Monitoring performance of road safety programs – application of control charts

Jagadish Guria
Land Transport Safety Authority

Kelly Mara
Consultant Statistician

Abstract:

Road crashes are random events. While the number of crashes during a certain time period such as a month or a year indicates the level of risk on the road, it may fluctuate without any change in the actual underlying risk. If the number of crashes increases or decreases, it indicates one of two possibilities: (1) the risk has changed, (2) the difference is due to the stochastic nature of the event, i.e., it is due to a random fluctuation. A control chart system is developed in the paper to identify the occurrence of actual risk changes.

The paper discusses the development of control charts to monitor fatalities at the national level and the potential for applying the method to fatal and serious injuries at a district level

Safety programmes are developed to reduce the risk to a target level Drawing a trend line from the current road toll level to an appropriate value, the control chart method discussed in the paper will indicate the likelihood of the target being achieved.

Contact author:

Dr Jagadish Guria
Chief Economic Adviser
Land Transport Safety Authority
PO Box 2840
Wellington
NEW ZEALAND

Telephone: +64 4 494 8718
Email: jcg@ltsa.govt.nz

Fax: +64 4 494 8601

Introduction

Road crashes are random events. For a given level of risk on the road, the crash statistics may vary considerably. Such variations are often treated as variations in the actual risk. While this is a problem in interpreting the crash statistics, there are other implications. Most crashes are due to risks taken by road users. Police enforcement aims at improving road user behaviour, more specifically, driver behaviour on the road. If the actual risk of crashes has increased then additional resources will be required to reduce the expected road toll. Otherwise the road toll is likely to increase. Also while the average risk on the network may remain the same, it may increase in certain areas and decrease in some other areas. In that case, a re-allocation of resources should improve the overall productivity of enforcement resources and reduce the total risk. On the other hand, if road toll is high during a certain period of time in an area, it does not necessarily mean, the risk there has increased. And so a shift of resources to that area from somewhere else could reduce the overall productivity of the enforcement resources

The term risk is used in different contexts. Here we mean the probability of a crash or an injury during a period of time. The total number of road crashes or injuries is likely to increase if there is an increase in the risk of a crash per vehicle kilometre of travel or there is an increase in vehicle km or an increase in both.

While the risk per km of travel should be of concern to most road users, the total effect, i.e., the number of fatalities and number of injuries, is usually considered for planning and allocation of resources

Because of the random nature of crashes and consequent fatalities and injuries, it is not obvious from crash statistics if the programmes are producing the expected results.

This paper employs the control chart method to identify the risk changes as soon as practicable so that where feasible necessary improvements can be made on police enforcement either through an increase in the level of resources or through reallocation.

Control charts can be drawn either for number of crashes/injuries during a period or social costs of crashes. These can also be used as performance monitoring tools. For a specific programme, such as drink driving or speeding, the expected trend line and the expected natural variation around it can be determined. The actual occurrence of crashes can then be compared against these limits

Road toll targets are developed through a combination of statistical analysis, including international comparison and a strong desire to improve road safety. Safety programmes are then developed to achieve the target values. This approach will not assess the feasibility of meeting the target with a given level of resources and its application. However, it will indicate within a few months, whether or not the crash trend differs from the trend required to reach the target. In terms of social cost, the loss of life has maximum impact on the society. Therefore, while targets can be set on number of

crashes, road tolls or number of injuries etc. usually maximum attention is given on road toll targets

The targets can be set either to mean the expected number of fatalities or the maximum number of fatalities If it is the maximum, then the programmes should be developed to achieve a lower expected level of road toll.

A monitoring tool

The control charts discussed in the paper are aimed at monitoring the achievability of the set target If at any time the charts indicate the risk to be higher than the expected risk it suggests that the target is unlikely to be achieved without further resources or resource re-allocation. The difference in risk from the expected risk could be due to several factors It could be due to:

- an increase in risky behaviour or
- more than expected increase in the level of travel or
- less than expected improvement on road infrastructure or
- less than expected effects of police enforcement and advertising programmes or
- a combination of all of these.

