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Application of Shewhart Control Chart in Monitoring Road Accident Fatalities in Kelantan

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ABSTRACT

A traffic accident was defined as an incident involving at least one vehicle on a public road that results in the injury or death of at least one person. The rate and the actual number of road fatalities have increased significantly in a number of developed countries. Accidents can occur in distinct locations and in a variety of situations, making it hard to identify which areas are likely to cause an accident. This information is required by the communities and the respective authorities to enforce the law. This study was conducted to monitor the stability of road accident fatalities in Kelantan for the year 2019 by using Shewhart control chart, according to the number of road accident fatalities every four weeks. The control chart for variable such as mean and standard deviation control charts were constructed. Based on the findings, the number of road accident fatalities every four weeks' data in Kelantan for the year 2019 was in statistical control. Hence, all the control limits of mean value Shewhart control charts can be used as a tool to monitor the road accident fatalities in Kelantan. If the cases were more than 10 cases, the road traffic authorities should take an appropriate action to overcome this out of control situation. In this study, the mean number of road accident fatalities in Kelantan was 6 cases per week, with Kota Bharu having the highest total number of cases in Kelantan, while Jeli had the lowest. Hence, Kelantan contributed 5.2% of the cases out of the total weekly cases in Malaysia for the year 2019. The findings of this study can be used by the authorities to prevent and reduce the number of road accident cases in Kelantan, as well as in other Malaysian states. It is recommended for future studies to consider other types of statistical control charts and other scopes of accident data for better findings.

Keywords: Shewhart Control Chart, Road Accident, Fatalities

1 INTRODUCTION

A traffic accident was defined as an incident involving at least one vehicle on a public road that resulted in the injury or death of at least one person. Roads were shared by a lot of motor vehicles, which helped many countries flourish economically and socially all over the world. Accidents on the road happened all the time, and the injuries most people incurred could range from minor injuries to fatalities [1].

Road traffic accidents have become the major cause of injury and death. People were using transportation more frequently as a result of the world's increasing urbanization and population density, which increased the likelihood of road traffic accidents. Traffic accidents had been reported as one of the top tenth most common causes of death, according to the World Health Organization (WHO). Based on the latest WHO data published in 2018, road traffic accidents claimed the lives of 6,855 people in Malaysia, which represented 4.87 percent of total deaths. Malaysia had an age-adjusted death rate of 23.40 deaths per 100,000 people. However, data from WHO indicated that Malaysia’s expected fatality rate was among the highest rates in the world in 2013 [2].

According to the Malaysian Institute of Road Safety Research (MIROS), there were 476,196 road traffic accidents in 2016, with 6,676 road deaths, 4,432 seriously injured cases, and 8,598 mildly injured cases as well. Malaysia's Road Transports Department (RTD) claimed that, on average,road traffic accidents cost the country more than ten billion ringgits per year. Based on data published by the Ministry of Transport Malaysia in 2017, there were a total of 533,875 cases of road traffic accidents, with 13.5 percent of the cases involving motorcyclists [3]. In Malaysia, road traffic accidents have become a serious concern that had resulted in the loss of life or property. Since the implementation of the Movement Control Order (MCO),the number of people killed on the road had decreased by 32.7 percent, and the number of roadtraffic accident cases had decreased by 36.1 percent. Overall, a total of 248,116 road accident cases were reported nationwide between March 18, 2020, and November 18, 2020. During the same period of time in 2019, there were 388,015 cases reported [4]. It indicated that MCO indirectly contributed to the mitigation of road traffic accidents.

Report from the Head of the Traffic Police in Bukit Aman stated that, the average daily fatality caused by traffic accidents in Malaysia was 19 persons. With Malaysia's entire population of 28 million people, this statistic shows a relatively high daily death rate [5]. The Malaysian Institute of Road Safety Research (MIROS) did, however, release statistics for road fatalities in 2020, which revealed a 24.9 percent decrease from 2019. The data form the Royal Malaysia Police (PDRM), 4,634 people died in road accidents last year, compared to 6,167 in 2019. That was an average of 12.7 deaths per day [6].

As people know, Malaysia was afflicted by a COVID-19 pandemic, which forced the government to issue the Movement Control Order (MCO) in each state in the early part of 2020. The MCO appeared to have led to a reduction in road fatalities as part of preventing the spread of COVID-19. Based on road accident data reported to the Royal Malaysian Police, Kelantan was the third-lowest state that was involved in road accidents in 2018, compared to any other Malaysian state, where there were 2,406 cases, and only 420 of those cases involved deaths. According to [7], Kelantan police believed that users' impatience and behaviour when overtaking other vehicles seem to be the main causes of the majority of traffic accidents in the east coast state, including fatality accidents that occurred during the Hari Raya Aidilfitri festival period. Chief Superintendent Markandan Subramaniam of the state traffic enforcement investigation department (TEID), said that the decision was made based on the series of road accidents recorded by TEID between May 29 and June 4. He also said that the districts with the highest number of road accidents recorded were Tanah Merah, Kuala Krai, Gua Musang, Pasir Mas, Kota Bharu, and Machang.

