A structured approach to shift scheduling in the emergency department: Implementation of simple statistical methods to evaluate physician workload

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Abstract

Introduction: The University of Alberta hospital emergency department provides care for approximately 150 adult patients each day. Emergency physician consists of seven shift of eight hours each. Informal observation suggests that the patient volume appears to be unequally distributed among the shifts, with certain shifts being routinely over-worked while others and under-worked. A statistical analysis of the patient volume seen during each shift may allow a more rational approach to shift scheduling.

Hypothesis: The null hypothesis of equal patient volumes for each shift was tested against the alternative hypothesis of inequality of patient volumes.

Methods: Patient volume for forty-nine consecutive shifts was obtained by direct observation from the computer tracking system. Differences in patient volume between each of the seven shifts was compared using Analysis of Means (ANOM). Possible cofactors including daily patient volume, average triage score and operator, were assessed using ANOM and Analysis of Variance(ANOVA).

Results: Mean patient volume per shift was 18.8 (SD=7.5). ANOM revealed a significant difference between shifts with a large range between the highest and lowest volume shift (10.9 – 29.4). Three shifts were consistently below mean patient volume, and two consistently above. Patient daily volume and average triage score were not shown to be significant using ANOVA. Unfortunately, it was difficult to separate operator effect from the shift effect due to the small sample size and large number of operators. Simple statistical functions for analysis of patient volume are presented.

Conclusions: The null hypothesis of equivalent patient volumes between shifts was rejected, as some shifts clearly performed above the mean and others below. A suggestion for an alternative shift pattern was described, which should be implemented on a trial basis and the study methods repeated. Further studies are likely to be indicated to further characterize the effect of average triage score and operator. Future replication of the study methods at other sites is suggested.

Purpose

To evaluate – using simple statistical methods -- patient volume seen by Emergency Physicians at the University of Alberta Hospital and suggest possible shift changes.   A secondary goal of the study was to produce a reusable set of statistical functions to allow other investigators to replicate the same study at other sites.

Introduction

The University of Alberta Hospital Emergency Department attends to approximately 150 adult patients each day. At present, Emergency Physicians are scheduled for 8 hour shifts (7 shifts per day). Generally, physicians work at their fullest capacity as dictated by patient flow for the first 5 – 6 hours of their shifts, at which point the next shift starts --- effectively their is an overlap of 2-3 hours at each shift change. Because of the unpredictable nature of patient flow and injury severity, the volume of patients seen by a single physician can vary between 5 to 40. At slower times, physicians are often sitting idle in their office, awaiting further patients to assess, while at busy time, patients may wait several hours before the physician is available. Ideal patient volume per emergency physician has not been established, however a recent large Canadian study counted 11716 patients in 592 eight hour shifts (mean=19.8 patients/shift). (Dryer et al, 2009). Ancedotely, physicians at the University of Alberta Hospital emergency department appear to usually prefer patient volumes of between 15 and 20 patients per eight hour shift. Clearly, it appears that at the University of Alberta Hospital Emergency Physicians are occasionally overworked, and at other times their productivity is under-utilized.

Shifts are further subdivided into subgroups. Shifts beginning at 0600, 1200, and 1800 are “A-Pod” shifts, where physicians are primarily responsible for the more acute patients. Shifts beginning at 0900, 1400, and 1900 are “C-Pod” shifts, where physicians are primarily responsible for the less acute patients (Table 1). The shift beginning at midnight is responsible for the entire emergency department. Patients are sorted into five categories, triage codes 1 – 5 based on the Canadian Triage and Acuity Score (CTAS) based on illness acuity, with CTAS 1 being the most acutely ill. (Bullard et. al, 2008)

Anecdotal evidence suggests that volume of patients seen on particular shifts is not equivalent. Some physicians clearly perceive certain shifts as consistently too busy, and others as too slow. Although the volume of patients may be related to triage codes – assuming that higher acuity patients require more physician time – this has not been evaluated. Conversely, many physicians feel that the daily patient volume is entirely random and that no changes to the shift schedule could compensate for this randomness.

The null hypothesis of equal patient volumes for each of the shifts was tested against the alternative hypothesis that patient volume between shifts was unequal.

Methods

Initial data acquisition took place in the Emergency Department. A research assistant gathered data using the computer printout which listed the patients – by name – seen by each physician on shift for that day. Although the actual printouts cannot be reproduced due to patient confidentiality, a copy of a sample data collection tally sheet has been reproduced (Figure 1). On the tally sheet the research assistant collected data including, date, practitioner initials, shift start time, shift type, and number of patients seen in each of the five triage categories. The research assistant was a third medical resident in emergency medicine, and was familiar with the computer patient tracking system and the workings of the emergency department. Data was collected for forty-nine consecutive shifts (seven shifts daily for one week).

