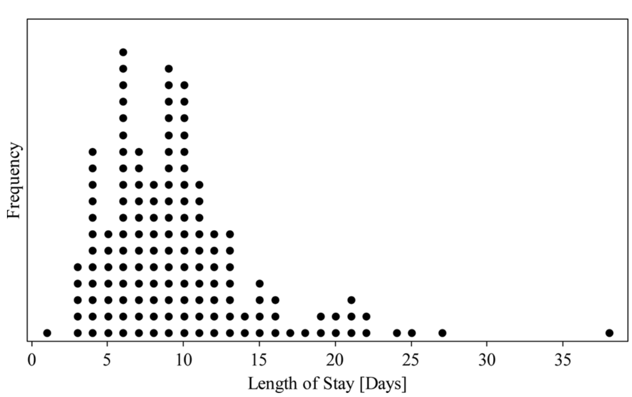


**FIGURE 3** **Dot plot of the length of stay for the COPD patients.**

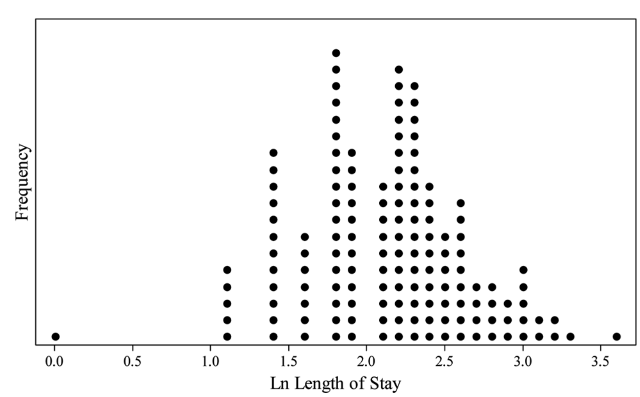


**FIGURE 5** **Dot plot of the natural log of the length of stay data.**

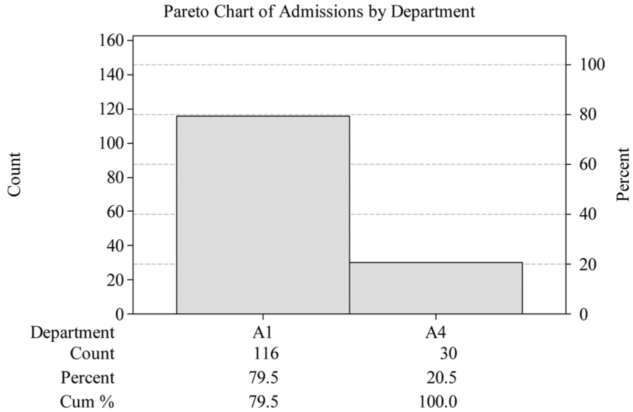


**FIGURE 6** **Pareto chart of patients admitted to the pulmonary department (A1) and the internal medicine department (A4).**

such as the analysis of variance (ANOVA). For comparison, in Figure 5 we show a dot plot of the log transformed length of stay data. We see that, except for the outliers, the distribution now looks much more approximately normal and symmetric.

## PARETO ANALYSIS

Before analyzing the length of stay data, we provide a few examples of graphical analysis, some of which are not directly relevant to the primary objective of finding potential causes for the length of stay but nevertheless informative. Using a Pareto chart is a good way to get a feel for the information buried in data collected in a quality improvement study. For example, Figure 6 shows that about 80% of the COPD patients were admitted to the pulmonary department (coded as A1) and the remaining approximately 20% to the internal medicine department (coded as A4). If we stratify the admissions on planned versus urgent admissions as in Figure 7, we see that although the internal medicine department (A4) admitted fewer patients, the overwhelming number of those were urgent admissions. This confirms what we already knew; namely, that the IMD is an overflow department that admits COPD patients primarily when there is not enough bed capacity in the PD. Are those urgent patients more severely ill than the general patient population? If so, could that explain why they may stay longer? We will try to answer that question below.

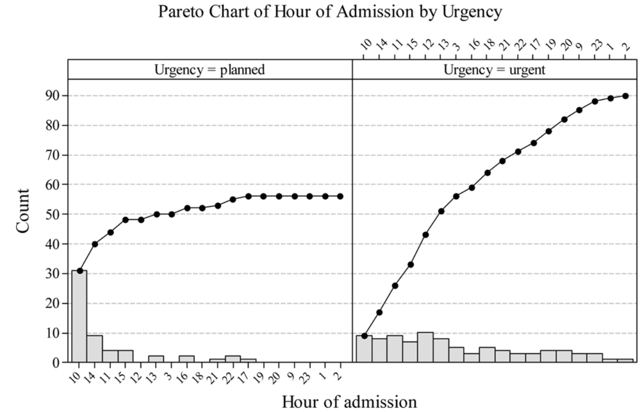


**FIGURE 8** **A Pareto chart of COPD patients by the hour of the day (military time) admitted to the Red Cross Hospital stratified on urgent versus planned admission.**

Figure 8 is a Pareto chart showing another interesting, but obvious, fact; namely, that planned admissions predominantly occur at 10 am, whereas urgent admissions occur at any time of the day, although somewhat less during the late-night hours. Like some of the other Pareto charts, this may not have a direct bearing on the issue of length of stay but is useful to know.