In view of the fact that road accidents were a serious issue, especially in Malaysia, there were so many consequences of this situation, such as the impact of economic, psychological trauma, and health issues. There seemed to be no doubt that motorization had played a vital role in Malaysia's economic development. However, the cost of doing so was exorbitant. In Malaysia, road accidents that result in injury or death, lost manpower, lost productivity, high medical bills, expensive management, property damage, and other costs were estimated to be worth approximately RM 7 billion per year [5].Traffic accidents and related deaths have been on the rise around the world as populations and vehicles on the roads have increased. This dangerous scenario must be ended in order to avoid massive economic losses and save lives. According to World Health Organization and World Bank data, low and middle- income countries were disproportionately affected by road traffic fatalities, accounting for nearly 90% of all road traffic-related deaths worldwide [8].

When compared to other countries, the fatality toll on Malaysian roadways was relatively high. Road traffic accidents inhibited social and economic development. They were linked to millions of premature deaths and injuries, billions of dollars in medical bills, a strain on the welfare system, lost productivity, slow economic growth, and poverty. The huge numbers of road accidents on Malaysian roadways were a terrible "economic waste" for the country, as the rising frequency and cost of road accidents would only generate higher insurancerates. Road accidents were one of the major causes of human deaths in Malaysia. In a developing country like Malaysia, the number of vehicles on the roads had increased dramatically from year to year. This had led to a significant increase in the number of traffic accidents on the streets of Malaysia. Based on statistics, the number of accidents in 2003 was 298,651. While in 2012, the data showed that the number of road accidents increased from about 163,772 cases to 462,423 cases. This shows that the number of road accidents had increased by 54.84% in the past 10 years [9].

Hence, the purpose of this study is to develop Shewhart Control Charts for state-level monitoring of road traffic fatalities. The application of control charts would be applied in this study to monitor the stability of the mean and variation of road accident fatalities and to keep the occurrence on target as well.

2 MATERIAL AND METHODS

2.1 Data Collection

2.1.1 Study Area

Kelantan, which is one of the states in Malaysia, had been used as the case study area.It was located in the north-eastern corner of the peninsula. Kelantan was bordered on the north by Thailand's Narathiwat Province, on the south by Terengganu, on the east by Perak, and on the south by Pahang. Meanwhile, to the north-east of Kelantan was the South China Sea. The capital of the state was Kota Bharu, which performed all the administrative duties over the state, while the royal seat was Kubang Kerian. Kelantan was divided into ten main districts, which were Kota Bharu, Pasir Mas, Tumpat, Pasir Puteh, Bachok, Kuala Krai, Machang, Tanah Merah, Jeli and Gua Musang.

2.1.2 Data Description

The secondary data on road accident fatalities cases by the district in Kelantan for the year 2019 was obtained from Kelantan Contingent Police Headquarters, Kota Bharu. The details information on road traffic accident fatalities started from January to December 2019 was obtained for each of Kelantan's districts. A weekly road accident facilities data from every Tuesday to Monday, which consisted of

52 weeks in total were recorded at 10 different traffic stations in Kelantan's districts. Table 1 showed the dummy tabulation of data acquired.

Table 1: Dummy Tabulation on Road Accident Fatalities Data in Kelantan for the Year 2019

Week	Date	Traffic Station	Number of Fatal Accident
1	01/01/2019 – 07/01/2019	Bachok	…..
		Gua Musang	…..
		Jeli	…..
		Kota Bharu	…..
		Kuala Krai	…..
		Machang	…..
		Pasir Mas	…..
		Pasir Puteh	…..
		Tanah Merah	…..
		Tumpat	…..
2	08/01/2019 – 14/01/2019	Bachok	…..
		Gua Musang	…..
		:	:
		:	:
		Tumpat	…..
:	:	:	:
:	:	:	:
52	24/12/2019 – 30/12/2019	Bachok	…..
		Gua Musang	…..
		:	:
		:	:
		Tumpat	…..

The original data was arranged by 13 samples or subgroups with each sample consisted of every four weeks' data on road accidents fatalities. Then, the average of weekly data for each subgroup would be calculated to construct the Shewhart control chart as summarized in Table 2.

Table 2: Dummy Tabulation of Total Number Road Accident Fatalities Every 4 Weeks in the Year 2019

Sample (Subgroup)	Number of Fatal Road Accident by Week				Sample Mean	Sample Standard Deviation
	1	2	3	4		
1	…..	…..	…..	…..	…..	…..
2	…..	…..	…..	…..	…..	…..
3	…..	…..	…..	…..	…..	…..
4	…..	…..	…..	…..	…..	…..
5	…..	…..	…..	…..	…..	…..
6	…..	…..	…..	…..	…..	…..
7	…..	…..	…..	…..	…..	…..

