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MONITORING THE REPRODUCTION NUMBER AND STRINGENCY INDEX OF COVID-19 PANDEMIC IN NIGERIA

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ABSTRACT: *In order to track the Covid-19 pandemic's reproduction number and stringency index in Nigeria, this research presents the implementation of control chart approaches. This will assist in monitoring these pertinent parameters and assist decision-makers in determining whether to impose stricter or less strict containment measures to stop the spread of the disease. The data for this study was sourced from the Our World In Data (OWID) website (https://www.owid.org). This database contains information about how the Covid-19 pandemic has spread globally. The data consists of the reproduction number and the stringency index of the pandemic from February 2020 to July 2022. The range chart was used to monitor the variability in these indices. The findings indicate that during the first 42 days of infection, the pandemic's reproduction number and stringency index are not within statistically significant ranges, and hence out of statistical control. This could explain the virus's quick spread as well as the nation's economy's suffering due to harsh government measures. The study concludes, therefore, that statistical quality control charts are a viable option for tracking a few key pandemic metrics. This would assist in educating interested parties about the necessity of taking the necessary actions to stop the spread of such a pandemic.*

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INTRODUCTION

The coronavirus first appeared in China towards the end of 2019, and it quickly spread to almost every continent in the world. Africa, America, and Europe had a daily rapid increase in the pandemic cases (Samuel, Muhammad, Samuel, Haruna, & Rafiu, 2020).

According to the United Nations (2020), Covid-19 is far more than just a health emergency because it can seriously harm every nation it comes into contact with. It might also lead to catastrophic social, economic, and political crises that would leave lasting damage.

They can cause both endemic and epidemic respiratory illnesses. The gastrointestinal, pulmonary, hepatic, and neurological systems can all be affected by the coronavirus disease, which can be symptomatic or asymptomatic. This, in some cases, results in hospitalization of patients at the intensive care unit (Drexler *et al*, 2010; Woo, Huang, Lau, & Yuen, 2010; Yin & Wunderink, 2018).

Peiris, Lai, Poon, Guan, Yam, Lim, and Yuen (2003) stated that the severe acute respiratory syndrome (SARS) caused by the coronavirus makes it extremely pathogenic. In addition to SARS, the Middle East Respiratory Syndrome Coronavirus (MERS-CoV) is another extremely deadly coronavirus that originated in the Middle East (Zaki, Van Boheemen, Bestebroer, Osterhaus, & Fouchier, 2012).

Its symptoms include fever, coughing, generalized breathing difficulties, organ failures, and even death. The World Health Organisation declared the coronavirus epidemic a worldwide health emergency on January 30, 2020 (World Health Organization, 2020).

The outbreak of the coronavirus pandemic (Covid-19) has stimulated a number of responses from individuals, government and researchers from various fields. Statisticians have also applied a number of statistical methods to study various aspects of the pandemic. Ahmad, Aminu, Usman, and Suleiman (2021) estimated the case fatality rate of the Covid-19 pandemic in Nigeria using both simple and polynomial regression models. The study was carried out using the disease's epidemiological data of 44 days from the first reported case of death. Edike, Braimah and Agbedeyi (2020) studied and monitored the prevalence of the pandemic using statistical quality control techniques. The study observed that the daily confirmed cases of Covid-19 was already out of statistical control as of 18th August, 2020.

Yusuf (2020) examined the empirical links between Covid-19 situation report and available data in Nigeria. According to the study, there is no Nigerian state which has up to 12 laboratory-confirmed cases of Covid-19 per 10,000 population. This implies that the number of confirmed Covid-19 cases is less than 0.15% of the population of people across each state in Nigeria. The study further revealed that, compared to the population, the proportion of samples tested for Covid-19 is low with percentages ranging from less than 0.1% to a maximum of 0.7% of each state population, in which 23 states out of the 36 states are within or less than 0.1%.

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Reproduction Number

The average number of new infections generated by an infected individual during their infectious period among a population that lacks immunity is known as the basic reproduction number (or simply the reproduction number) of the infection. It is a significant indicator in detecting the transmission risks of an infectious disease. The basic reproduction number of an infection is denoted by R_0. *When* $R_0 < 1$, *the infection does not have the potential to spread among a susceptible population and will eventually die out. On the other hand if* $R_0 \geq 1$, *the infection has the potential to spread among a susceptible population.*

The basic reproduction number of the Covid-19 pandemic has been studied as a way to understand its transmissibility and ability to spread through a population. Iyaniwura, Rabiu, David and Kong (2022) estimated the basic reproduction number of Covid-19 for Nigeria to be *3.86* with 90% confidence interval of [3.61, 4.16].