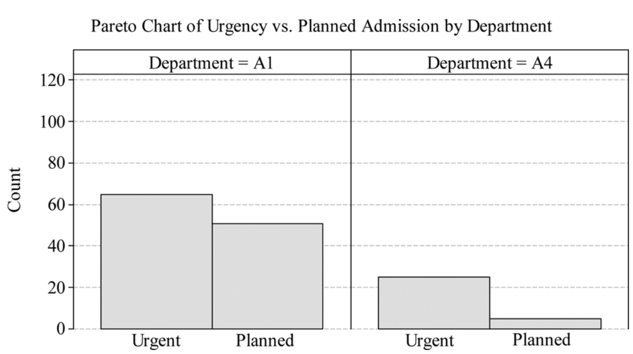


**FIGURE 7** **Pareto chart of patients admitted to the pulmonary department (A1) and the internal medicine department (A4) stratified on urgent versus planned admission.**

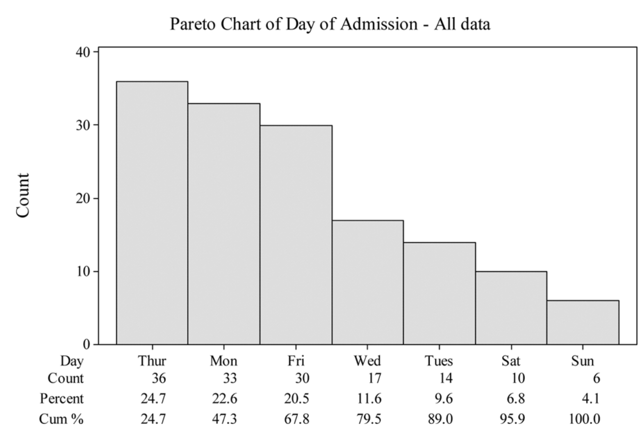


**FIGURE 9** **Pareto chart of COPD patients by the day of the week admitted to the Red Cross Hospital.**

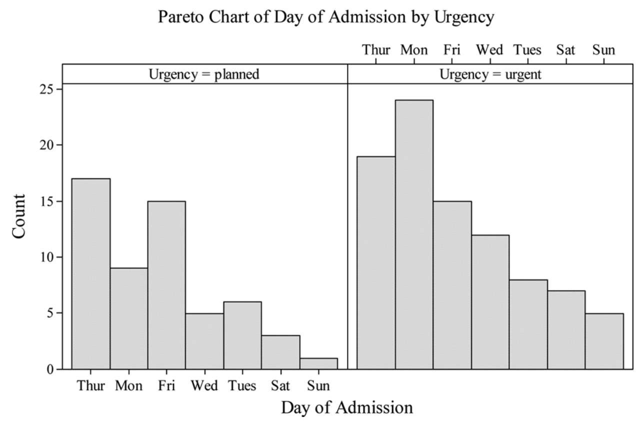


**FIGURE 10** **Pareto chart of COPD patients by the day admitted to the Red Cross Hospital stratified on planned versus urgent admissions.**

A further Pareto study with somewhat more bearing on the length-of-stay issue concerns the day of the week of admission. The Pareto chart in Figure 9 shows that COPD patients are most often admitted on Thursdays. However, a large number are also admitted on Mondays and Fridays. When we stratify on planned versus urgent admissions as in Figure 10, we see that planned admissions primarily occur on Thursdays and Fridays, whereas urgent admissions occur most frequently on Mondays. That urgent admissions occur most frequently on Mondays seems plausible. However, that scheduled admissions most frequently occur on Thursdays and Fridays, right before the approaching weekend, seems to point to possible poor planning. We also notice from Figure 10 that there were a few planned admissions on Saturdays and Sundays. Is this true or due to recording errors?

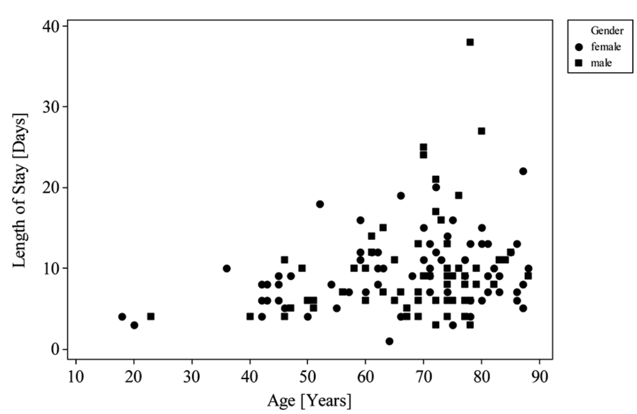


**FIGURE 11** **Scatterplot of length of stay versus patient's age stratified by gender.**

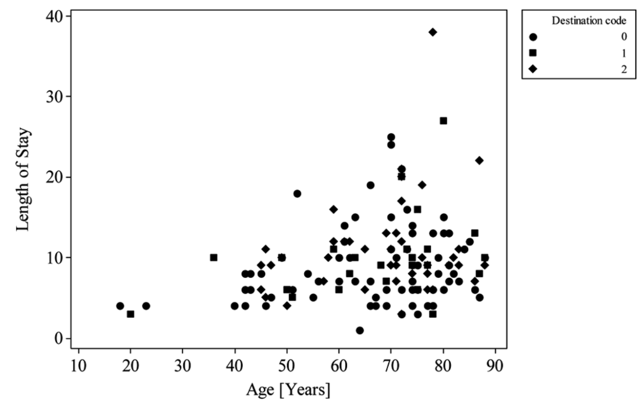


**FIGURE 12** **Scatterplot of length of stay versus patient's age stratified by discharge destination: 0 = Home, 1 = assisted living, 2 = other institution (including nursing homes).**

## OTHER INFORMATIVE PLOTS

Figure 11 shows a scatterplot of the length of stay versus the patient's age using different plotting symbols for gender. This plot illustrates the not surprising fact that older COPD patients in general tend to stay longer. However, to the naked eye, there does not seem to be a gender difference; we will test this more formally below. Figure 12 shows a similar scatterplot but stratified on the discharge destination. Code 0 indicates that the patient was discharged to his or her own home, code 1 that the patient was discharged to an assisted-living facility, and code 2 to another institution, including nursing homes. We see that, in general, younger patients tend to be discharged earlier and go back to their own homes. Older patients generally stay longer in the hospital and are more frequently discharged to assisted living, a nursing home, or another institution.