8	.....	.....	.....	.....	.....	.....
9	.....	.....	.....	.....	.....	.....
10	.....	.....	.....	.....	.....	.....
11	.....	.....	.....	.....	.....	.....
12	.....	.....	.....	.....	.....	.....
13	.....	.....	.....	.....	.....	.....

2.2 Descriptive Analysis

Based on the data, statistics on total number of road accident fatalities in Kelantan for the year 2019, mean of the total cases, the proses mean (grand mean) and mean of sample standard deviation mean were calculated. In addition, to approximate the percentage of weekly road accident fatalities in Kelantan for the year 2019 compared to the weekly road accident fatalities in Malaysia for the year 2019, the Eq. (1) was used.

$$\%\,\text{of cases} = \frac{\text{Average Weekly Road Accident Fatalities in Malaysia for the Year 2019}}{\text{Average Weekly Road Accident Fatalities in Kelantan for the Year 2019}} \tag{1}$$

Pareto chart was used to describe the frequency of road accident fatalities in Kelantan by district for the year 2019.

2.3 Shewhart Control Chart

Walter Andrew Shewhart was an American physicist, engineer and statistician. He was regarded as the father of controlled charts, having developed them for practical used in 1924. The belief that internal (natural) variability, which was typical of each process, might been controlled independently of external (non-accidental) factors that negatively affected the examined phenomena underpins their usage [9].

However, based on statistical theory, statistical process control charts were chronological graphs of process data that were used to assist understand, regulate, and improved processes – such as infection restraint or adverse event procedures – and were straightforward for practitioners to used and interpret. Hypothesis tests in which the procedure was statistically controlled were known as controlled charts. That was, a plot pointed inside the controlled limits was the same as not rejecting the statistical controlled hypothesis, whereas a plot pointed beyond the limitations was the same as rejecting it [10].

Figure 1 depicted the overall format and interpretation of the most prevalent and basic form, known as a Shewhart control chart [9]. Some interesting information, such as the number of road accident fatalities per 30 days, was displayed on the chart over time as well as explained on a weekly or every four weeks basis, will be discussed in this study. Based on Figure 1, the Centre Line (CL), Upper Control Limit (UCL), and Lower Control Limit (LCL) were three horizontal lines which define the central tendency and range of natural variation of the plotted values, presuming that the number of cases of road accident fatalities did not changed [11].