The control charts will not point out the reasons for diversion from the expected path. Once it indicates a diversion, the likely reasons need to be investigated The aim of this study is to develop tools for the Police to monitor road safety outcomes in New Zealand at each Police district The charts discussed here have begun that process by addressing the total fatalities at the national level This approach assumed that other factors would be as expected and improving the quality or quantity of police enforcement help achieve the target.

New Zealand is currently going through a roading reform Several studies have been carried out over the last few years investigating issues related to road pricing Last year the Government formed a Roading Advisory Group to look at the institutional structure that would be most appropriate The Group has produced a report (Roading Advisory Group, 1997) which recommends 4-6 roading companies covering the whole network in New Zealand who would operate commercially If established, these roading companies will in the future determine the appropriate price for road use by time and space, collect the revenue and invest on road network expansion, maintenance and safety quality according to their assessment of the demand The report also recommends that there should be a safety system for the roading companies to follow which will ensure the safety quality expected on their network. The Land Transport Safety Authority will have the responsibility to monitor and audit the roading companies on their safety performance. While the Roading Advisory Group is not Government policy, its recommendations for safety management provide a useful framework to consider the issues of safety monitoring

As far as the safety responsibility of roading companies is concerned it can vary from only the safety quality of the roading network to the total safety responsibility. In the later case, they would be able to allocate their resources including purchase of police enforcement optimally to achieve the agreed target under the safety system.

It is not our intention to discuss the pros and cons of various institutional structure in terms of their safety performance. This background is provided here to indicate the usefulness of this monitoring tool. The Land Transport Safety Authority will be able to use this to determine the likelihood of meeting the target and then take necessary action.

This paper discusses the control chart technique and how it can be applied to monitor safety performance in terms of meeting the targets and then discusses its application in New Zealand.

Control chart

The monitoring process developed here covers nationally reported fatalities. However, the method can be used for monitoring fatalities or any other attribute at the national, local government or police district level.

Control charts show the expected level of risk and the confidence limits within which the observed road tolls are expected to vary for a given risk environment. By risk environment we mean a combination of the risk as defined above and the total traffic volume. If an observed value is outside the confidence limits that indicates the possibility of a change in the actual risk environment. If the road toll over a few consecutive time periods is always on the upper or lower part of the control chart, then also it gives an indication of a change in the actual risk environment.

Probability distribution

In order to standardise comparisons of any monthly fatality rates, the different number of days in a month must be accommodated. Additionally, different risk (of crash) levels between weekend days/holidays and weekdays must be identified. For convenience, weekend days/holidays are referred to as weekend days hence forth.

The distributions of the average number of fatalities per weekday and per weekend are shown in Figure 1. Each observation is an average over a month during the period 1987-1996. As can be seen there is clear difference (statistically significant) between the expected number of fatalities per weekday and per weekend day. The difference between daily fatality rates in weekend days and holidays is not statistically significant.
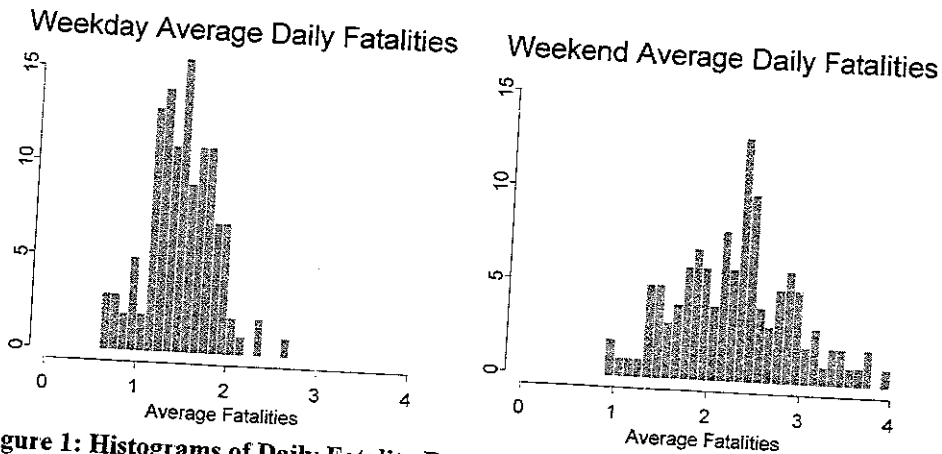
Figure 1: Histograms of Daily Fatality Rates

