Stochastic Traffic Flow Prediction Over the Section of Road Using Monte Carlo Simulation

Mehboob Ali Jatoi*, Shakeel Ahmed Kamboh†, Muhammad Aslam Soomro‡, Saeed Ahmed Rajput§

Abstract

The prediction of traffic flow on the roads is very important for efficient management of well-managed and intelligent transport system, which is essential for the developed country. The traffic flow is subdivided into vehicle types and routes and are control with different ways like signal system, road infrastructure upgrading, ramp mattering, and is quite good for the intelligent transport system. But it's quite challenging with mixed traffic flow (congestion) with no traffic signal system and ramp mattering. In order to overcome the congestion with mixed traffic flow, the prediction method can play an important role in overcoming congestion of flow on road section. In this study, A Monte Carlo Simulation algorithm is proposed to predict the traffic flow. Different hypothesis tests are applied with goodness-of-fit. Also the MATLAB distribution fit toolbox is used to check the stochastic behavior of traffic flow. The proposed prediction method is validated with error estimation between the collected and predicted data. The current study is useful to predict the future state of traffic flow over the section of road for the formulation of intelligent transform system.

***Keywords**:* Traffic Flow Prediction; Monte Carlo Simulation, Goodness-of-fit; Normal Distributions; Lognormal Distributions.

Introduction

Now a days, the traffic flow plays an important role in development of country. Due to increase in population, the traffic demand increases every day. This may create the heavy traffic flow over the road and negative effects may occur. There are lots of chances for the negative effects of traffic flow like accidents, increased fuel usage, increased arrival and delay time and congestion. To overcome the negative effects of traffic flow, the prediction of traffic flow plays an important role for the future state of traffic flow.

*Corresponding Author: Department of Basic Science & Related Studies, Quaid- e-Awam University of Engineering, Science & Technology, Nawabshah 67480, Pakistan, mehboobali.ques@gmail.com

†Department of Mathematics & Statistics, Quaid-e-Awam University of Engineering, Science & Technology, Nawabshah 67480, Pakistan, sakamboh@quest.edu.pk

‡Department of Mathematics, Shaikh Ayaz University, Shikarpur 78100, Pakistan, aslamsoomro@saus.edu.pk

§Department of Basic Science & Related Studies, The University of Larkano, Larkana 77280, Pakistan. saeedahmed@uolrk.edu.pk

Cheslow et al. (1992) investigated that traffic prediction is one of the main factor to overcome traffic congestion. The main structure of the road can be constructed to avoid traffic congestion using prediction management system. The traffic prediction may take place using the real-time traffic collection of data over the section of the road. Therefore for real-time data collection, a section of road is to be considered a congested traffic road. Continuous change in the demand of traffic flow creates the uncertainty, the Monte Carlo Simulation is used to solve the problems which involve the certainty using random number (stochastic) and probability statistics. In this study, Monte-Carlo simulation algorithm is used to predict the traffic flow over the section of road of Shaheed Benazir Abad, Nawabshah, Sindh Pakistan.

The Monte Carlo Simulation method is investigated by Nam et al. (2012) and used in different fields of research as pavement, traffic, reliability and risk analysis. Monte Carlo simulation is highlighted by Herbold (2002) in pavement cost analysis, Demos et al. (2006) analyze for Accelerated Pavement Testing (APT), Bhutto et al. (2022) applied for simulation by detached eddy simulation (DES) to predict the flow behavior of the fluid, Alaye et al. (2020) consider the MCS for the reliability of traffic volume under different condition of the flow of traffic, Deshpande et al. (2012) used life cycle cost analysis of pavements with uncertainty, rehabilitation and maintenance.

Li et al. (2019) had also been used MCS for reliability analysis to estimate the traffic noise on highways and taking probability distribution driven from collected data. Bhutto et al. (2023) developed the algorithm for the simulation of fluid flow using the CDF tool, Alimohammadi et al. (2005) developed the stochastic model for estimating mean annual sediment load to a stream and to estimate the uncertainty in the plot scale model of road section using Monet Carlo simulation. Jones, et al. (2008) proposed the MCS model for analyzing the traffic vehicles collision using the collision calculation of vehicles. Gidlewski et al. (2019) have applied the Monte Carlo simulation for risk using the impact of variability and uncertainty with the total probability distribution model and to find the cost of specific pavement material by incorporating the various factors of traffic flow volume as daily average traffic and surface type material. Salling et al. (2006) developed a model for network by taking probabilities in intersections.