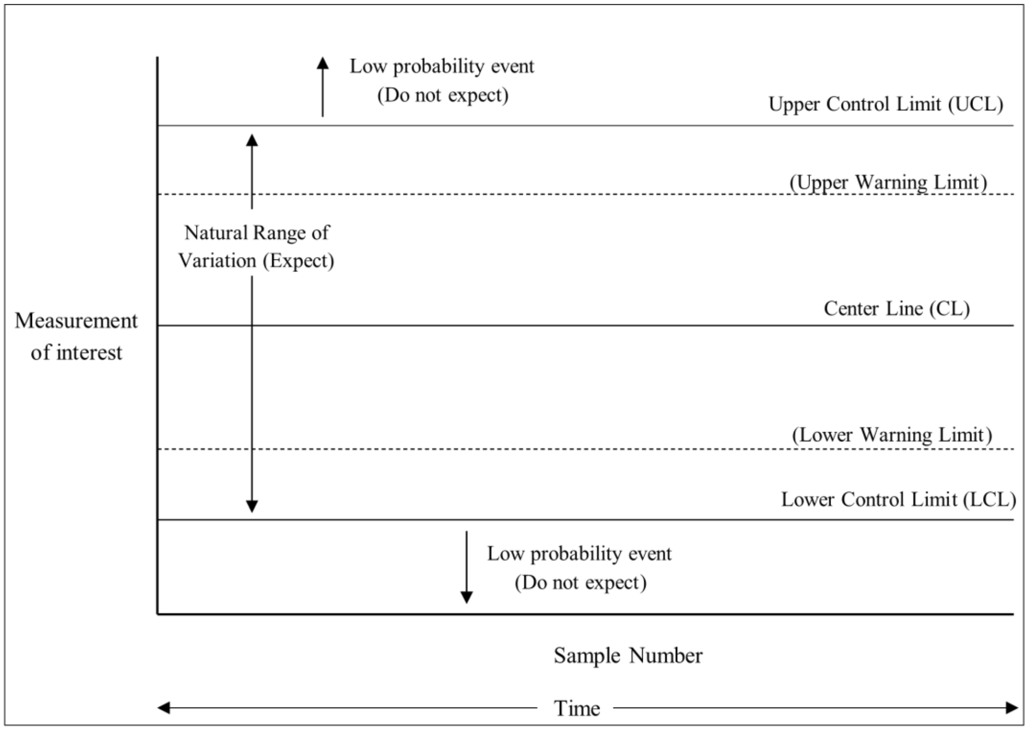

Figure 1: General Format and Interpretation of a Statistical Control Chart

The Shewhart control charts are divided into two types which are control charts for variable and control charts for attribute. There were a few types of Shewhart control charts for variable, such as mean and standard deviation chart and mean and range chart. Meanwhile, control charts such as sample total, sample fraction, sample rate and sample rate adjusted per common based are among the control charts for attribute. The type of control chart to be used is determined by the type of tested feature and the underlying process. This study constructed the Shewhart control chart for variable because this chart typically leads to more efficient control chart procedures and offers more process output information than the control chart for attribute.

The application of control charts had several phases which are control limits, revise control limits and the new control limits. However, this study only focused on the first phase which is to understand current and past performance and its degree of consistency and predictability. In addition, this primary phase was also beneficial in checking the stability of the performance and determining whether the road accident fatalities was in statistical control or not. The charts will be used to monitor road accident fatalities, reveal variations and illustrate the effect of new limits designed to manage road accident fatalities.

2.3.1 Control Chart for Variable

In this study, the mean and standard deviation charts ($\bar{X}$ and S), had been used to monitor the stability of mean and variation of an occurrence based on samples taken from the occurrence at a given time. The quality characteristic in this study was the number of road accident fatalities in Kelantan for the year 2019. To estimate the mean and standard deviation of an occurrence, an initial set of subgroups was usually utilized. The mean and standard deviation were then used to calculate control limits for each subgroup's mean and standard deviation. The time measurement approximately in weeks (based on every 4 weeks' consideration) constitute as the subgroups of the observations (m=13). Meanwhile, the total 52 weeks that have been taken into consideration was used as a measurement of interest to construct this control charts. So that the size of each subgroup was equivalent to four (n=4).

This control chart was appropriate since the measurements of observations were numerical in nature. The $\bar{X}$ and S control chart could be used with assumption of the quality characteristic distribution was approximately normal (Gaussian) distribution with mean, μ and standard deviation, σ. Alternatively, mean and range chart ($\bar{X}$ and R) sometimes could be used. One advantage of using the standard deviation instead of the range was that the standard deviation took into consideration all the data, not just the maximum and the minimum values.

The strength of control charts came from their ability to detect sudden changes in a process that resulted from the presence of assignable caused. The S control chart should be examined first to correctly interpret $\bar{X}$ and S chart. The $\bar{X}$ chart control limits were determined from the sample standard deviation (s) values; if the values in the S chart were out of controlled, the $\bar{X}$ chart control limits were incorrect. Stopped the process if the points in the S chart were out of controlled. Determined the special caused and addressed the issue. Took those subgroups out of the calculations. After the S chart was under controlled, examined the $\bar{X}$ chart and compared the points to the control limits. Identified the specific reason of any points was out of controlled in $\bar{X}$ chart, identified the special caused and addressed the issue.

Once the control limits for the $\bar{X}$ and S charts had been defined, these limits could be used to track the mean and variance of the process in the future.

2.3.2 Constructing the Mean and Standard Deviation Control Charts

To construct a mean and standard deviation charts ($\bar{X}$ and S), the process mean ($\bar{\bar{x}}$) and the mean standard deviation ($\bar{s}$) need to be calculated first. Both, $\bar{\bar{x}}$ and $\bar{s}$ can be computed in Eq. (2) and Eq. (3), respectively [9] [12] [13].

$$\bar{\bar{x}} = \frac{\bar{x}_1 + \bar{x}_2 + ... + \bar{x}_m}{m} \tag{2}$$

where

$\bar{\bar{x}}$ = process mean
$\bar{x}$ = mean of the observation in each subgroup
m = number of subgroups

$$\bar{s} = \frac{s_1 + s_2 + ... + s_m}{m} \tag{3}$$

where

$\bar{s}$ = mean of m standard deviation
s = sample standard deviation in each subgroup

m = number of subgroups

Then, the upper control limit (UCL), the lower control limit (LCL) and the center line (CL) should be determined for both charts. The formula to construct these limits on the $\overline{X}$ chart are defined in Eq. (4). Meanwhile the limits on the S chart are defined in Eq. (5) [9].

$$\text{UCL} = \bar{\bar{x}} + A_3\bar{s}$$

$$\text{CL} = \bar{\bar{x}}$$

$$\text{LCL} = \bar{\bar{x}} - A_3\bar{s} \quad (4)$$

where

$\bar{\bar{x}}$ = process mean
$\bar{s}$ = mean of m standard deviation
A_3 = factor that includes three standard deviations of ranges and is dependent on the sample size being considered (see Appendix)

$$\text{UCL} = B_4\bar{s}$$

$$\text{CL} = \bar{s}$$

$$\text{LCL} = B_3\bar{s} \quad (5)$$

where

$\bar{s}$ = mean of m standard deviation
B_3 , B_4 = factor that includes three standard deviations of ranges and is dependent on the sample size being considered (see Appendix)