## ANALYSIS OF THE LENGTH OF STAY

We now turn to the study of length of stay. A useful tool for investigating whether there may be a potential causal relationship between certain (categorical) factors and a continuously varying output variable such as the length of stay is the one-way analysis of variance (ANOVA). ANOVA is a simple but powerful tool for quickly screening a large number of categorical factors for a potential relationship. Note that when we test the difference between only two groups, we could also use a *t*-test, which is essentially a special case of ANOVA with two groups; see Box et al. (2005, chs. 3 and 4).

**TABLE 2** Analysis of Variance Table (*a*) Based on all Data and (*b*) After Removing Two Outliers

| | Source | Deg. of freedom | Sum of squares | Mean squares | *F* -ratio | *P* |
|---|---|---|---|---|---|---|
| (*a*) All data | Department | 1 | 1.114 | 1.114 | 3.97 | 0.048 |
| | Error | 144 | 40.446 | 0.281 | | |
| | Total | 145 | 41.560 | | | |
| (*b*) Outliers removed | Department | 1 | 1.435 | 6.12 | 6.12 | 0.015 |
| | Error | 142 | 33.286 | 0.234 | | |
| | Total | 143 | 34.721 | | | |

Above we showed that if we take the natural logarithm of the length of stay, then the transformed data look approximately normal. Thus, it appears legitimate to use ANOVA. Below we will use ANOVA repeatedly, not only to check factors we believe may make a difference to the length of stay but also to eliminate factors that do not.

From the Six Sigma team's discussion of the cause-and-effect matrix, the factor primarily suspected of influencing the length of stay is the department. In other words, the team suspected that it made a difference if a COPD patient was admitted to either the pulmonary department or the internal medicine department. To analyze this issue we are confronted with the question of whether we should include the two outliers, observations number 94 and 123. In such situations, it is often wise to perform the analysis with and without the outliers. If the conclusion is the same either way, then there is little question about what to conclude. However, if the outliers significantly change the conclusion, then we need to think harder about what we ought to conclude.

Table 2 shows the ANOVA conducted on the full data set as well as with the two outliers removed. When including the outliers, the *p*-value is 0.048. According to conventional practice, the department is therefore (borderline) significant. However, if we remove the two outliers, then the *p*-value is 0.015 and the department clearly is significant. Moreover, the two residual checks without and with the outliers removed, respectively shown in Figures 13 and 14, indicate that the assumptions underlying the ANOVA are not seriously violated, especially in the latter case. In conjunction with the fact that we found that the two outliers were caused by circumstances that made them exceptional, we felt it safe to conclude that there indeed seems to be a difference in length of stay between the two departments. Not surprisingly, the

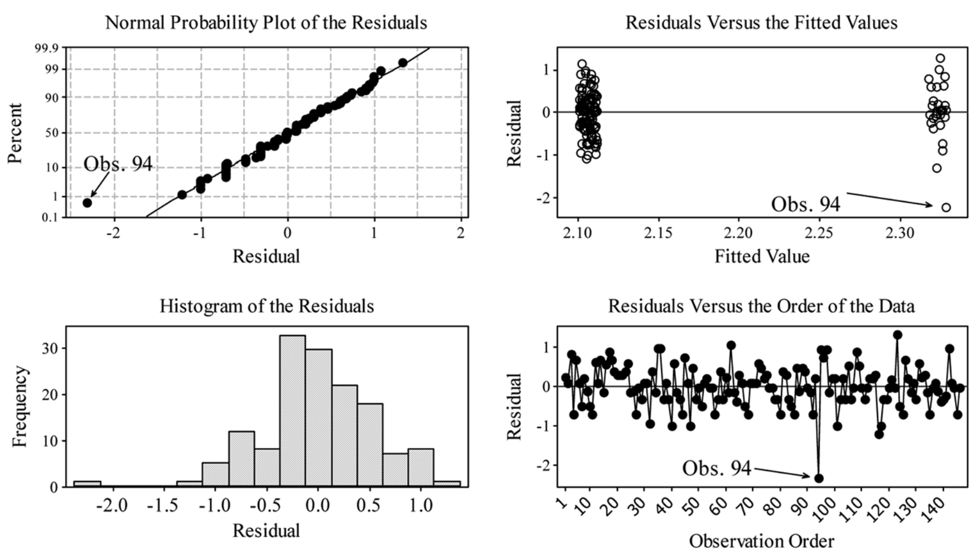


**FIGURE 13** Residual plot after performing a one-way ANOVA for a difference between departments using the full data set. Note that jitter has been added to the residuals versus fitted values plot.