Ullman et al. (2008) represent the model using MCS for the prediction of the remaining service life of different materials which randomly generate the descent rate and stochastic descent function. Du et al. (2009) formulated the Monte Carlo Simulation and Markov chain for traffic behavior, and Kumar et al. (2013) and Kumar et al. (2015)

formulated for autonomous cars and compared both MCS and Markov chain methods with their probabilistic performance to predict the traffic situation. Zhang et al. (2009) and Ci et al. (2009) developed the Monte Carlo simulation model to predict the traffic flow for a short time of traffic with corresponding the past collected data of traffic flow over the road section.

Althoff et al. (2011) established the stochastic traffic flow model taking real-time traffic time estimation and prediction using MCS. Stathopoulos et al. (2003) investigate the use of MCS for short-term traffic flow prediction in peak hours. Sau et al. (2007) formulated the Sampling Markov Chain method for incomplete data and summarized that the Markov chain method is better than the joint probability distribution re-calculating method and Historical average method for incomplete data. Canaud et al. (2013) suggested the Additive Seasonal Vector Autoregressive Moving Average (A-SVARMA) model for forecasting short-term traffic flow prediction. Khokhar et al. (2023) developed the algorithm using MCS to predict the non-Newtonian fluid.

Mishraa et al. (2015) included the variation into the MCS with fuzzy mathematics and MATLAB to design an intelligent traffic flow prediction model for the traffic pattern in a single interaction. Sun, et al. (2004) explained the multivariate Artificial Neural Network (ANN) modeling for traffic prediction. Khokhar et al. (2023) proposed Taylor-Galerkin/Pressure-Correction finite element algorithm to predict the fluid flow. Jatoi et al. (2024) developed an algorithm to investigate the stochastic behavior of traffic flow over a section of road. Bhutto et al. (2022) discussed the simulation of oscillating flow using the fast Fourier transform with two-dimensional flow. Mai et al. (2012) addressed the use of ARIMA model to predict the traffic flow.

Shengda et al. (2013) have addressed the sufficient use of the Monte Carlo simulation model in the field of civil engineering to predict and formulate the traffic model and for the prediction of traffic flow. Although many researchers have used the Monte Carlo simulation to predict the traffic flow prediction and using the same method as MATLAB, this study is adopted for the section of road. The main aim of this study is to predict the future state of traffic flow using the Monte-Carlo simulation with MATLAB Algorithm.

For the validation of model, the traffic data is collected and used for the new predicted value of traffic flow by considering a section of the road of Shaheed Benazir Abad Nawabshah, Pakistan. The considered section is very congested traffic, so the data with high traffic flow with one path was collected and then predicted using the Monte Carlo simulation using

MATLAB program with minimum and maximum values of collected data with Mean and standard deviation.

Proposed Methodology

The current study is based on the high congested traffic data. For the data collection, the area with an easy approach and high congested is considered. Figure 1 shows a Satellite view of the section of the road of Shaheed Benazir Abad Nawabshah Sindh Pakistan. The road is 2.0 miles starting from New Naka to Zero Point Nawabshah, the starting point consists of 8 lanes, out of them 4 incoming and 4 outgoing lanes for traffic flow with ramps in and out. Out of them the data shall be collect only one lane with no ramp in or out, that is for smooth lane.

After collection of data, statistical analysis and different distribution tests shall be applied for the goodness of fit with 95% confidence. Then the Monte-Carlo simulation using MATLAB shall be applied to predict the new traffic data and same statistical analysis and test shall be applied to check the goodness of fit, at last the error analysis shall be perform between the collected and predicted data.