Data were entered into a MySQL (SUN Microsystems, Santa Clara, CA) using the Navicat (PremiumSoft, Hong Kong) graphical front-end by the same research assistant. Statistical calculation were performed on the statistical package R (R Foundation for Statistical Computing, Vienna, Austria) on the SUSE 11.3 Linux operating system. R functions for interpretation were developed by the author. In hope that other investigators will replicate the same study protocol at other sites, R functions are reproduced in the appendix and also available as a download on the author's website at *www.disastermed.ca.*

Control charts were constructed with control limit at 3σ above and below the mean unless otherwise specified. Analysis of means was performed using α=0.05 unless otherwise specified. Range charts were prepared using an upper control limit of $D_4\bar{R}$ and a lower control limit of $D_3\bar{R}$. P-values of less than 0.05 were considered significant for all statistical tests.

Results

Data from a single week (7 days) was obtained. All data for each of the 49 shifts was available, and no data appeared to be missing. Mean volume per shift was 18.8 patients, with a standard deviation of 7.5.

Total volume of patients per shift were plotted on a control chart with limits of 3σ using the R function `run.chart()` (Figure 2). The median patient volume was 17, and the control chart reveals 34 runs about the mean. The observed 34 runs is well above the expected (26) and above the upper limit at significance of $\alpha=0.01$. (Swed and Eisenhart, 1943). As the control chart clearly indicated that the process was not in statistical control, further analysis was indicated.

The apparent cyclical nature of the control chart is apparent at first glance, and the cycle appears to form a daily peak, suggesting that certain shifts are much higher than the mean on a daily basis. To further illustrate and clarify the apparent discrepancy between shifts, an analysis of means(ANOM) was performed on the shift type using the R function `anom.variables()` (Figure 3). The number of patients seen on S19(mean=29.4) and S24 (mean=25.8) are far above the upper control limit. Conversely, the number of patients seen on shift S06(mean=12.4), S12(mean=10.9), and S18(mean=13.4) are below the lower control limit.

A range chart was constructed using the `range.chart()` function by grouping the data into seven groups (each representing one shift). All ranges appear to be with the 3σ control limits with a maximum range of 17 and a minimum of 5 (Figure 4).

Patient daily volume throughout the study cycle appeared relatively stable with a mean of 131.9, a maximum of 142, and minimum of 120 (Figure 5).

Patient volume was plotted against average triage score (Figure 6) for each shift to assess the influence of CTAS score on patient volume. A trend line was drawn using the built-in linear regression function in R with a slope of 10.0 and intercept of -10.6. Mean CTAS overall was 2.9.

Analysis of influence of operators was more difficult. Since the study design was not balanced, and many operators worked only a small quantity of shifts (range 1-5 shifts), ANOM analysis was not appropriate. To assess for confounding variables, a control chart was performed for the mean number of patients seen by operator. Although the upper and lower control limits are only approximate as the number of shifts per operator varied, the control chart does clearly reveal a large range of mean patients per shift (maximum=27, minimum=11) (Figure 7).

An ANOVA analysis performed using the four factors of date, shift, operator, and CTAS (Table 2). The ANOVA confirmed the significance of the shift and operator terms and showed the lack of significance of day and average CTAS.

Discussion

Clearly the control chart of Figure CC indicates that patient distribution among the emergency department shifts at the University of Alberta Hospital is not in statistical control. The wide range of patient volumes indicate lack of control. Moreover, the cyclical pattern of patient volume suggests that an assignable cause may be present.

The ANOM figure clearly suggests that the shift start-time is closely associated with patient volume. Clearly the average patient volumes differ significantly between the different shifts. Moreover, the data support that the S9 and S14 shift workload appear to be very near the 19.8 patients/shift as found in the POWER study (Dryer et al, 2009).

Importantly, the data are able to lend doubt to many myths that seem to be perpetuated by emergency department staff. Firstly, mean patient load in the sample (19.8) matches closely to patient volumes in the POWER study, and is consistent with what emergency physicians intuitively interpret as acceptable. This supports the assumption that the volume of patients does not mandate introduction of more shifts, but rather redistribution of workload.

Secondly, the data does not appear to support the notion that patient volume varies greatly on a daily basis and thus limits ability to adequately schedule physician coverage. Rather, the data suggest that the patient volume per day remains very near the mean of approximately 132 patients. This is encouraging, as it suggests that the predictability of patient flow may allow for scheduling to reduce the statistical variation among shifts.