Matthew, Akindele, Farah, Funmilayo, and Ahmad (2021) estimated the basic reproduction number as 0.675 with 99% confidence interval of [0.669, 0.680]. Okuonghae and Omame (2020) assessed the basic reproduction number for Covid-19 pandemic in Lagos (the epicenter of Covid-19 in Nigeria) as $2.006 \leq R_0 \leq 2.1074$, based on the "active cases" data obtained from the NCDC from 16th March 2020 to 2nd May 2020.

Alimohamadi, Taghdir and Sepandi (2020) estimated the pooled R_0 for Covid-19 using the random effects model. The study estimated the pooled reproductive number of Covid-19 as 3.32 with 95% confidence interval of (2.81, 3.82). The study further revealed that the type of model used to estimate R_0 has no significant effect on heterogeneity among studies. Mizumoto, Tariq, Roosa, Kong, Yan, and Chowell (2019) studied the variability in the effective reproduction number of Ebola disease in Congo DR. The study observed that fluctuations in the reproduction number of a disease poses substantial uncertainty, which suggests improvements in the control of the disease.

Many other studies have estimated the reproduction number of Covid-19 pandemic in Nigeria. These estimates differ from time to time and there is a need to monitor its mean variability.

This study applied the range control chart to monitor the reproduction number and stringency index of Covid-19 pandemic in Nigeria. This will help researchers to appreciate early monitoring of the reproduction number and stringency index of any outbreak in order to avert drastic spread. It will also help other stakeholders to better understand the dynamics of such a pandemic among the Nigerian population and provide useful knowledge on managing its spread.

The production number and stringency index of Covid-19 pandemic in Nigeria has been estimated and recorded over time (www.ourworldindata.org). Researchers seem to be interested only when the reproduction number of any outbreak is greater than unity. However, there is a need to monitor the fluctuations of these indices as these fluctuations may also impact the susceptible population if not in statistical control.

This study takes into consideration the daily estimated reproduction number and stringency index of Covid-19 pandemic in Nigeria from February 2020 to July 2022. It monitors variation in the reproduction number and stringency index of Covid-19 pandemic in Nigeria using the range chart.

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The study will make the government, non-governmental organizations, and researchers understand the nature of the variability of containment policies and the disease reproduction number, and possibly stimulate further research on these indices.

MATERIALS AND METHODS

Data Collection

The data for this study was obtained from the website of *Our World In Data (OWID)* (https://www.owid.org). It is a database providing data on the global spread of the Covid-19 pandemic. The Covid-19 data for Nigeria was obtained and used for the purpose of this research work. The features of interest are the reproduction number and the stringency index of the pandemic from February 2020 to July 2022.

The Range Chart

The range chart is a quality control chart used in monitoring process variability (usually in a manufacturing process). It is used to detect a shift in the process variability. This study employed the range chart to monitor variability in the reproduction number and the stringency index of Covid-19 pandemic in Nigeria. The reproduction number is basically the expected number of cases directly generated by one case in a population where all individuals are susceptible to infection (Fraser *et al*., 2009), while the stringency index is a measure of the strength of Covid-19 response policies. It is a composite measure of nine of the response metrics which include school closures, workplace closures, cancellation of public events, restrictions on public gatherings, closures of public transport, public information campaigns, restrictions on internal movements and international travel controls (www.ourworldindata.org). A typical range chart is shown in Figure 1.