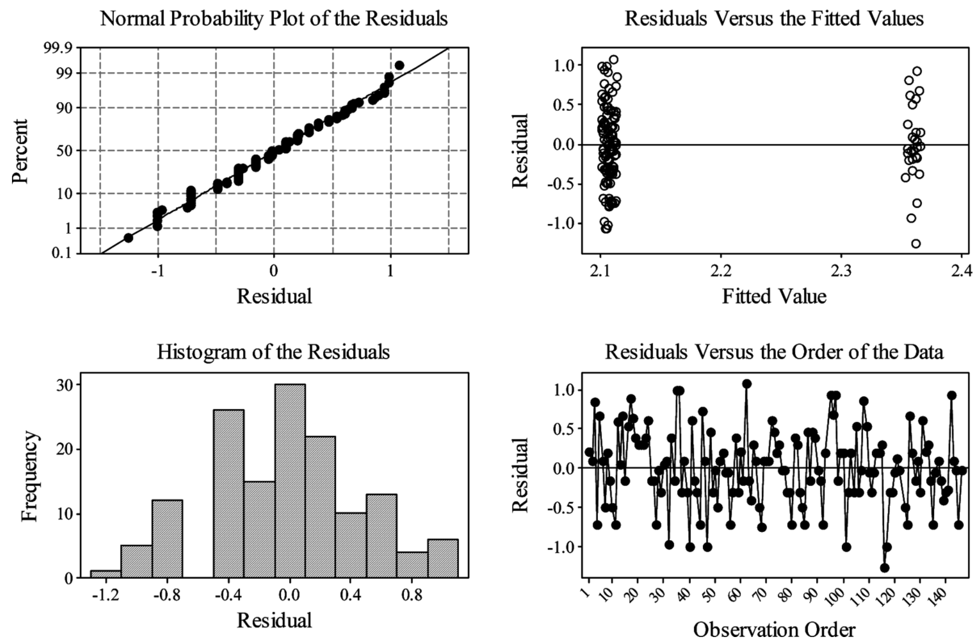


**FIGURE 14** **Residual plot after performing a one-way ANOVA for a difference between departments after removing two outliers. Note that jitter has been added to the residuals versus fitted values plot.**

pulmonary department appears to be better at treating COPD patients! Excluding the two outliers from the calculation and using the sample geometric mean as a measure of location (i.e., anti-logging the sample means of the log transformed data) the patients were discharged after 8.17 days from the PD and after 10.60 days from the IMD. In other words, there appears to be a difference of approximately 2.4 days.

As we mentioned above, now that we have detected a difference between the two departments, it is important to check whether there could be alternative explanations. As a screening tool we conducted a number of additional tests using ANOVA. For example, could there be a gender difference in the length of stay? Although the box plot in Figure 15 indicates a small gender difference, we see from the ANOVA summarized in Table 3 that the difference is not large enough to be significant.

Above, we conjectured that perhaps the urgent patients were more seriously ill than those with planned admissions. Perhaps it took them longer to recover. Unfortunately, we do not have available any direct measure of the severity of the illness. However, as a surrogate we can conduct a two-way analysis of variance to see whether the factors "department" and "urgency" are significant and, in particular, if there was a significant interaction effect between the two. An interaction effect between department and urgency would be an indication that the difference in lengths of stay between patients admitted to the PD or the IMD depends on whether

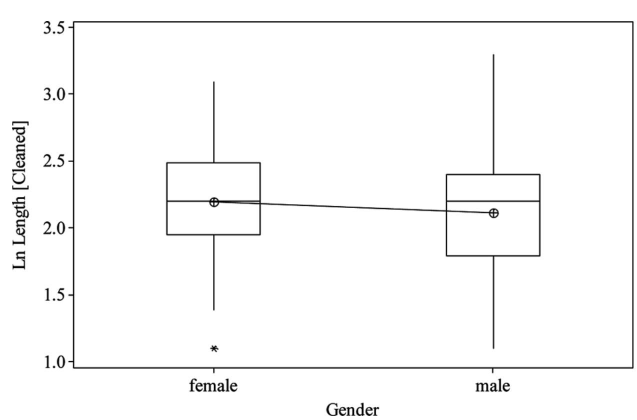


**FIGURE 15** **Box plot of the natural log of length of stay versus gender. The connecting line is between averages and the horizontal bar in the box is the median.**

**TABLE 3** **Analysis of Variance Table for Testing Gender Differences After Removing the Two Outliers**

| Source | Deg. of freedom | Sum of squares | Mean squares | *F*-ratio | *P* |
|---|---|---|---|---|---|
| Gender | 1 | 0.241 | 0.241 | 0.99 | 0.321 |
| Error | 142 | 34.480 | 0.243 | | |
| Total | 143 | 34.721 | | | |

**TABLE 4** Number of Cases of the Study in each of Four Categories

| Department | Planned | Urgent | All |
|---|---|---|---|
| Pulmonary (PD) | 51 | 65 | 116 |
| Internal medicine (IMD) | 5 | 25 | 30 |
| All | 56 | 90 | 146 |

the patient was admitted urgently and hence was possibly more severely ill or as a planned hospitalization and possibly less seriously ill.

As it turns out, the available data are not well suited for a two-way ANOVA. Table 4 shows the number of cases in each of the four combinations of two factors each at two levels. We see that unlike a designed experiment, this observational study is not well balanced, with only five observations in the category planned admission to the IMD. Therefore, a two-way analysis of variance will not be very reliable. Thus, we acknowledge that it may not have much validity. Nevertheless, we performed the two-way analysis for exploratory purposes. The ANOVA is summarized in Table 5. We see that neither urgency nor the interaction effect between department and urgency appeared to be significant. This is further indicated in the plot in Figure 16 showing the log of the length of stay versus department and urgency. The open circles with a cross symbol are the group averages. If the two (solid) lines connecting the averages between the urgent and planned admissions are parallel, then it provides a graphical indication that there does not seem to be any interaction effect between department and urgency. The graph seems to indicate that urgent patients, regardless of department, seem to stay for a slightly shorter time. However, as the ANOVA shows, the difference is not significant.

Another interesting issue is whether the day of admission matters. Since the length of stay is

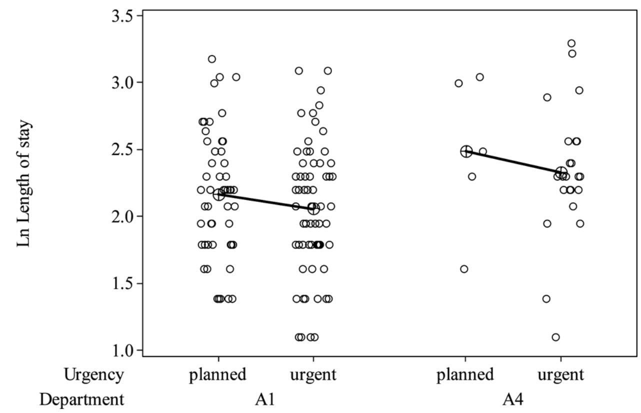


**FIGURE 16** A plot of the log of the length of stay versus department and urgency; A1 = pulmonary department and A4 = internal medicine department. The two solid lines connect the averages of the planned versus urgent groups for each department. Nonparallel lines would indicate a possible interaction effect.

approximately 8 to 10 days, it may be possible that some patients are discharged early because of the approaching weekend or end up staying two more days because of the weekend. We saw in the Pareto analysis above (Figure 10) that planned admissions predominantly occurred on Thursdays and urgent admissions happed most frequently on Mondays. Would an "average" patient admitted on a Thursday be discharged the following Friday or kept two more days and discharged the following Monday? In either case, the weekend might influence the discharge decision and therefore the length of stay.