Unfortunately, there were several limitations inherent in the study design. Firstly, comparison of patient volumes to the previously published POWER study should also be interpreted with caution, as mean CTAS was higher in the POWER study(3.28) compared to the University of Alberta sample (2.9) (Dryer et al, 2009). Although the ANOVA did not suggest that average CTAS was a statistically significant factor in shift volume, the relationship between the shift time and the average CTAS appeared to be linear with the plot of patient volume vs average CTAS clearly reveals a trend to smaller patient volumes when mean CTAS is smaller. This confuses the analysis to some extent, as it is difficult to know how much additional time is needed to treat patients with a lower CTAS. Although intuitively, patients with lower CTAS have a more acute injury and should require more invasive emergency department care, to what extent this translates to the need for additional physician time to care for the patients is unclear. Assessment of this relationship between average CTAS and time needed for patient care would require a different study design to assess.

Since the study design was not balanced, it is difficult to separate the effect of shift from that of operator. This is partly due to the fact that there were many operators – twenty-two. In addition, the shifts were not randomly distributed between operators, as the emergency department schedule is not random, rather, operators are scheduled for a series of similarly timed shifts, such as a series of morning, afternoon, or evening shifts. Clearly what is needed is either a balance design, where operators are distributed equally among the shifts, or a much large study sample.

Finally, since emergency department patient care may involve a number of unpredictable factors, a much larger study over a larger time period is probably warranted.

Despite the limitations of the study, it seems reasonable to pursue a trial period of an alternate shift pattern. A shift pattern should be developed which adds additional manpower to assist the busiest shifts (S19 and S24), and decrease the amount of physician coverage during the slower shifts (S06, S12, and S18). One method may be to decrease the overlap on the shifts early in the day, and increase the overlap at the evening shifts. Furthermore, shifting the start times of the shifts may also give additional assistance to the busiest shifts. One possible arrangement for an alternate shift trial is presented in Table 3. During the trial period, data should be collected and the data should be re-analyzed to confirm improvement in patient distribution.

Conclusions

The study findings allow the rejection of the null hypothesis of no difference in patient volume between shifts. It is apparent that patient volume seen by physicians at the University of Alberta Hospital emergency department is not equally distributed between shifts. This does not seem to be accounted for by variations in patient acuity (CTAS) or daily volume. It is likely that this difference is due largely to the time scheduling of the shifts, although the operator effect may also be significant. Since present data does not appear to suggest the need for introduction of additional shifts,a trial of shift rearrangement with focus upon shift coverage during the evening and night hours is suggested.

References

Bullard MJ, Unger B, Spence J, Grafstein E and the CTAS National Working Group. Revisions to the Canadian emergency department triage and acuity scale (CTAS) adult guidelines. CJEM 2008;10:136-42.

Dryer JF, McLeod SL, Anderson CK, Carter MW, Zaric GS. Physician workload and the Canadian emergency department triage and acuity scale: the predictors of workload in the emergency room (POWER) study. CJEM 2009; 11:321-9.

Swed S and Eisenhart C. Tables for testing randomness of sampling in a sequence of alternatives. Ann Math Sci 1943; 14:66-87.

Table 1

Description of Shifts at The University of Alberta Hospital Emergency Department

Shift	Start Time	End Time	Pod Coverage
S06	0600h	1400h	Both (0600-0900) A (0900-1400)
S09	0900h	1700h	C
S12	1200h	2000h	A
S14	1400h	2200h	C
S18	1800h	0200h	A
S19	1900h	0300h	C
S24	0000h	0800h	Both