2.3.3 Supplementary Rules for Statistical Control

Some criteria might be applied to a control chart at the same time to evaluate whether the process was out of control or not stable. The most important criterion was one or more points outside of the control limits. The additional criterion was often used to boost the sensitivity of the control charts to a small process shifted so that the assignable caused could be detected more quickly. Table 3 listed some of the between-limit rules for unnatural variability or sensitizing rules for control charts that were widely used in practice [11]. Frequently, the control chart could be concluded have been out of control after inspection if any one or more of the criteria in Table 3 were satisfied. However, for this study, only the first three rules were suggested to prevent false signaling. If at least one out of three rules were observed, the process's mean was said have been out of controlled, then, when the control chart shows an out-of-control process, an assignable reason was suspected. During this initial phase, the assignable caused should be identified, as well as the subgroup should be eliminated from the estimating process.

Table 3: Between-Limit Rules for Unnatural Variability

Supplementary Rules for Statistical Control	
No.1	Any point outside either control limit
No.2	8 consecutive points on the same side of the Centre Line (CL)
No.3	4 or 5 consecutive points outside of CL ± 1 SD, on the same side
No.4	13 consecutive values within CL ± 1 SD, indicating a reduction in variability
No.5	2 of 3 consecutive points outside of CL ± 2 SD, on the same side
No.6	12 of 14 consecutive points on the same side of CL
No.7	8 consecutive points exhibiting either an increasing or decreasing trend
No.8	8 Cyclic or periodic behavior.

3 RESULTS AND DISCUSSION

3.1 Descriptive Analysis

Table 4 represented the summary on the number of road accident fatalities in the year 2019. The data was arranged and organized into 13 subgroups, m=13, with sample size of four, n = 4. All 13 subgroups were referred to the number of road accident fatalities every 4 weeks for the year 2019, and each observation of subgroup was the mean number of road accident fatalities for every four weeks.

The total number of road accident fatalities in Kelantan for the year 2019 was 321 cases. A study reported by [14], Kelantan had a lower number of road accident fatalities reported in 2018, with 420 cases. However, compared to any other Malaysian state, Kelantan had a considerably greater rate of road accident injuries with 1,626 cases. As summarized in Table 4, the mean of the total cases, the proses mean (grand mean) and mean of sample standard deviation were 24.69, 6.17 and 2.36 respectively. The result showed that approximately the road accident fatalities in Kelantan for the year 2019 was approximately 25 cases per four weeks or about six cases per week. The Table 4 also showed that the cases was within four to eight cases per week. According to a report from the Head of the Traffic Police in Bukit Aman, the total number of fatalities caused by road accidents in Malaysia for the year 2019 was 6,167, which was 118.596 cases on average per week, approximately 119 deaths per week. Hence, Kelantan contributed approximately 5.2% of the cases from the total weekly cases in Malaysia for the year 2019.

Table 4: Statistics on Road Accident Fatalities in Year 2019

Sample	Week				Total	Sample Mean	Sample Standard Deviation
	1	2	3	4			
1	5	12	7	5	29	7.25	3.3040
2	3	7	4	4	18	4.5	1.7321
3	4	5	11	2	22	5.5	3.8730
4	7	4	4	4	19	4.75	1.5000

5	10	7	6	9	32	8	1.8257
6	4	8	8	12	32	8	3.2660
7	4	4	10	10	28	7	3.4641
8	11	7	6	7	31	7.75	2.2174
9	6	5	7	4	22	5.5	1.2910
10	7	6	4	4	21	5.25	1.5000
11	12	6	10	4	32	8	3.6515
12	4	4	5	5	18	4.5	0.5774
13	4	1	7	5	17	4.25	2.5000
Total					321	80.25	30.7021
Mean					24.69	6.1731	2.3617