This question is not easy to answer given the available data. We tried a variety of approaches. One was to use a one-way ANOVA of the log of the length of stay versus the day of the week. This analysis suggested that there might be a difference in length of stay depending on which day the patient is admitted. The pattern is shown graphically with a box plot in Figure 17; COPD patients admitted on Thursdays seem to stay the longest. However, there are few patients admitted over the weekend, making it

**TABLE 5** Analysis of Variance Table for Testing Department, Urgency, and Their Interaction; The Two Outliers Removed

| Source | Deg. of freedom | Sum of squares | Adjusted sum of squares | Adjusted mean squares | *F*-ratio | *P* |
|---|---|---|---|---|---|---|
| Department | 1 | 1.4347 | 1.2593 | 1.2593 | 5.37 | 0.022 |
| Urgency | 1 | 0.4360 | 0.2553 | 0.2553 | 1.09 | 0.299 |
| Depart × Urgency | 1 | 0.0081 | 0.0081 | 0.0081 | 0.03 | 0.853 |
| Error | 140 | 32.8423 | 32.8423 | 0.2446 | | |
| Total | 143 | 34.7211 | | | | |

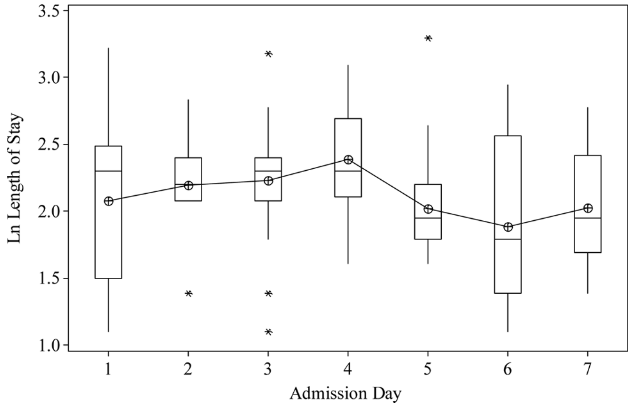


**FIGURE 17** **Box plot of log length of stay versus admission day: Mondays = 1, Tuesdays = 2, Wednesdays = 3, Thursdays = 4, Fridays = 5, Saturdays = 6, and Sundays = 7. Connected symbols are the group averages.**

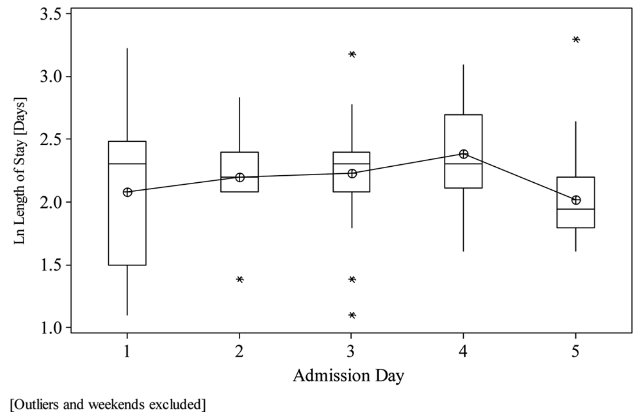


**FIGURE 18** **Box plot of the log of the length of stay by day in the week: Mondays = 1, Tuesdays = 2, Wednesdays = 3, Thursdays = 4, and Fridays = 5. Connected symbols are the group averages.**

questionable to include Saturdays and Sundays. Moreover, we know from above that there is a difference between the admission day pattern between planned and urgent admissions.

We therefore tentatively performed a three-way ANOVA with "department," "day of admission," and "urgency" as factors. We say "tentatively" because the data are very unbalanced, with few or no observations in some of the factor combinations. To make the analysis less questionable we eliminated all weekend admissions, a total of 18 cases. Although we are not entirely comfortable with this approach, discoveries made this way may be interesting. The ANOVA summary, which should be used only for exploratory purposes and not to draw conclusions, is shown in Table 6. We see that department is still significant and that the admission day might also influence the length of stay. However, urgency does not seem to make a difference. The influence of the admission day is illustrated with a box plot in Figure 18. We see that COPD patients admitted on Thursdays seem to end up staying slightly longer. This finding is puzzling. Is there a weekend effect? Why are planned admissions predominantly occurring on Thursdays?

## DISCUSSION

A number of additional analyses were performed. However, none yielded new discoveries. Therefore, it was concluded that the department was the factor that most significantly influenced the length of stay. It seems plausible that the pulmonary department is better at treating pulmonary patients! As we showed above, patients admitted to the internal medicine department tend to stay 2.4 days longer than those admitted to the pulmonary department. Based on this, it was decided not to further investigate what caused the difference between the departments but instead simply to rebalance the bed capacity so that it became possible for all COPD patients to be admitted to the pulmonary department.