Our crash statistics system defines a Weekend as the period from 4pm Friday to 8am Monday. For our analysis we have estimated the number of fatalities per 24 hour day using the average number of fatalities per hour during the weekend period. Similar estimates have been made for fatalities per weekday.

The number of fatal crashes during a period is expected to follow a Poisson distribution. This does not necessarily mean that the number of fatalities should follow a compound Poisson distribution. However, since the fatalities per day is based on average values per hour, the number of fatalities per day can be approximated by a Normal distribution. Figure 1 demonstrates the general validity of this assumption. To further reinforce this assessment, a rankit plot was produced for each of the weekday and weekend daily fatality rates. [Rankits were generated as quantiles of a Normal distribution with a given mean and standard deviation.]

The interpretation is that if the plot of the ranked data (fatality rates) versus the computed rankits is close to linear, then the data may be assumed to be approximately Normal. Figure 2 shows that in both cases (weekdays and weekends) the assumption of Normality appears reasonable.

A formal goodness of fit test, based on sample deciles, for each of weekday rates and weekend daily fatality rates, was also conducted. The null distributions were Normal, with means and variances equal to the historical means and variances of daily fatality rates. This test also supported the validity of the Normality assumption. This is discussed in detail in Mara (1997).
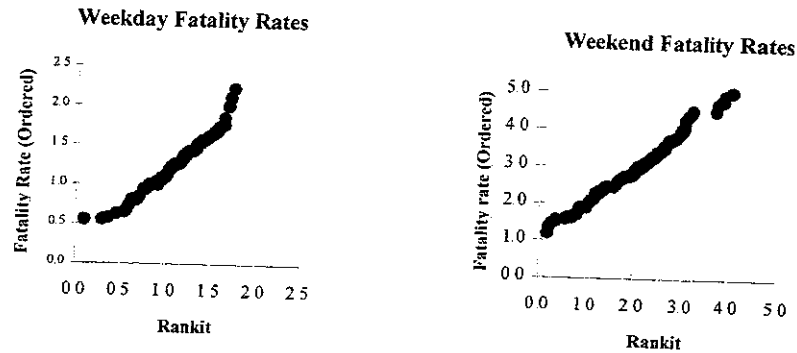
Figure 2: Rankit Plots for Weekday and Weekend Daily Fatality Rates

Estimation of variance

During the period of study, the rate of fatalities per day shows a declining trend. This is particularly true for weekend rates. Any simple estimate of variance will consequently be biased too high.

The variances could be estimated in two ways:

1. Estimate the variance of the rates for each year and take a simple average of these figures. However, there are only twelve data points per year for control charts on monthly data. Annual based estimates are themselves likely to be quite variable. Furthermore, trend effects are merely damped, not removed, by this process.

2. Estimate variance on the basis of consecutive differences between monthly fatality rates. Provided the trend is linear (ie not accelerating), this method essentially eliminates trend. This is the option chosen for our analysis.

The general formula for estimating variance using consecutive differences is:

$$\text{Variance} = \frac{\sum_{1}^{n}|X_{i+1} - X_i|}{1\,128(n-1)} \quad \text{...} (1)$$

The method is based on estimating standard deviation from the range of samples of size two (Snedecor & Cochran, 1980, p 138). We used this method to estimate the variances.