Figure 2 depicted the Pareto chart on frequency of road accident fatalities in Kelantan by district for the year 2019. The districts in the Pareto chart were rated based on the number of accident cases in each district. From the figure, it was clearly shown that the highest total cases were in Kota Bharu, with 66 cases, followed by Gua Musang, Machang, Bachok, Pasir Puteh, Pasir Mas, Tanah Merah, Kuala Krai, Tumpat, and Jeli with 42, 41, 31, 30, 29, 28, 26, 20, and eight cases, respectively. The number of road accident facilities was the lowest in Jeli, indicating that it was the safest district in Kelantan. According to state traffic enforcement investigation department (TEID) Chief Superintendent Markandan Subramaniam, the highest number of road accidents were recorded in Tanah Merah, Kuala Krai, Gua Musang, Pasir Mas, Kota Bharu, and Machang (Abdullah, 2019). There could be several causes for the higher accident rate in Kota Bharu than in Jeli. One of the major factors was the district's high population density. Kota Bharu had the most people, with 608.6 thousand and the tiniest district area of 115.6 km^2 compared to Jeli, which had 51.9 thousand people and a district area of 1,330 km^2. As a result, Kota Bharu became a highly compact location with rapid urbanization, infrastructure, and a focus on the sector of employment. This would result in a rising number of vehicles and traffic flows, as well as an increase in the probability of road accidents. Conversely, agriculture and plantations were the mainstays of Jeli's economy. The population density was significantly lower than in Kota Bharu, and the traffic conditions would have been much better.

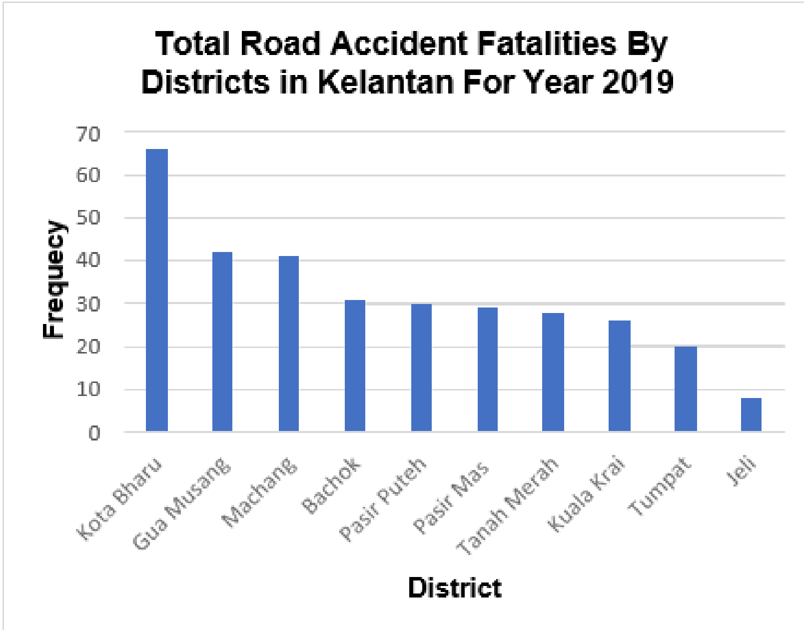

Figure 2: Pareto Chart of Total Road Accident Fatalities by District

3.2 Mean and Standard Deviation Control Charts

Based on the $\bar{X}$ and S control charts in Figure 3 and 4, the upper limit (UCL), centre line (CL) and lower limit (LCL) for the $\bar{X}$ chart are 10.0176, 6.1731 and 2.3283 respectively. Hence, the road accident fatalities in Kelantan are expected to vary from 2 to 10 cases per week. Meanwhile, the UCL, CL and LCL for the S chart are 5.3516, 2.3617 and 0 respectively.