**TABLE 6** **Analysis of Variance Table for Testing the Influence of Department, Admission Day, and Urgency After Removing Two Outliers and Weekend Admissions**

| Source | Deg. of freedom | Sequential sum of squares | Adjusted sum of squares | Adjusted mean squares | *F*-ratio | *P* |
|---|---|---|---|---|---|---|
| Department | 1 | 0.8033 | 0.8886 | 0.8886 | 4.19 | 0.043 |
| Admission day | 4 | 2.7198 | 2.6757 | 0.6689 | 3.15 | 0.017 |
| Urgency | 1 | 0.0728 | 0.0728 | 0.0728 | 0.34 | 0.559 |
| Error | 121 | 25.6600 | 25.6600 | 0.2121 | | |
| Total | 127 | 29.2559 | | | | |

After this change, in-patient days were saved and more admissions were possible. As a rough estimate, if a bed in a hospital costs about $500 per day and the length of stay on average is reduced by 2.4 days for a patient volume of say 30 patients per year (i.e., the number of patients admitted yearly to the internal medicine department) the annual savings is approximately $36,000. Moreover, any patient who can go home earlier is undoubtedly happier to do so and the hospital can treat more patients with 72 more bed days available per year. Except for the inevitable turf battles between departments over resources, this Lean Six Sigma project benefited everyone.

The exploratory ANOVA in Table 6 may suggest that perhaps the day of admission also had an influence. This and why the planned admissions predominantly occurred on Thursdays and Fridays close to the upcoming weekend were left for future studies to look into.

## CONCLUSION

To arrest the escalating costs of health care while improving quality will require a wide variety of concerted initiatives with input from the political, economical, scientific, and managerial realms. There are no simple solutions. For a broad-based discussion of health care problems and possible strategic solutions, see, e.g., Porter and Teisberg (2006). Nevertheless, and regardless of what will be decided politically, we can immediately start to deploy quality management principles to health care. Although health care obviously is different from industry, a hospital is an operation just like any other service operation and, in some aspects, not unlike a manufacturing facility. Many of the same principles for the elimination of waste and defects, perhaps with some minor modifications, also apply to health care.

When we recommend the use of quality management to health care we need to be careful about what we mean. Not all quality management approaches have been equally successful. Some versions of quality management focus on compliance with specific process standards. Compliance with process standards is a noble goal but does not necessarily lead to improved results. Indeed, bureaucratic activity-oriented approaches are sometimes very costly and inefficient. The general approach we advocate and illustrated above is focused acutely at achieving better results. Results-oriented approaches, and in particular Lean Six Sigma, have been shown to produce improved quality and at the same time reduced costs on both the clinical and the operational side of health care. This approach to quality benefited the patients, the health care providers, and the bottom line.

## ACKNOWLEDGMENTS

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## REFERENCES

Box, G. E. P., Hunter, J. S., Hunter, W. G. (2005). *Statistics for Experimenters*. New York: John Wiley & Sons.

George, M. L., Rowlands, D., Price, M., Maxey, J. (2005). *The Lean Six Sigma Pocket Toolbook*. New York: McGraw-Hill.

Juran, M. (1989). *Juran on Leadership for Quality*. New York: The Free Press.

Liker, J. K. (2004). *The Toyota Way*. New York: McGraw-Hill.

Porter, M. E., Teisberg, E. O. (2006). *Redefining Health Care: Creating Value-Based Competition on Results*. Boston: Harvard Business School Press.

Van den Heuvel, J. (2007). *The Effectiveness of ISO 9001 and Six Sigma in Health Care*. Alphen aan den Rijn, The Netherlands: Beaumont Quality Productions.

**TABLE A1** A Subset of the Data Used in the COPD Study

| No | L-St | Dprt | Gnd | Age | Urgy | AdD | AdH | Dch | Dist |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 13 | A4 | F | 78 | U | Mon | 15 | Sat | 0 |
| 2 | 9 | A1 | M | 70 | P | Thur | 10 | Fri | 2 |
| 3 | 19 | A1 | F | 66 | U | Mon | 12 | Fri | 0 |
| 4 | 4 | A1 | M | 69 | P | Sat | 22 | Wed | 0 |
| 5 | 16 | A1 | F | 59 | U | Wed | 15 | Thur | 2 |
| 6 | 9 | A1 | F | 47 | U | Mon | 14 | Tues | 2 |
| 7 | 5 | A1 | F | 87 | U | Fri | 22 | Wed | 0 |
| 8 | 10 | A1 | M | 79 | U | Mon | 18 | Wed | 0 |
| 9 | 9 | A4 | M | 74 | U | Mon | 22 | Wed | 1 |
| 10 | 5 | A1 | F | 55 | U | Thur | 22 | Tues | 0 |
| 11 | 4 | A1 | F | 50 | P | Tues | 10 | Fri | 2 |
| 12 | 19 | A4 | M | 76 | U | Sat | 18 | Wed | 2 |
| 13 | 11 | A4 | F | 77 | U | Wed | 11 | Sat | 1 |
| 14 | 16 | A1 | F | 75 | P | Sun | 22 | Tues | 1 |
| 15 | 7 | A1 | M | 63 | P | Sat | 15 | Fri | 0 |
| 16 | 18 | A4 | F | 52 | U | Mon | 19 | Thur | 0 |
| 17 | 20 | A1 | F | 72 | P | Thur | 10 | Tues | 2 |
| 18 | 20 | A4 | F | 72 | P | Thur | 10 | Tues | 1 |
| 19 | 12 | A1 | F | 72 | U | Thur | 10 | Mon | 2 |
| 20 | 11 | A1 | F | 73 | U | Wed | 14 | Sat | 0 |
| 21 | 11 | A1 | F | 73 | U | Wed | 14 | Sat | 1 |
| 22 | 11 | A1 | M | 83 | U | Tues | 14 | Fri | 2 |
| 23 | 12 | A1 | F | 62 | U | Mon | 14 | Fri | 2 |
| 24 | 15 | A1 | F | 70 | P | Thur | 14 | Thur | 0 |
| 25 | 7 | A1 | M | 66 | P | Fri | 10 | Thur | 0 |
| 26 | 9 | A4 | M | 75 | U | Fri | 14 | Sat | 0 |
| 27 | 4 | A1 | M | 74 | U | Sat | 23 | Wed | 0 |
| 28 | 8 | A1 | F | 62 | P | Wed | 11 | Wed | 1 |
| 29 | 6 | A1 | M | 74 | P | Fri | 10 | Wed | 0 |
| 30 | 11 | A4 | M | 84 | U | Mon | 20 | Fri | 0 |
| 31 | 9 | A1 | M | 88 | U | Tues | 16 | Wed | 2 |
| 32 | 4 | A4 | M | 77 | U | Mon | 21 | Fri | 0 |
| 33 | 12 | A1 | M | 85 | U | Fri | 20 | Wed | 0 |
| 34 | 7 | A1 | M | 69 | U | Fri | 10 | Thur | 1 |
| 35 | 22 | A1 | F | 87 | U | Thur | 12 | Thur | 2 |
| 36 | 22 | A1 | F | 87 | U | Thur | 12 | Thur | 2 |
| 37 | 6 | A1 | M | 50 | U | Mon | 11 | Sat | 1 |
| 38 | 9 | A1 | F | 83 | P | Fri | 10 | Sat | 2 |
| 39 | 6 | A1 | M | 78 | U | Fri | 15 | Wed | 0 |
| 40 | 3 | A1 | M | 78 | U | Mon | 17 | Wed | 1 |
| 41 | 15 | A1 | M | 63 | P | Wed | 14 | Wed | 0 |
| 42 | 7 | A1 | F | 71 | U | Fri | 11 | Thur | 2 |
| 43 | 6 | A1 | M | 60 | U | Fri | 11 | Wed | 1 |
| 44 | 4 | A1 | M | 40 | P | Tues | 21 | Sat | 0 |
| 45 | 17 | A1 | M | 72 | U | Tues | 11 | Thur | 2 |
| 46 | 9 | A1 | M | 71 | P | Tues | 10 | Wed | 2 |
| 47 | 3 | A1 | M | 72 | U | Mon | 11 | Wed | 0 |
| 48 | 13 | A1 | M | 69 | P | Fri | 10 | Wed | 2 |
| 49 | 6 | A1 | M | 69 | U | Sun | 23 | Sat | 0 |
| 50 | 8 | A1 | F | 45 | U | Tues | 13 | Tues | 0 |
| 51 | 5 | A1 | F | 46 | U | Mon | 10 | Fri | 2 |
| 52 | 9 | A1 | F | 77 | U | Wed | 12 | Thur | 1 |