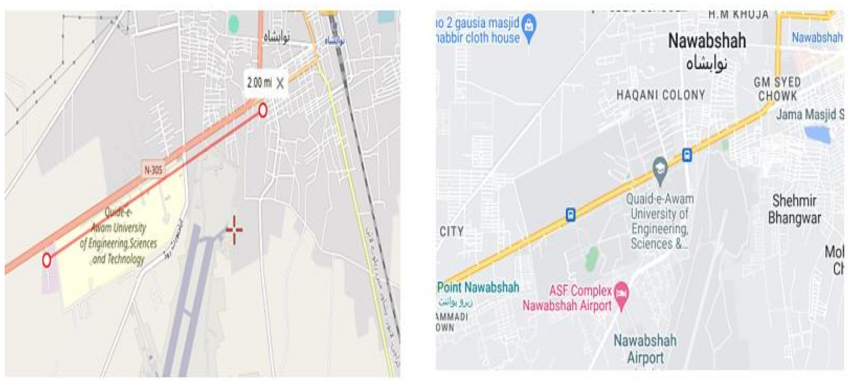

Figure 1: Satellite view of section of road of Nawabshah, Shaheed Benazir Abad.

Data collection

The data may be collect using different methods, like video recording method, sensor method, manual method, radar system and many more. Due to the unavailability of the above-described methods, the manual method is used to collect the data. the data is collected by visiting the targeted place of the section of road, the data is collected for one day continuously from 7:00 to 18:00 for a complete week of the month from January 15, 2024, to January 21, 2024, at the main position of inflow and outflow of the section of road. The vehicles are to be considered as volume of traffic including all types of traffic as cars, bikes, cycles and heavy vehicles because there is no restriction for the entry or existence of any type of vehicle. Table 1 shows the total number of vehicles flowing over the section of the road.

Table 1(a): Vehicles flow data collection over the section of road.

Day/Time	7:00-8:00	8:00-9:00	9:00-10:00	10:00-11:00	11:00-12:00
Monday	198	313	412	431	466
Tuesday	242	323	348	411	512
Wednesday	233	297	334	377	389
Thursday	311	432	512	623	602
Friday	263	366	412	427	467
Saturday	248	456	411	518	511
Sunday	152	373	375	287	390
Total	1,647	2,560	2,804	3,074	3,337
Average	235.29	365.71	400.57	439.14	476.71
St: Dev	50.07	60.45	58.65	106.49	74.77
Range	159.00	159.00	178.00	336.00	213.00
Skewness	-0.32	0.51	1.08	0.56	0.40

Table 1(b): Vehicles flow data collection over the section of road.

Day/Time	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00	17:00-18:00
Monday	501	477	422	391	297	202
Tuesday	628	492	455	402	310	232
Wednesday	428	511	459	421	318	294
Thursday	484	487	392	429	411	334
Friday	535	512	499	474	329	276
Saturday	474	433	487	389	413	377
Sunday	344	516	412	367	310	311
Total	3,394	3,428	3,126	2,873	2,388	2,026
Average	484.86	489.71	446.57	410.43	341.14	289.43
St: Dev	87.99	28.96	39.55	34.86	49.35	59.53
Range	284.00	83.00	107.00	107.00	116.00	175.00
Skewness	0.03	-1.40	-0.02	0.91	1.07	-0.10

Tables 1(a) and 1(b) shows the total number of vehicles for a week from Monday to Sunday, from 7:00 to 18:00 with the interval of one hour. The data is statistically tested with a total number of vehicles week-wise. The average flow of vehicles is calculated day-wise and week-wise, in figure 3, the green color data shows the total week-wise average, standard deviation, range and skewness, of the collected data. Monte Carlo simulation prediction algorithm is consider given by Mishraa et al. (2015)

and MATLAB software is used to implement the traffic flow prediction algorithm.

1. Predicted flow = ln(Present actual flow/previous flow)

Now calculate AVERAGE, STDDEV.P and Variance respectively.

2. Drift = Average Periodic flow – (0.5*Variance)
3. Random = Standard Deviation * NORMINV(Rand())
4. Predicted Value = Present Actual flow *$e^{\text{Drift + Random value}}$

To consider the total number of iterations, the total number of data points for a week are 84 and run simulation 100 times. Therefore, the total number of simulations is 84*100. The mention algorithm is used to predict the traffic flow using the past collected traffic data using analysis of the data, taking the minimum and maximum flow of vehicles in a time interval of one hour, the average flow and standard deviation of collected data considering as present actual/previous flow. The Monte Carlo simulation technique is used in MATLAB by considering the collected data as past data to predicting the new traffic data. In the current study, the data set is first set into the format for a data of one week as a single data set.