Estimation of monthly (weekly) fatality rates

If $E[X_1]$ and $E[X_2]$ are the average daily fatality rates for weekdays and weekends respectively, and k_1 & k_2 are the number of weekdays and weekend days, respectively, in the month (week), then if Y is the number of fatalities in the month (week), then:

$$E[Y] = k_1 * E[X_1] + k_2 * E[X_2] \quad \text{..(2)}$$

$$Var[Y] = k_1^2 * Var(X_1) + k_2^2 * Var(X_2) \quad \text{..(3)}$$

where $Var(X_1)$ and $Var(X_2)$ are the estimated variances for weekday and weekend daily fatality rates. This computation for variance assumes that weekday fatal crash rates are independent of weekend fatal crash rates. Since crashes are themselves randomly occurring, this is a reasonable assumption.

Interpretation of chart

The simplest use of control charts involves in identifying data points whose occurrence is not explained by random variation about a target or mean value, at least within a predetermined range of variability (in this case, we have chosen a 95% range or equivalently, a 5% risk of Type I error). Any single data point in the series of daily fatality rates which lies outside the upper and lower limits of the chart is considered sufficient evidence for a special cause (that is, outside the range of expectation for random fluctuation).

There are many other non-random patterns which could be identified as indicating non-random variation, allowing for a 5% Type I error. However, in order to ensure that the chart is a useful process monitor, some care must be taken to avoid classifying an enormous range of patterns as exceptions to randomness.

The chart as presented, gives 95% range estimates for fatalities for each month. Interpretation of plotted data can be based on the following rules:

1. Any single point (month or week) falling outside the upper or lower limit

2. Five successive points on one side of the target line

3. Four successive points of either increase or decrease.

4. Eight successive points within middle zone.

The middle zone is the band of the control chart within +/- 1SD of the target (or mean). To keep the charts simple and tidy, we have not shown this band in the charts

Rule 3 is derived from Feller (1968, p43) The probability of monotone sequence of length n is n/(n-1)!

Occurrence of any of the above events indicates the presence of a Special Cause. Note that an event indicated by rule 4 indicates that the variability has reduced It may be taken as possible evidence of consistent, effective daily fatality reduction

Results

The simple computation of variance of the daily fatality rates produces estimates of 0.1365 for weekdays and 0.4104 for weekend days. However, using equation 1 the estimated variances for daily fatalities are 0.1316 for weekdays and 0.2990 for weekends.

Control charts for weekday & weekend Rates

Shewhart charts for both weekday daily fatality rates and weekend daily fatality rates were constructed These appear in Appendix 1 The reference target values for these charts were the sample averages of daily fatality rates during 1996. These were 1.573 and 1.293 for weekday and weekend daily averages respectively. The upper and lower control limits for the charts were constructed as 1.96 * standard deviation from the target These were:

Weekday Fatality Upper and Lower Limits : 1.293 and 0.568 respectively;
Weekend Fatality Upper and Lower Limits : 1.573 and 0.501 respectively.

Control chart for monthly fatalities

Using the monthly fatality data series from January 1987 to December 1996, the mean value is 54.8 with a standard deviation of 10.9. However, a simple control chart based on this series is less than useful since there is a clear and systematic decline in the number of fatalities per month. This is merely a matter of historical record The practical value in any control chart is its ability to provide a guide for future monitoring. Consequently, the trend effect must be accounted for in prospective charts.

The data chosen for assessing prospective use are the monthly fatality counts for 1996.