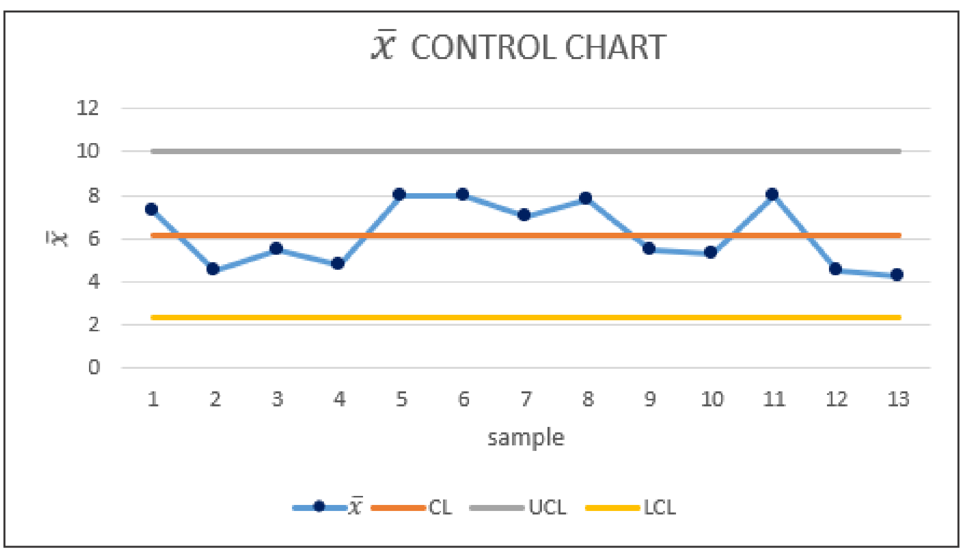

Figure 3: Mean Control Chart

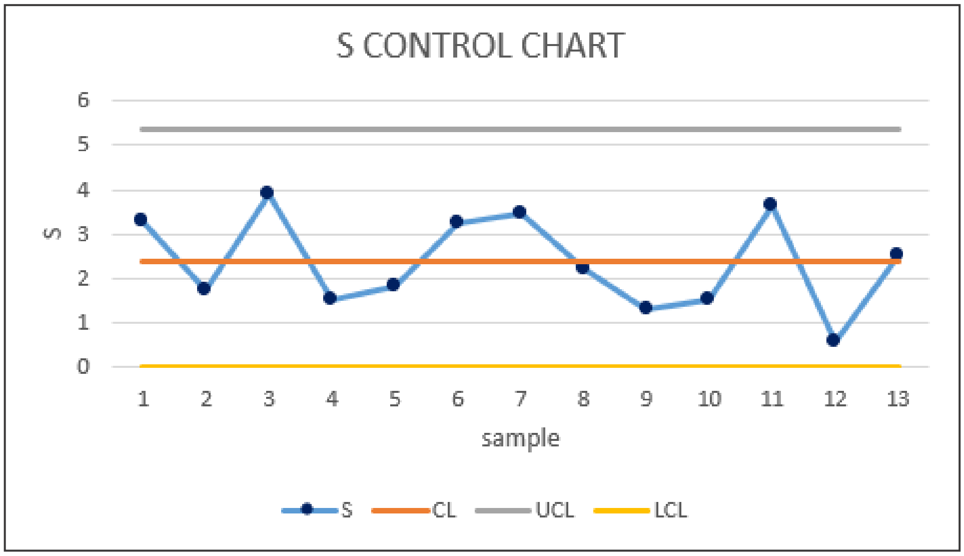

Figure 4: Standard Deviation Control Chart

Based on Figure 3, most of the mean number of road accident fatalities was approximately within the center line of the chart. Besides, there were no points that exceeded the control limits, and there was no specific pattern of the points on the chart. However, a slight decrease in the number of road accident fatalities between the Sample 11 and Sample 13 was noticeable. Since all of the points on the $\bar{X}$ chart were between the upper and lower control limits, the occurrence of road accident fatalities was statistically controlled. Thus, there was no further action needed to be taken. Hence, the upper and lower control limit which were 10.0179 and 2.3283 respectively, could be used to monitor every four weeks of road accident fatalities. If the cases were more than 10 cases, the road traffic authorities should take an appropriate action to overcome this out of control situation.

Based on S chart in Figure 4, the sample standard deviation of road accident fatalities decreased drastically from Sample 11 to Sample 12 but still did not exceed the lower control limit of the chart. As a result, by using the specified rule for detection of out of control conditions, none was found to be out of control. Hence, the occurrence of road accident fatalities seemed to be in statistical control. Although the road accident fatalities in Kelantan was classified as high, but based on the control chart, the average weekly death is still in statistical control. The mean control chart as Figure 3 could be accurately used for monitoring the road accident fatalities since the standard deviation control chart was in statistical control.

4 CONCLUSION

This research was conducted to determine whether the number of road accident fatalities for every four weeks in Kelantan in the year 2019 were within the boundaries of statistical control or not. The mean and standard deviation control charts ($\bar{X}$ *and* S) for every four weeks (subgroup) data were being used for monitoring the number of road accident facilities in Kelantan for the year 2019. Based on the findings, the data were in statistical control. Hence, all the control limits of mean and standard deviation control charts can be used as a tool to monitoring the road accident fatalities in Kelantan. The mean number of road accident fatalities in Kelantan was six cases per week, with Kota Bharu had the highest total number of cases in Kelantan, while Jeli had the lowest. The mean cases are expected varied from two to 10 cases per week. Kelantan contributed 5.2% of the cases out of the total weekly cases in Malaysia for the year 2019. Since this study only focuses on road accident fatalities, another research should be expanding the scope of accident data through many scopes such as data on Road Traffic Accidents consisting with information on fatal, major, minor and with no injuries. In addition, the accident data based on the type of injuries (death, serious injuries, minor injuries) also recommended being used for future study. For both suggested data, attributes control chart also can be applied to monitoring the road accident in Kelantan since this control chart can give more information on fatalities cases compared to non-fatalities. In addition, other control charts such as CUSUM control chart also can be used for monitoring road accident fatalities [15] [16]. Hence the feasibility of various control charts can be determined.