Statistical Analysis

The data set is tested using a Normal probability distribution function using Normal distribution and a goodness of fit to check the Normality of the, collected data and predicted data. The data is described only for normal or lognormal probability distribution function to check the stochastic behavior of traffic flow. The Kolmogorov-Smirnov (K-S) test, Kolmogorov-Smirnov Modified test, and Anderson-Darling (AD) test are applied for Normal and lognormal distribution and the result is shown in the following table with its statistics, p-value, and decision at 95% of confidence level.

For normal and lognormal distributions the Probability plot is used for both the collected and for predicted data. A distribution fit is also applied using the MATLAB fit for both normal distribution fit and Lognormal distribution fit and found mostly fitted distribution as Normal distribution using the p-values and its decision of hypothesis, as for the Normal distribution the K-S test, K-S modified and AD test are accept the hypothesis as they can’t reject the hypothesis test, while for Lognormal distribution the AD test rejects the hypothesis test. Hence the stochastic behavior of the traffic flow is normally distribution. Table 2 describes the statistic for the goodness-of-fit for the normal and lognormal distributions, all the tests accept (Can't reject Normal) the distribution then the distribution is to be considered the best-fit distribution for the data.

Table 2: Distribution fit for the collected data.

Distribution	Goodness of fit Tests	Statistics	p-value	Decision
Normal	K-S test	0.05922	1.00000	Can't reject Normal
	K-S modified test	0.05922	0.15000	Can't reject Normal
	A-D test	0.31649	0.53398	Can't reject Normal
Lognormal	K-S test	0.10783	0.26392	Can't reject Lognormal
	K-S modified test	0.09592	0.05521	Can't reject Lognormal
	A-D test	1.12404	0.00575	Reject Lognormal

Results and Discussion

Tables 3(a) and 3(b) show the predicted value found from the Monte Carlo simulation algorithm to predict the random numbers. The data points were generated in one column and then according to the collected data the data set was formatted as Monday to Sunday from 7:00 to 18:00 and then a statistical analysis used the are applied on predicted data, the average, standard deviation, range and skewness were found. Similarly all normality tests are also applied on predicted data for Normal and Lognormal distributions to check the stochastic behavior of predicted data, and found the K-S test, K-S modified test and AD test for normal distributed (can't reject the hypothesis) and since the p-value is also greater than 0.005 for the 95% of confidence level, while for the Lognormal distribution the K-S modified test and AD test rejected the hypothesis. Finally, using MATLAB distribution fit toolbox for both the collected data and predicted data showing in Figure 2 and Figure 3 respectively. The normal distribution and lognormal distributions fit is applied and found that all the data is much near to the normal distribution fit line as compared to the lognormal distribution fit line, meanwhile both the collected and predicted data are normally distributed.

Table 3(a): Predicted Vehicles flow over the section of road

Day/Time	7:00-8:00	8:00-9:00	9:00-10:00	10:00-11:00	11:00-12:00
Monday	203	322	403	407	476
Tuesday	233	344	360	402	501
Wednesday	229	301	339	388	398
Thursday	316	432	512	623	602
Friday	260	378	402	424	460
Saturday	239	349	414	507	503
Sunday	159	367	380	281	398
Total	1,639	2493	2,810	3,032	3,332
Average	235.29	365.71	400.57	439.14	476.71
St: Dev	50.07	60.45	58.65	106.49	74.77
Range	159.00	159.00	178.00	336.00	213.00
Skewness	-0.32	0.51	1.08	0.56	0.40