Using the method for computing monthly means and variances and in order to eliminate historical bias, the daily averages for 1996 were used as before. Using the estimated variances from above (since these account for trend) produces a control chart for 1996 in Figure 3.
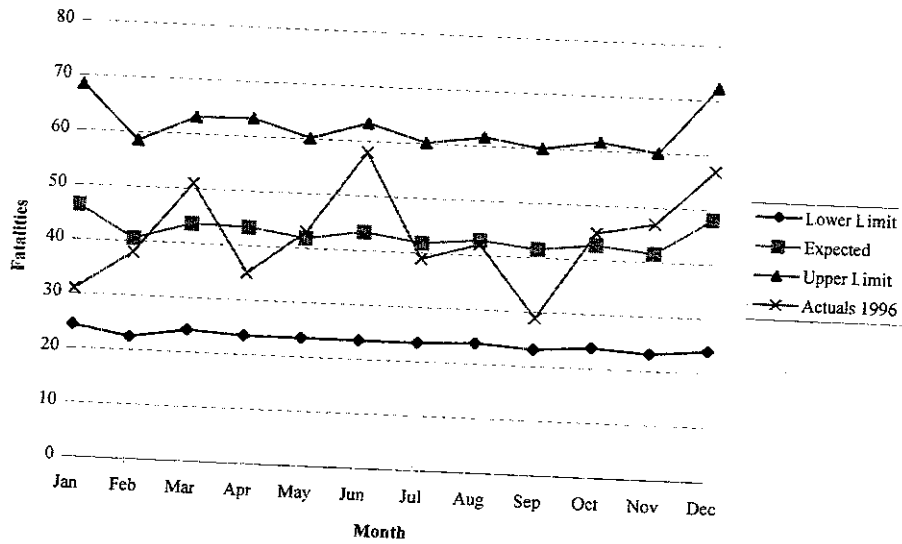
Figure 3: Control Chart : 1996 Monthly Fatalities

There is a quite high level of month to month variation on the number of fatalities. However, in 1996, no month could be identified as indicating a *special* or *assignable cause.* Even though the number of fatalities varied widely from month to month, this variation was not found to be outside the limits of what can be expected from Common Cause, or random variation.

Chart for weekly fatalities

Figure 4 shows the chart for weekly fatalities. The fluctuation is similar. One point in this chart is above the upper limit. This indicates that the number of fatalities for the week is significantly higher than the number expected under random fluctuation. Further investigation showed that every day of the week had one or more fatal crashes. There did not appear to be a regional concentration of crash events. No assignable cause could be clearly established. The rest of the year had fatalities within the chart limits. Since no assignable cause could be established for that unusual week. our conclusion is that this was purely due to the stochastic nature of crashes and it is not an indication of an increase in the risk level
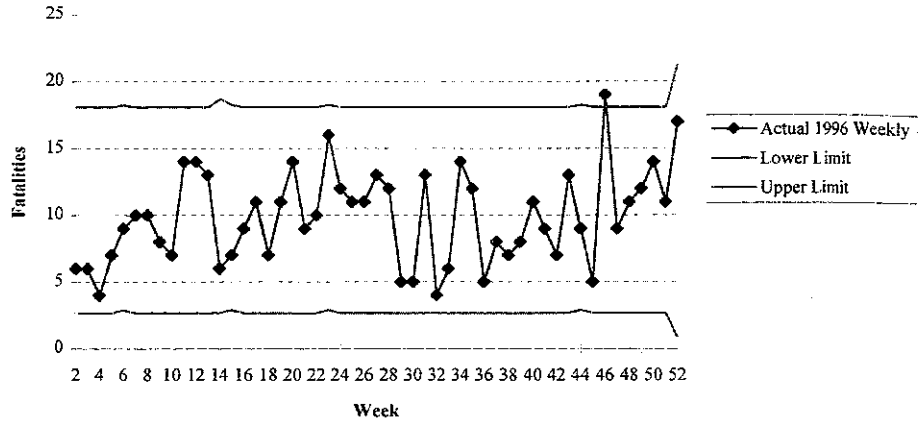
Figure 4: Control Chart for Weekly Fatalities : 1996 Data Using Adjusted SD