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APPENDIX

Factors for Constructing Variables Control Charts

Observations in Sample, n	Chart for Averages: Factors for Control Limits			Chart for Averages: Factors for Center Line		Chart for Standard Deviations: Factors for Control Limits				Factors for Center Line		Chart for Ranges: Factors for Control Limits				
	A	A_2	A_3	c_4	$1/c_4$	B_3	B_4	B_5	B_6	d_2	$1/d_2$	d_3	D_1	D_2	D_3	D_4
2	2.121	1.880	2.659	0.7979	1.2533	0	3.267	0	2.606	1.128	0.8865	0.853	0	3.686	0	3.267
3	1.732	1.023	1.954	0.8862	1.1284	0	2.568	0	2.276	1.693	0.5907	0.888	0	4.358	0	2.574
4	1.500	0.729	1.628	0.9213	1.0854	0	2.266	0	2.088	2.059	0.4857	0.880	0	4.698	0	2.282
5	1.342	0.577	1.427	0.9400	1.0638	0	2.089	0	1.964	2.326	0.4299	0.864	0	4.918	0	2.114
6	1.225	0.483	1.287	0.9515	1.0510	0.030	1.970	0.029	1.874	2.534	0.3946	0.848	0	5.078	0	2.004
7	1.134	0.419	1.182	0.9594	1.0423	0.118	1.882	0.113	1.806	2.704	0.3698	0.833	0.204	5.204	0.076	1.924
8	1.061	0.373	1.099	0.9650	1.0363	0.185	1.815	0.179	1.751	2.847	0.3512	0.820	0.388	5.306	0.136	1.864
9	1.000	0.337	1.032	0.9693	1.0317	0.239	1.761	0.232	1.707	2.970	0.3367	0.808	0.547	5.393	0.184	1.816
10	0.949	0.308	0.975	0.9727	1.0281	0.284	1.716	0.276	1.669	3.078	0.3249	0.797	0.687	5.469	0.223	1.777
11	0.905	0.285	0.927	0.9754	1.0252	0.321	1.679	0.313	1.637	3.173	0.3152	0.787	0.811	5.535	0.256	1.744
12	0.866	0.266	0.886	0.9776	1.0229	0.354	1.646	0.346	1.610	3.258	0.3069	0.778	0.922	5.594	0.283	1.717
13	0.832	0.249	0.850	0.9794	1.0210	0.382	1.618	0.374	1.585	3.336	0.2998	0.770	1.025	5.647	0.307	1.693
14	0.802	0.235	0.817	0.9810	1.0194	0.406	1.594	0.399	1.563	3.407	0.2935	0.763	1.118	5.696	0.328	1.672
15	0.775	0.223	0.789	0.9823	1.0180	0.428	1.572	0.421	1.544	3.472	0.2880	0.756	1.203	5.741	0.347	1.653
16	0.750	0.212	0.763	0.9835	1.0168	0.448	1.552	0.440	1.526	3.532	0.2831	0.750	1.282	5.782	0.363	1.637
17	0.728	0.203	0.739	0.9845	1.0157	0.466	1.534	0.458	1.511	3.588	0.2787	0.744	1.356	5.820	0.378	1.622
18	0.707	0.194	0.718	0.9854	1.0148	0.482	1.518	0.475	1.496	3.640	0.2747	0.739	1.424	5.856	0.391	1.608
19	0.688	0.187	0.698	0.9862	1.0140	0.497	1.503	0.490	1.483	3.689	0.2711	0.734	1.487	5.891	0.403	1.597
20	0.671	0.180	0.680	0.9869	1.0133	0.510	1.490	0.504	1.470	3.735	0.2677	0.729	1.549	5.921	0.415	1.585
21	0.655	0.173	0.663	0.9876	1.0126	0.523	1.477	0.516	1.459	3.778	0.2647	0.724	1.605	5.951	0.425	1.575
22	0.640	0.167	0.647	0.9882	1.0119	0.534	1.466	0.528	1.448	3.819	0.2618	0.720	1.659	5.979	0.434	1.566
23	0.626	0.162	0.633	0.9887	1.0114	0.545	1.455	0.539	1.438	3.858	0.2592	0.716	1.710	6.006	0.443	1.557
24	0.612	0.157	0.619	0.9892	1.0109	0.555	1.445	0.549	1.429	3.895	0.2567	0.712	1.759	6.031	0.451	1.548
25	0.600	0.153	0.606	0.9896	1.0105	0.565	1.435	0.559	1.420	3.931	0.2544	0.708	1.806	6.056	0.459	1.541

For $n > 25$.

$$A = \frac{3}{\sqrt{n}} \qquad A_3 = \frac{3}{c_4\sqrt{n}} \qquad c_4 = \frac{4(n-1)}{4n-3}$$

$$B_3 = 1 - \frac{3}{c_4\sqrt{2(n-1)}} \qquad B_4 = 1 + \frac{3}{c_4\sqrt{2(n-1)}}$$

$$B_5 = c_4 - \frac{3}{\sqrt{2(n-1)}} \qquad B_6 = c_4 + \frac{3}{\sqrt{2(n-1)}}$$