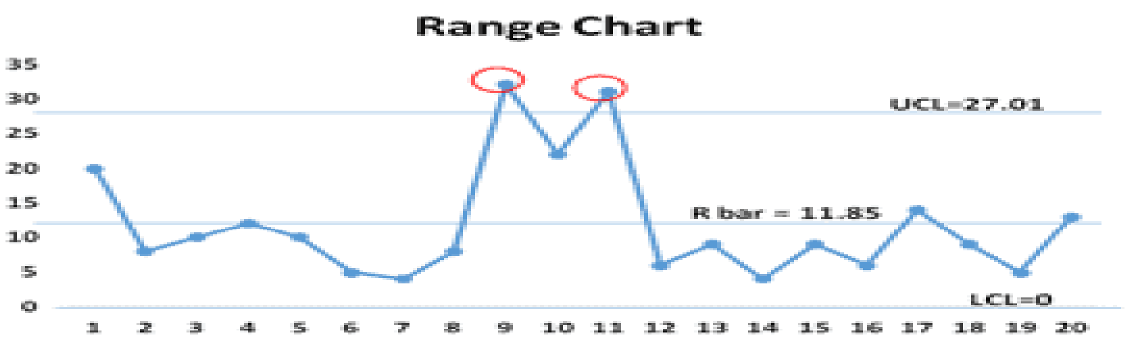

Figure 1: The Range Chart

The range chart consists of the center line (CL), the upper control limit (UCL) and the lower control limit (LCL). Unlike other control charts, the lower control limit of the range chart is usually set at zero (0) since the point zero represents no variability in the process. In other words, the interest of the investigator is usually in the upper control limit. The variability of a process is said to be out of control if at least two of the plotted points are above the upper control limit.

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To develop the range chart, the data is first put into subgroups of suitable size, m. In this study, the maximum time (in days) taken for a Covid-19 patient to develop symptoms of the disease, known as the incubation period, is used as the subgroup size of the chart. This maximum time is generally estimated to be 14 days (Ke, Yihao, Xia, Guangwei, Jingjing, Yanyan, Ashley, Wenbin, Li, Guan, & Wu, 2020; Henry, 2023).

In developing the range chart, the range of each subgroup is first computed. The range is simply the difference between the highest and the lowest values in each subgroup, i.e.,

$$R = (x) \ - min\ (x) \quad (1)$$

The centerline is given as the average range across all subgroups, i.e.,

$$\bar{R} = \frac{\sum_{i=1}^{m} R_i}{m} \quad (2)$$

where *m* is the number of subgroups.

The Upper Control Limit (UCL) and the Lower Control Limit (LCL) are given respectively as:

$$UCL = D_4\bar{R} \quad (3)$$

$$LCL = D_3\bar{R} \quad (4)$$

where D_3 and D_4 are control chart constants which depend on the subgroup size, *n*. (See Appendix.)

In this study, the Minitab 17 software is used to compute the control limits and plot the R charts for the reproduction number and stringency index of Covid-19 pandemic in Nigeria.

RESULTS AND DISCUSSION

Monitoring the Reproduction Number of Covid-19 Pandemic in Nigeria

The variability of the reproduction number of Covid-19 pandemic was monitored using the range chart. The center line, upper control limit and the lower control limit were obtained using Equations (2), (3) and (4) respectively. The subgroup size was taken to be the maximum incubation period of Covid-19 virus, which is 14 days (Ke *et al*, 2023). This is because any newly infected patient is deemed to have exhibited some symptoms at this time which will prompt the adjustment of the reproduction number for that period. Hence, the study adopted *n* = 14 as the subgroup size for the range chart. The control chart is as shown in Figure 1 below.

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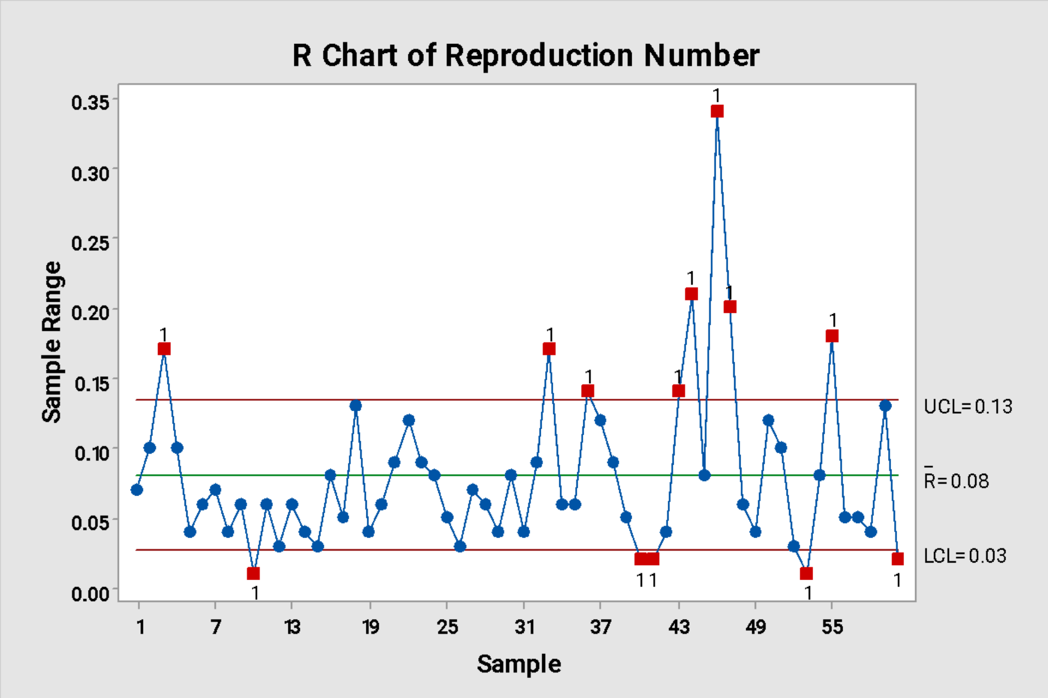