Chart for pre-set annual target

Figure 3 shows the control chart based on 1996 actual monthly outcomes. However, if a chart was desired for a pre-set target then a scale effect would apply.. This applies to estimates of expected values, control limits and monthly standard deviations. Figure 5 shows the control chart developed with a pre-set annual target of 500 fatalities.. [During 1996, the actual total fatalities was 514.]
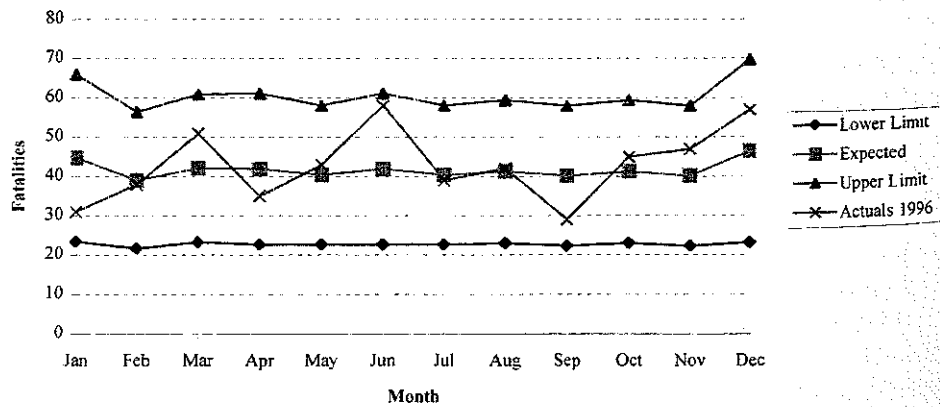

Figure 5: Control Chart 1996 Monthly Fatalities : Annual Target 500

Maximum number of fatalities

The use of the term target in designing a control chart is standard. The intent is that the process average will match the target. However, when examining road crash fatalities, the policy requirement is that any 'target' is, in fact, a maximum figure. That is, the intent is to achieve a result which is no worse than, say, 500 fatalities in the year. This will have implications for the design of the monitoring tool. The basic chart, covered above, will ensure that there is approximately, a 50% chance that the target road toll will be exceeded. In order to design a monitoring chart which produces a low probability that a pre-defined number is exceeded, some adjustment is necessary.

In particular, the monthly targets (in control chart terms) will be lower than those in Figure 5. It is the upper bound and, of course, the variance for the control chart which determines what the monthly target will be

If the chance of exceedance of the policy requirement is to be at most, say 5%, then using Normal theory, the chart target will be at most 1.645*standard deviation below the upper limit. This could be applied on a month by month basis, the same basis on which the chart was developed. However, if the annual enforcement goal is a maximum (say 500) for which there is at most a 5% chance of exceedance then the chart target values should be reduced, month by month, to achieve an annual target of 500 less 1.645*standard deviation of total annual fatalities. In 1996, this standard deviation figure is 34.71. [The sum of independent Normal variates is also Normal with a variance equal to the sum of the monthly variances.]

Thus, for an enforcement goal of 500, the chart target should be set at 443 Figure 6 gives the amended chart for the 1996 fatality information.
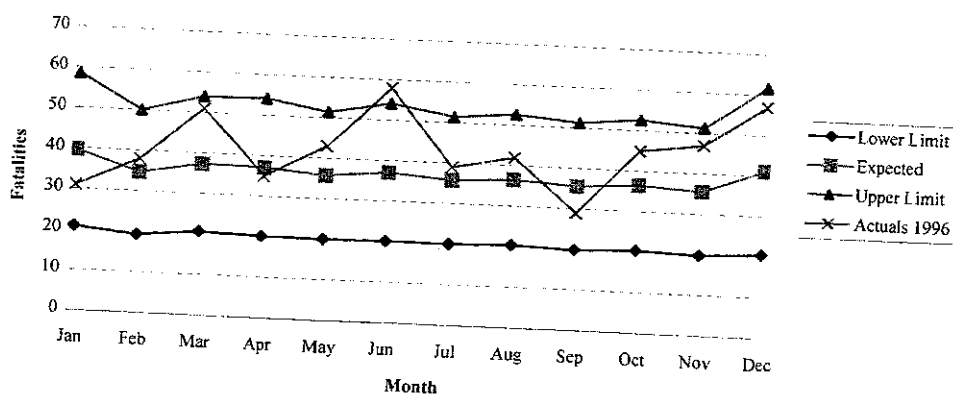