Figure 1

Sample Data Collection Form

Sheet1

OBS	Date	Initials	Time	Type	CTAS-1	CTAS-2	CTAS-3	CTAS-4	CTAS-5
1	1APR/10	SD	06-14	AB	1	3	7	2	3
2	"	BH	09-17	CD	Ø	4	7	4	3
3	"	AN	12-20	AB	Ø	3	4	Ø	Ø
4	"	RY	14-22	CD	Ø	3	10	2	2
5	"	AB	18-02	AB	Ø	8	7	Ø	Ø
6	"	KN	19-05	CD	Ø	7	16	10	Ø
7	"	KF	24-09	BOTH	Ø	6+2=8	10+6=16	3	1
8	2APR/10	SS	6-14	AB	1	3	5	Ø	Ø
9	"	SD	09-17	CD	Ø	3	12	3	2
10	"	AH	12-20	AB	1	7	2	2	Ø
11	"	AN	14-22	CD	Ø	Ø	16	15	1
12	"	KF	18-02	AB	2	8	5	Ø	Ø
13	"	AB	19-05	CD	Ø	2	13+2=15	9	1
14	"	KN	24-09	BOTH	1	1+4=5	4+5=9	2+3=5	2+1=3
15	3APR/10	RMcD	06-14	AB	Ø	6	4	2	Ø
16	"	JF	09-17	CD	Ø	Ø	10	4	1
17	"	DH	12-20	AB	Ø	6	5	1	Ø
18	"	AH	14-22	CD	Ø	2	9	4	Ø
19	"	RY	18-02	AB	1	5	3	Ø	Ø
20	"	AB	19-05	CD	Ø	6	15	9	Ø
21	"	KN	24-09	—	2	5+6=11	9	5	Ø
22	4APR/10	JF	06-14	AB	1	6	1	2	Ø
23	"	SS	09-17	CD	Ø	1	15	2	4
24	"	AH	12-20	AB	Ø	10	2	Ø	Ø
25	"	DH	14-22	CD	Ø	4	9	5	3
26	"	MI	18-02	AB	Ø	6	2	3	Ø
27	"	RY	19-05	CD	Ø	2	17	12	1
28	"	KN	24-09	—	1	9	12	1	3
29	5APR/10	JF	06-14	AB	Ø	6	4	5	Ø