(*Continued*)

TABLE 1 Continued

| No | L-St | Dprt | Gnd | Age | Urgy | AdD | AdH | Dch | Dist |
|---|---|---|---|---|---|---|---|---|---|
| 53 | 10 | A1 | M | 49 | U | Thur | 3 | Sat | 2 |
| 54 | 10 | A4 | M | 49 | U | Thur | 3 | Sat | 1 |
| 55 | 10 | A4 | M | 49 | U | Thur | 3 | Sat | 0 |
| 56 | 4 | A1 | M | 46 | U | Sat | 21 | Wed | 0 |
| 57 | 6 | A1 | F | 78 | U | Thur | 3 | Tues | 2 |
| 58 | 12 | A1 | F | 61 | P | Mon | 14 | Fri | 2 |
| 59 | 6 | A1 | F | 45 | U | Fri | 14 | Wed | 2 |
| 60 | 13 | A4 | F | 81 | U | Thur | 12 | Tues | 0 |
| 61 | 7 | A1 | F | 83 | U | Thur | 13 | Wed | 0 |
| 62 | 24 | A1 | M | 70 | P | Wed | 10 | Fri | 0 |
| 63 | 7 | A1 | F | 74 | P | Fri | 10 | Thur | 0 |
| 64 | 7 | A4 | F | 57 | U | Fri | 11 | Thur | 2 |
| 65 | 11 | A1 | F | 70 | U | Wed | 13 | Sat | 2 |
| 66 | 9 | A1 | M | 77 | P | Thur | 10 | Fri | 2 |
| 67 | 5 | A1 | M | 47 | P | Fri | 10 | Tues | 0 |
| 68 | 5 | A4 | M | 47 | P | Fri | 10 | Tues | 0 |
| 69 | 9 | A1 | F | 81 | P | Thur | 10 | Fri | 0 |
| 70 | 9 | A1 | F | 81 | P | Thur | 10 | Fri | 2 |
| 71 | 9 | A1 | F | 68 | P | Thur | 10 | Fri | 1 |
| 72 | 15 | A1 | F | 80 | P | Tues | 13 | Tues | 0 |
| 73 | 13 | A1 | F | 80 | P | Sat | 16 | Thur | 0 |
| 74 | 10 | A1 | F | 36 | P | Wed | 10 | Fri | 1 |
| 75 | 11 | A1 | M | 46 | P | Tues | 10 | Fri | 2 |
| 76 | 8 | A1 | M | 79 | U | Fri | 16 | Fri | 0 |
| 77 | 8 | A1 | F | 42 | P | Fri | 14 | Fri | 0 |
| 78 | 6 | A1 | F | 42 | U | Thur | 15 | Tues | 0 |
| 79 | 6 | A1 | F | 43 | U | Thur | 10 | Tues | 0 |
| 80 | 4 | A1 | F | 42 | U | Mon | 13 | Thur | 0 |
| 81 | 12 | A1 | F | 59 | U | Mon | 9 | Fri | 2 |
| 82 | 11 | A1 | F | 59 | P | Thur | 10 | Sun | 1 |
| 83 | 6 | A1 | M | 51 | P | Fri | 10 | Wed | 0 |
| 84 | 5 | A1 | M | 51 | P | Fri | 14 | Tues | 1 |
| 85 | 4 | A1 | F | 18 | P | Mon | 16 | Thur | 0 |
| 86 | 13 | A1 | M | 74 | U | Mon | 19 | Sat | 0 |
| 87 | 9 | A4 | F | 45 | U | Thur | 15 | Fri | 2 |
| 88 | 13 | A1 | F | 86 | P | Thur | 10 | Tues | 1 |
| 89 | 12 | A1 | F | 85 | P | Mon | 15 | Fri | 0 |
| 90 | 8 | A1 | F | 87 | P | Thur | 10 | Thur | 1 |
| 91 | 7 | A1 | F | 86 | U | Fri | 13 | Thur | 2 |
| 92 | 4 | A1 | M | 23 | U | Mon | 11 | Thur | 0 |
| 93 | 10 | A1 | F | 82 | P | Thur | 13 | Sat | 2 |
| 94 | 1 | A4 | F | 64 | U | Fri | 16 | Fri | 0 |
| 95 | 21 | A1 | M | 72 | P | Thur | 11 | Wed | 2 |
| 96 | 21 | A4 | M | 72 | P | Thur | 11 | Wed | 2 |
| 97 | 21 | A1 | M | 72 | P | Thur | 11 | Wed | 0 |
| 98 | 7 | A1 | F | 60 | U | Sun | 10 | Sat | 0 |
| 99 | 10 | A1 | F | 88 | U | Thur | 12 | Sat | 1 |
| 100 | 10 | A1 | F | 88 | U | Thur | 12 | Sat | 0 |
| 101 | 3 | A1 | M | 72 | U | Mon | 12 | Wed | 2 |
| 102 | 6 | A1 | M | 77 | P | Fri | 17 | Wed | 2 |
| 103 | 10 | A1 | M | 60 | U | Mon | 2 | Wed | 0 |
| 104 | 6 | A1 | F | 80 | U | Sat | 10 | Thur | 0 |