Figure 6: Chart for Annual Maximum Target
Control Chart 1996 Monthly Fatalities : Enforcement Goal 500, Chart Target 443

If the chart was constructed with reference to a maximum goal, then the chart would indicate relatively quickly, the extent to which the annual goal was being achieved. As is evident from Figure 6, while most points were within the control limits, a majority were above the mean target line.

Discussion

The control charts in this paper have been constructed as a means of monitoring levels of risk over a period of time. The intent is to ascertain whether or not the risk levels are changing and to indicate to what extent road safety policy goals are being achieved. More particularly, they can serve to indicate when further intervention may be appropriate.

The charts have been constructed by incorporating the differences in risk levels between days of the week. The different fatality rates per 24 hours on weekends and holidays as opposed to weekdays have been used to estimate the expected fatality rates for each month or week of the year, according to the nature of the week. To this extent, the chart targets are more closely a reflection of risk for the month or week, rather than simple averages across the year.

In the future, the patterns of fatalities and serious injuries combined will be examined with the intention of producing a tool for enforcement authorities to identify changes in risk at a district level. When considering the use of control charts at a district level, the use of weekly fatalities is inappropriate, because of very small expected numbers in some districts. In order to get some clear idea of the pattern of risk variability, fatalities could be considered only at a monthly level. Preliminary indications are that this is a productive approach.
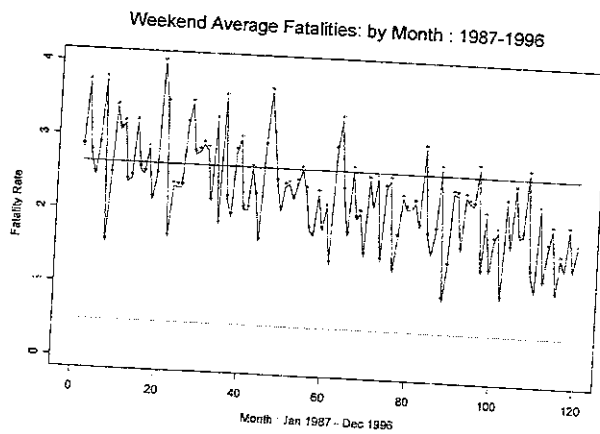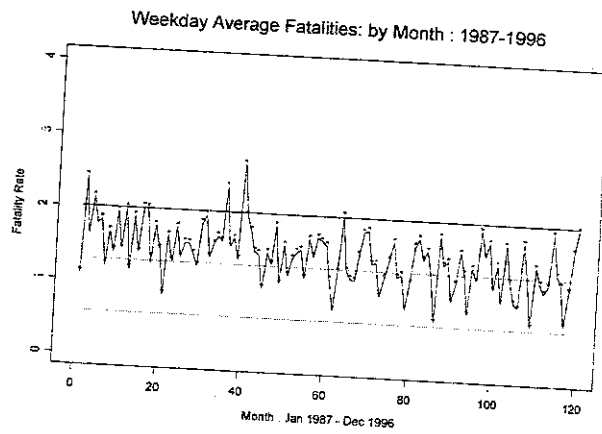
Acknowledgement

Appendix 1

Shewhart Charts for

Weekday and Weekend Daily Fatality Rates

January 1987 to December 1996

Target is 1996 Average

Weekday Average Fatalities: by Month : 1987-1996

Weekend Average Fatalities: by Month : 1987-1996

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