Page 1

Figure 2

Patient Volume for Forty-Nine Consecutive Shifts

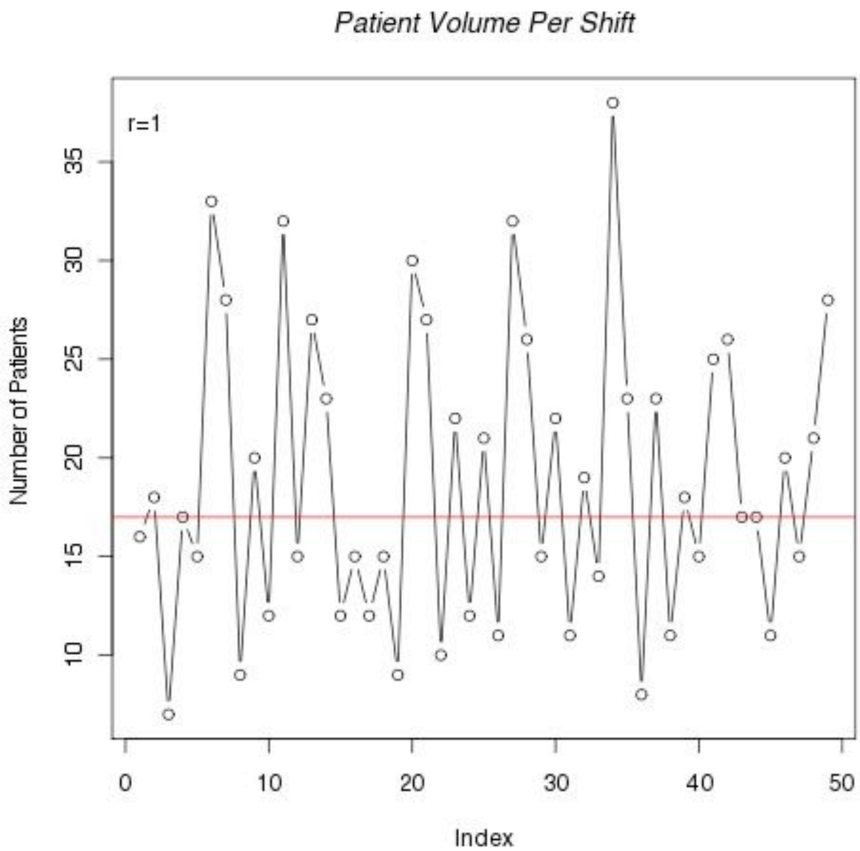

Figure 3

Analysis of Means for Patient Volume by Shift

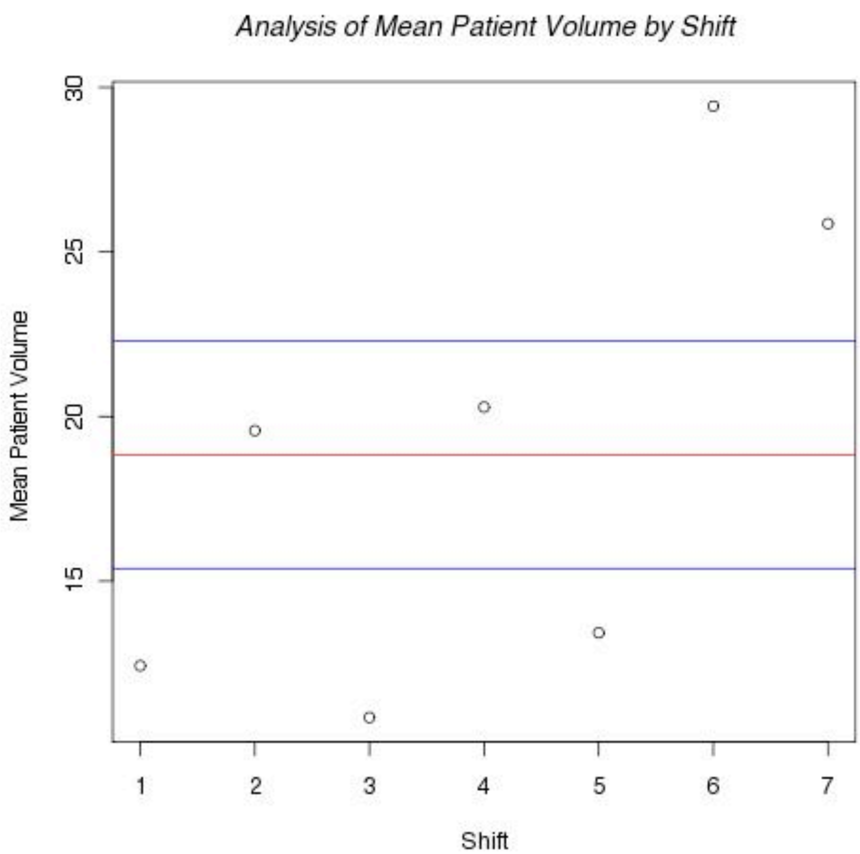

Figure 4

Range Chart for Each of Seven Shifts

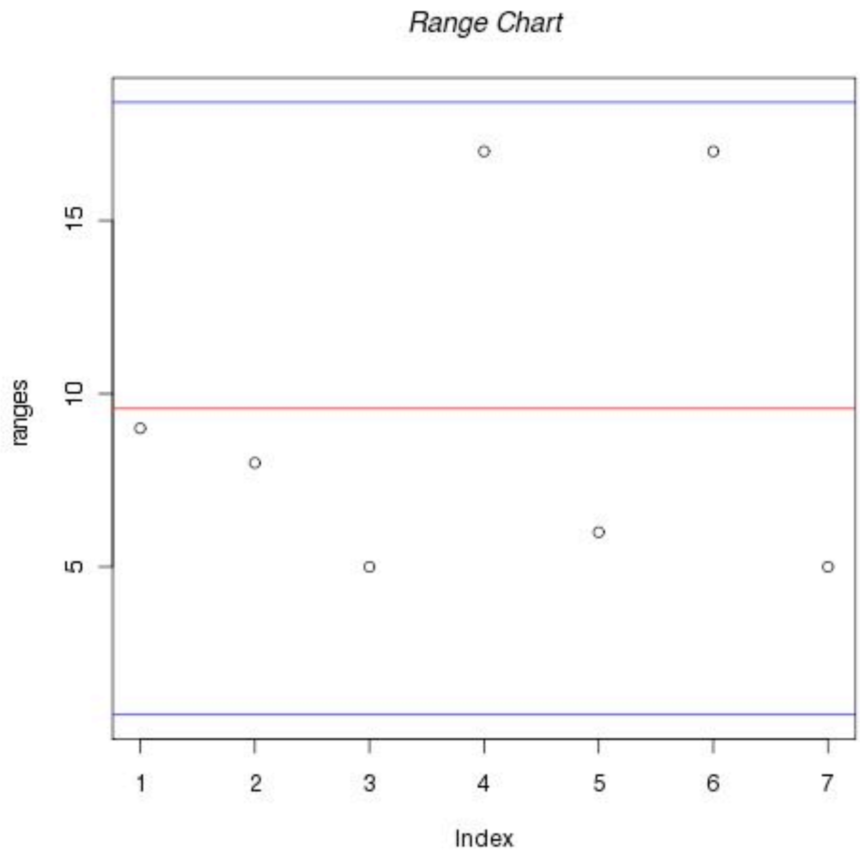

Figure 5

Analysis of Means for Patient Volume by Day

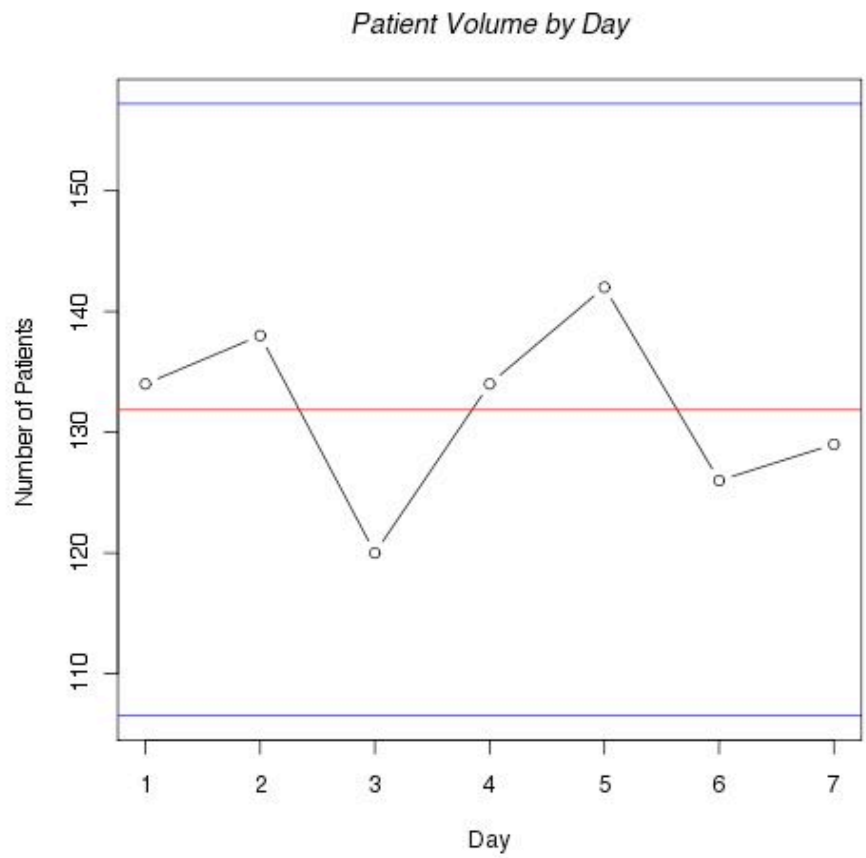

Figure 6

Patient Volume in Relationship to Mean CTAS

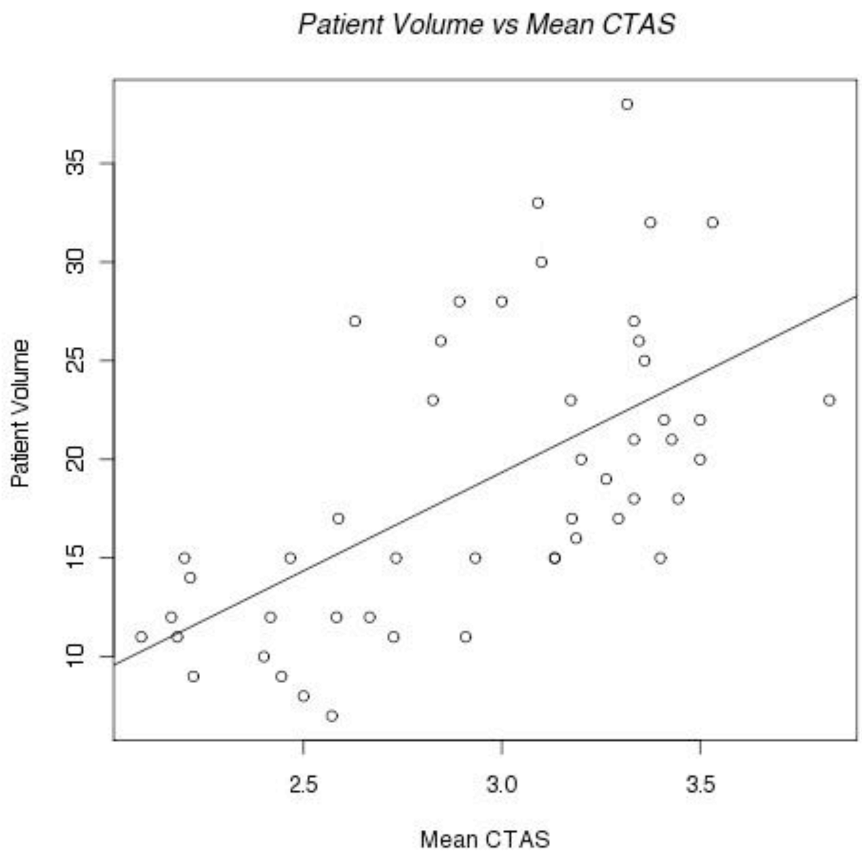

Figure 7

Patient Volume by Operator

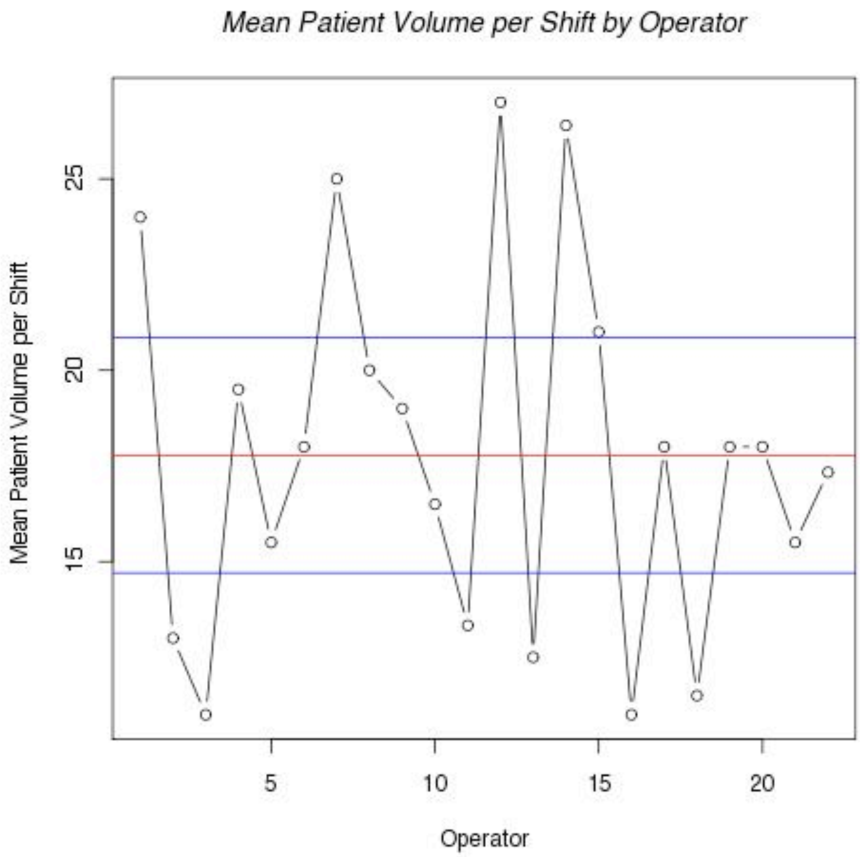

Table 2

Analysis of Variance

```
Response: total
          Df  Sum Sq Mean Sq F value    Pr(>F)    