(*Continued*)

TABLE 1 Continued

| No | L-St | Dprt | Gnd | Age | Urgy | AdD | AdH | Dch | Dist |
|---|---|---|---|---|---|---|---|---|---|
| 105 | 14 | A1 | F | 74 | U | Thur | 18 | Wed | 0 |
| 106 | 6 | A1 | M | 65 | U | Wed | 19 | Mon | 2 |
| 107 | 8 | A1 | M | 74 | U | Wed | 10 | Wed | 2 |
| 108 | 25 | A4 | M | 70 | U | Mon | 13 | Thur | 0 |
| 109 | 14 | A1 | M | 61 | P | Fri | 10 | Thur | 0 |
| 110 | 10 | A4 | F | 63 | U | Mon | 21 | Thur | 1 |
| 111 | 6 | A1 | F | 86 | P | Fri | 14 | Wed | 0 |
| 112 | 10 | A4 | F | 62 | U | Mon | 18 | Wed | 0 |
| 113 | 10 | A1 | F | 62 | U | Mon | 18 | Wed | 0 |
| 114 | 10 | A1 | M | 76 | U | Sun | 12 | Tues | 2 |
| 115 | 11 | A1 | M | 65 | P | Tues | 10 | Fri | 2 |
| 116 | 3 | A4 | F | 75 | U | Wed | 19 | Fri | 0 |
| 117 | 3 | A1 | F | 20 | U | Sat | 21 | Tues | 1 |
| 118 | 6 | A1 | M | 75 | P | Mon | 10 | Sat | 0 |
| 119 | 6 | A1 | F | 80 | P | Mon | 10 | Sat | 0 |
| 120 | 10 | A4 | M | 58 | U | Tues | 17 | Thur | 2 |
| 121 | 12 | A4 | M | 61 | P | Thur | 15 | Mon | 0 |
| 122 | 8 | A1 | M | 77 | U | Fri | 15 | Fri | 2 |
| 123 | 38 | A4 | M | 78 | U | Tues | 20 | Fri | 2 |
| 124 | 5 | A1 | M | 67 | P | Mon | 10 | Fri | 0 |
| 125 | 4 | A1 | M | 67 | U | Wed | 3 | Sat | 0 |
| 126 | 16 | A1 | M | 73 | U | Thur | 10 | Fri | 0 |
| 127 | 10 | A1 | M | 74 | P | Mon | 10 | Wed | 1 |
| 128 | 7 | A1 | M | 56 | U | Thur | 11 | Wed | 0 |
| 129 | 9 | A1 | M | 74 | P | Fri | 10 | Sat | 0 |
| 130 | 6 | A1 | M | 75 | U | Sat | 13 | Thur | 1 |
| 131 | 15 | A1 | F | 70 | U | Mon | 9 | Mon | 0 |
| 132 | 13 | A4 | F | 71 | U | Sat | 15 | Thur | 2 |
| 133 | 11 | A1 | F | 70 | U | Wed | 10 | Sat | 0 |
| 134 | 7 | A1 | F | 71 | P | Thur | 14 | Wed | 2 |
| 135 | 4 | A1 | F | 78 | P | Mon | 14 | Thur | 0 |
| 136 | 10 | A4 | F | 71 | P | Mon | 15 | Wed | 0 |
| 137 | 9 | A1 | F | 71 | U | Tues | 13 | Wed | 2 |
| 138 | 9 | A4 | F | 81 | U | Wed | 23 | Fri | 0 |
| 139 | 7 | A4 | F | 81 | U | Sun | 20 | Sun | 0 |
| 140 | 6 | A1 | M | 72 | P | Fri | 10 | Wed | 0 |
| 141 | 8 | A4 | F | 54 | U | Tues | 9 | Tues | 0 |
| 142 | 27 | A4 | M | 80 | U | Fri | 17 | Wed | 1 |
| 143 | 9 | A1 | F | 81 | U | Fri | 14 | Sat | 2 |
| 144 | 8 | A1 | M | 82 | U | Thur | 12 | Thur | 0 |
| 145 | 4 | A1 | F | 66 | U | Sun | 1 | Wed | 0 |
| 146 | 8 | A1 | F | 43 | P | Wed | 14 | Wed | 0 |