Figure 2: Range Chart of Reproduction Number of Covid-19 in Nigeria

Figure 2 shows the range chart of the reproduction number of Covid-19 pandemic in Nigeria. The chart revealed that the variation in the reproduction number of the virus showed out-of-control at point 3. This implies that the reproduction number was already out of control within the first 42 days after the index case.

Monitoring the Stringency Index of Covid-19 Pandemic in Nigeria

The variability of the stringency index was also monitored using the range chart. The center line, upper control limit and the lower control limit were calculated using Equations (2), (3) and (4) respectively. The incubation period of Covid-19 virus was again considered as the subgroup size. Hence, we adopted n = 14 as the subgroup size for the range chart. The control chart is as shown as in the figure below.

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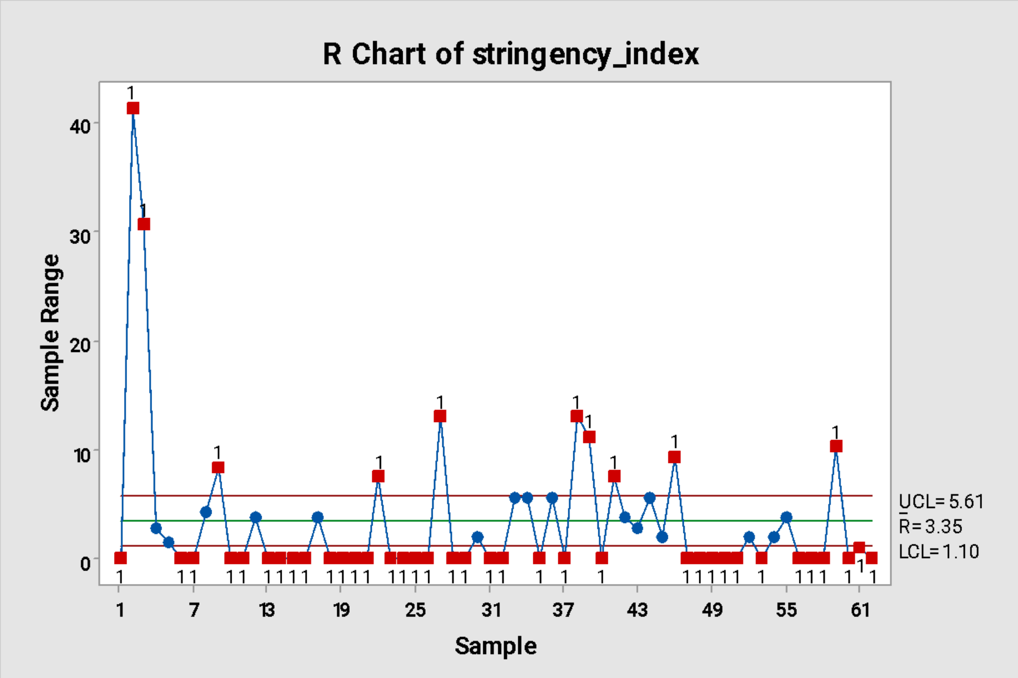

Figure 3: Range Chart of Stringency Index of Covid-19 in Nigeria

Figure 3 shows the range chart of the stringency index of Covid-19 pandemic in Nigeria. The chart revealed that the variation in the stringency index of the virus showed out-of-control at point 2. This implies that the stringency index was already out of control within the first 28 days after the index case. This accounts for the impact of government policy on the measures to contain the spread of the virus on households and the economy in general.