date       6   47.55   7.925  0.5161 0.7867303    
operator  21 1500.84  71.468  4.6543 0.0024360 ** 
shift      6  903.24 150.540  9.8037 0.0002419 ***
avg.ctas   1    6.09   6.092  0.3967 0.5389394    
Residuals 14  214.98  15.355                      
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Table 3

Suggested Alternative Shift Schedule

Shift	Start Time	End Time	Pod Coverage
S04	0400h	1200h	Both (0400-1000) A (0900-1400)
S10	1000h	1800h	C
S11	1100h	1900h	A
S16	1600h	0000h	C
S18	1800h	0200h	A
S22	2200h	0600h	C
S24	0100h	0800h	Both

Appendix

R Functions for Analysis

```
control.chart<-function(x,sigma=3,main="Control
Chart",xlab='x',ylab='Index') {
    xbar<-mean(x);
    n<-length(x);
    s<-sd(x);
    lcl<-xbar-((s*sigma));
    ucl<-xbar+((s*sigma));

    maxx<-max(x);
    minx<-min(x);

    if (maxx>ucl) {
        upylim=maxx;
    } else {
        upylim=ucl;
    }

    if (minx<lcl) {
        downylim=minx;
    }else{
        downylim=lcl
    }


    plot(x,type='b',ylim=c(downylim,upylim),main=main,xlab=xlab,ylab=ylab);
    abline(h=xbar,col='red');
    abline(h=lcl,col='blue');
    abline(h=ucl,col='blue');
}


run.chart<-function(x,main="Run Chart",xlab='x',ylab='Index') {
    xmed<-median(x);

    plot(x,type='b',main=main,xlab=xlab,ylab=ylab);
    abline(h=xmed,col='red');
    return(xmed);