CONCLUSION

This paper demonstrates the application of control chart techniques in monitoring the reproduction number and stringency index of Covid-19 pandemic in Nigeria. This will help to track these relevant metrics and inform policymakers on whether to implement more or less stringent containment policies in order to control the spread of a disease.

The variation in the reproduction number and stringency index of the pandemic are out of statistical control within the first 42 days of infection. This may account for the rapid spread of the virus and the scorching effects of government policies on the economy as experienced within the country. Statistical quality control charts can be considered in monitoring some important metrics of a pandemic. This would help to inform stakeholders on the need to take appropriate measures to contain the spread of such a pandemic.

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REFERENCES

Alimohamadi Y, Taghdir M, Sepandi M. (2020). Estimate of the Basic Reproduction Number for Covid-19: A Systematic Review and Meta-analysis. *J Prev Med Public Health*. 53(3):151-157. doi: 10.3961/jpmph.20.076. Epub 2020 Mar 20. PMID: 32498136; PMCID: PMC7280807.

Drexler, J. F., Gloza-Rausch, F., Glende, J., Corman, V. M., Muth, D., Goettsche, M. and Drosten, C. (2010). Genomic Characterization of Severe Acute Respiratory Syndrome-Related Coronavirus in European Bats and Classification of Coronaviruses Based on Partial RNA-Dependent RNA Polymerase Gene Sequences. *Journal of Virology*, *84*(21), 11336–11349. doi: https://doi.org/10.1128/jvi.00650-10

Edike, N., Braimah, J. O., and Agbedeyi, O. D. (2020). A Retrospective Analysis and Monitoring of the Spread of Covid-19 in Nigeria. *Global Journal of Pure and Applied Sciences*, 26(1), 157-163. doi: https://dx.doi.org/10.4314/gjpas.v26i2.7

Fraser, C., Donnelly, C. A., Cauchemez, S., Hanage, W.P., Van, K. M. D., and Hollingsworth T. D. (2009). Pandemic potential of a strain of influenza A (H1N1): early findings. *Science*, 324 (5934), 1557–61. doi:10.1126/science.1176062 Retrieved from https://www.ncbi.nlm.nih.gov/pmc/ articles/PMC3735127 on February 21, 2022.

Henry, H. (2023). Estimate the incubation period of coronavirus 2019 (Covid-19). *Computers in Biology and Medicine*, 158(1), 89-94. Doi: https://doi.org/10.1016/j.compbiomed.2023.106794

Iyaniwura, S.A., Rabiu, M., David, J.F. and Kong, J.D. (2022). The basic reproduction number of Covid-19 across Africa. *PLoS ONE* 17(2): e0264455. Doi: https://doi.org/10.1371/journal. pone.0264455

Ke, M., Yihao, L., Xia W., Guangwei Z., Jingjing, H., Yanyan, G., Ashley, H, Wenbin, L. and Li, Q., Guan, X., and Wu, P. (2020). Early Transmission Dynamics in Wuhan, China, of Novel Coronavirus-Infected Pneumonia. *N Engl J Med*. 12(3), 45-51.

Matthew, O. A., Akindele, A. O., Farah, A. A., Funmilayo, K. and Ahmad, I. M. I. (2021). Modeling the Dynamics of Covid-19 in Nigeria. *Int. J. Appl. Comput. Math*. 7(67), 1-25. https://doi.org/10.1007/s40819-021-01014-5

Mizumoto, K., Tariq, A., Roosa, K., Kong, J., Yan, P., Chowell, G. (2019). Spatial variability in the reproduction number of Ebola virus disease, Democratic Republic of the Congo, January–September 2019. Euro Surveill, 24(42). doi: https://doi.org/10.2807/1560-7917.ES.2019.24.42.1900588

National Health Commission of the People's Republic of China (2020). The updates of Covid-19 as of 29 February, 2020. Retrieved from http://www.nhc.gov.cn/xcs/ yqtb/202003/9d462194284840ad96ce75eb8e4c8039.shtml on December 12, 2022.

Okuonghae, D., and Omame, A. (2020). Analysis of a mathematical model for COVID-19 population dynamics in Lagos, Nigeria. *Chaos Solitons Fract*. 139, doi: https://doi.org/10.1016/j.chaos.2020.110032

Peiris, J. S. M., Lai, S. T., Poon, L. L. M., Guan, Y., Yam, L. Y. C., Lim, W., and Yuen, K. Y. (2003). Coronavirus as a possible cause of severe acute respiratory syndrome. *Lancet*, 361(9366), 1319–1325. Doi: https://doi.org/10.1016/S0140-6736(03)13077-2

Samuel, O. A., Muhammad, A. B., Samuel, O. O., Haruna, U. Y., and Rafiu, O. A. (2020). Modeling COVID-19 Cases in Nigeria Using Some Selected Count Data Regression Models. *International Journal of Healthcare and Medical Sciences*. 6(4), 64-73.

Article DOI: 10.52589/AJMSS-458RR403

DOI URL: https://doi.org/10.52589/AJMSS-458RR403

United Nations (2020). Covid-19 Pandemic: Humanity needs leadership and Solidarity to defeat the Coronavirus. Retrieved from https://www.undp.org/turkiye/news/humanity-needs-leadership-and-solidarity-defeat-covid-19 on May 11, 2022

Woo, P. C. Y., Huang, Y., Lau, S. K. P., and Yuen, K. Y. (2010). Coronavirus genomics and bioinformatics analysis. *Viruses*, 2(1), 1805–1820. Doi:https://doi.org/10.3390/v2081803

World health Organization. (2020). Director-General's remarks at the media briefing on 2019-nCoV Retrieved from https://www.who.int/dg/speeches/detail/who-director-generals-remarks-at-the-media-briefing -on-2019-ncov-on-11-february-2020 on May 11, 2022

Yin, Y., and Wunderink, R. G. (2018). MERS, SARS and other coronaviruses as causes of pneumonia. *Respirology*, 23, 130–137. Doi: https://doi.org/10.1111/resp.13196

Zaki, A. M., Van Boheemen, S., Bestebroer, T. M., Osterhaus, A. D. M. E., and Fouchier, R. A. M. (2012). Isolation of a novel coronavirus from a man with pneumonia in Saudi Arabia. *New England Journal of Medicine*, *367*(19), 1814–1820. https://doi.org/10.1056/NEJMoa1211721

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APPENDIX

Table of Control Chart Constants

	X-bar Chart Constants		for sigma estimate	R Chart Constants		S Chart Constants	
Sample Size = m	A_2	A_3	d_2	D_3	D_4	B_3	B_4
2	1.880	2.659	1.128	0	3.267	0	3.267
3	1.023	1.954	1.693	0	2.574	0	2.568
4	0.729	1.628	2.059	0	2.282	0	2.266
5	0.577	1.427	2.326	0	2.114	0	2.089
6	0.483	1.287	2.534	0	2.004	0.030	1.970
7	0.419	1.182	2.704	0.076	1.924	0.118	1.882
8	0.373	1.099	2.847	0.136	1.864	0.185	1.815
9	0.337	1.032	2.970	0.184	1.816	0.239	1.761
10	0.308	0.975	3.078	0.223	1.777	0.284	1.716
11	0.285	0.927	3.173	0.256	1.744	0.321	1.679
12	0.266	0.886	3.258	0.283	1.717	0.354	1.646
13	0.249	0.850	3.336	0.307	1.693	0.382	1.618
14	0.235	0.817	3.407	0.328	1.672	0.406	1.594
15	0.223	0.789	3.472	0.347	1.653	0.428	1.572
16	0.212	0.763	3.532	0.363	1.637	0.448	1.552
17	0.203	0.739	3.588	0.378	1.622	0.466	1.534
18	0.194	0.718	3.640	0.391	1.608	0.482	1.518
19	0.187	0.698	3.689	0.403	1.597	0.497	1.503
20	0.180	0.680	3.735	0.415	1.585	0.510	1.490
21	0.173	0.663	3.778	0.425	1.575	0.523	1.477
22	0.167	0.647	3.819	0.434	1.566	0.534	1.466
23	0.162	0.633	3.858	0.443	1.557	0.545	1.455
24	0.157	0.619	3.895	0.451	1.548	0.555	1.445
25	0.153	0.606	3.931	0.459	1.541	0.565	1.435

Control chart constants for X-bar, R, S, Individuals (called "X" or "I" charts), and MR (Moving Range) Charts.

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