}
```

```
control.factors<-function(r,k,cf='A',df=0,alpha=0.05) {
```

```
    #r=subgroup size
    #cf= "Halpha" "d2star" "zalpha" "A"  "A2" "D1" "D2" "D3" "D4" "A3" "B3"
"B4" "d2" "c4"
    #k=number of samples
    #df=degrees of freedom.  Calculated from k and r for most values
    if(cf=='Halpha'){
        zzz<-read.csv('halpha05.csv');

        #calculate df if not given

        if(df==0) {
            df=0.9*k*(r-1);
            df=round(df);
        }

        if (df>120){
            df<-999;
        }else if (df>60) {
            df<-120;
        }else if(df>40) {
            df<-60;
        }else if (df>30) {
            df<-40;
        }else if (df>24) {
            df<-30;
        }else if (df>20) {
            df<-24;
        }else {
        }



        if(sum(zzz$df==df)){

            response<-zzz[zzz$df==df,k];
        }else{
            response<-NULL;
            print ("please specify df manually!! Calculated df does not
exist");

        }


    }else if(cf=='d2star'){
        zz<-read.table('d2star.txt',header=TRUE);
        zz<-as.numeric(zz[,1]);
        zz<-matrix(zz,nrow=15,byrow=TRUE);
        response<-zz[k,r-1];



    }else if (cf=='zalpha'){
```

```
        #note zalpha is the z factor for nonrandom uniformit
        prob<-alpha^(1/k);
        x<-0.5+prob/2;
        response<-qnorm(x);


    }else{
        #for most factors

        z<-read.table('control_factors.txt',header=TRUE);
        z<-z[,-1];
        response<-z[r-1,names(z)==cf];
    }




    return(response);

}


range.chart<-function(z) {

    k=length(z[1,]);
    r=length(z[,1]);
    n=k*r;

    ranges<-apply(z,2,range.num);
    means<-apply(z,2,mean,na.rm=TRUE);

    mean=mean(means);
    Rbar=mean(ranges)






    d2star<-control.factors(r=r,k=k,cf='d2star');

    sd<-Rbar/d2star;
    s<-sd/sqrt(r);


    D4<-control.factors(r=r,cf='D4');
    D3<-control.factors(r=r,cf='D3');

    UCL=D4*Rbar;
    LCL=D3*Rbar;

    #build the ANOM plot
     maxp<-max(ranges);
```

```
    minp<-min(ranges);

    if (maxp>UCL) {
        upylim=maxp;
    } else {
        upylim=UCL;
    }

    if (minp<LCL) {
        downylim=minp;
    }else{
        downylim=LCL
    }

     plot(ranges,ylim=c(downylim,upylim),main="Range Chart");
    abline(h=Rbar,col='red');
    abline(h=LCL,col='blue');
    abline(h=UCL,col='blue');



    return(list(UCL=UCL,LCL=LCL));




}

anom.variables<-function(z,main="ANOM",ylab="Values",xlab="Index") {
    #z=data frame with rows as observations columns as factors
    #r=subgroup size (calculate)
    #k=number of factors(calculated)


    k=length(z[1,]);
    r=length(z[,1]);
    n=k*r;

    ranges<-apply(z,2,range.num);
    means<-apply(z,2,mean,na.rm=TRUE);

    mean=mean(means);
    Rbar=mean(ranges);

    d2star<-control.factors(r=r,k=k,cf='d2star');

    sd<-Rbar/d2star;
    s<-sd/sqrt(r);

     Halpha<-control.factors(r=r,k=k,cf='Halpha');

     UCL=mean+Halpha*s;
     LCL=mean-Halpha*s;
```

```
    #build the ANOM plot
     maxp<-max(means);
    minp<-min(means);

    if (maxp>UCL) {
        upylim=maxp;
    } else {
        upylim=UCL;
    }

    if (minp<LCL) {
        downylim=minp;
    }else{
        downylim=LCL
    }


    plot(means,ylim=c(downylim,upylim),main=main,ylab=ylab,xlab=xlab);
    abline(h=mean,col='red');
    abline(h=LCL,col='blue');
    abline(h=UCL,col='blue');



return(list(k=k,r=r,ranges=ranges,means=means,mean=mean,Rbar=Rbar,sd=sd,s=s
,Halpha=Halpha,UCL=UCL,LCL=LCL));

}


range.num<-function(x) {
    #returns the range as a single number
    max.x<-max(x,na.rm=TRUE);
    min.x<-min(x,na.rm=TRUE);
    range.x<-max.x-min.x;
    return(range.x);
}
```