Table 3(b): Predicted Vehicles flow over the section of road

Day/Time	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00	17:00-18:00
Monday	510	487	433	404	309	220
Tuesday	622	503	466	433	319	228
Wednesday	433	503	455	410	209	301
Thursday	584	487	392	429	411	334
Friday	529	517	502	466	320	267
Saturday	470	430	482	381	409	366
Sunday	338	512	407	370	302	302
Total	3,386	3,439	3,137	2,893	2,279	2,018
Average	484.86	489.71	446.57	410.43	341.14	289.43
St: Dev	87.99	28.96	39.55	34.86	49.35	59.53
Range	284.00	83.00	107.00	107.00	116.00	175.00
Skewness	0.03	-1.40	-0.02	0.91	1.07	-0.10

Table 4 describes the statistic for the predicted values of the traffic flow over the section of road using Monte Carlo simulation and for the (Goodness of fit) GOF for the normal and lognormal distribution, as two main distributions described the stochastic behavior of the traffic flow over the section of road. The K-S test, K-S modified and A.D tests are applied for the goodness of fit of the distributions. All the tests accept (Can't reject Normal) the distribution then the distribution is to be considered the best-fit distribution for the data. Hence the predicted values show that the data is normally distributed. It can also be concluded that the traffic flow is normally distributed.

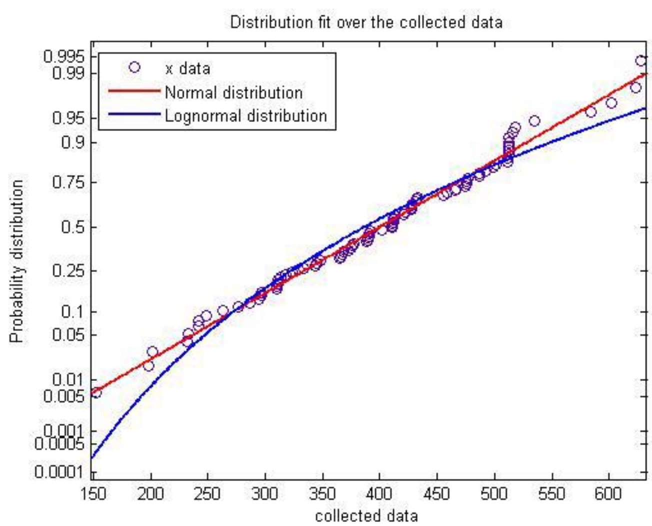

Figure 2: Distribution fit over the collected data.

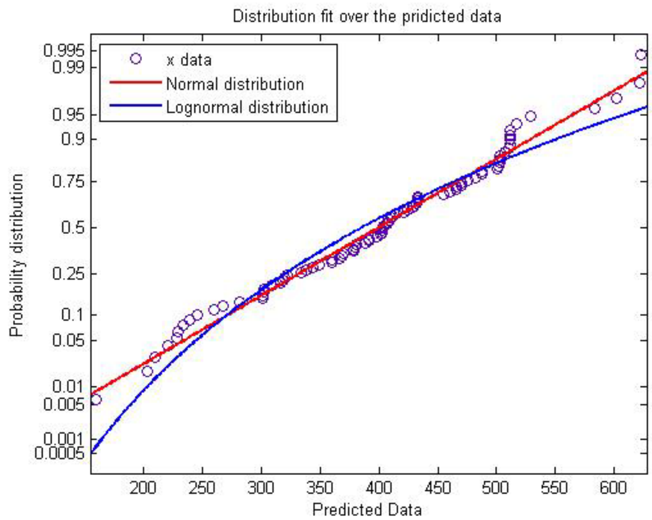

Figure 3: Distribution fit over the Predicted data

Table 4: Distribution fit for the Predicted data

Distribution	Goodness of fit Tests	Statistics	p-value	Decision
Normal	K-S test	0.06096	1.00000	Can't reject Normal
	K-S modified test	0.06096	0.21500	Can't reject Normal
	A-D test	0.44763	0.27333	Can't reject Normal
Lognormal	K-S test	0.11579	0.19451	Can't reject Lognormal
	K-S modified test	0.10388	0.03358	Reject Lognormal
	A-D test	1.46511	0.000819	Reject Lognormal

Figure 3 and Figure 4, show the distribution fit over the collected and predicted data. The collected and predicted data are converted into the probability distribution. The normal and lognormal distribution is applied using the MATLAB distribution fit toolbox.

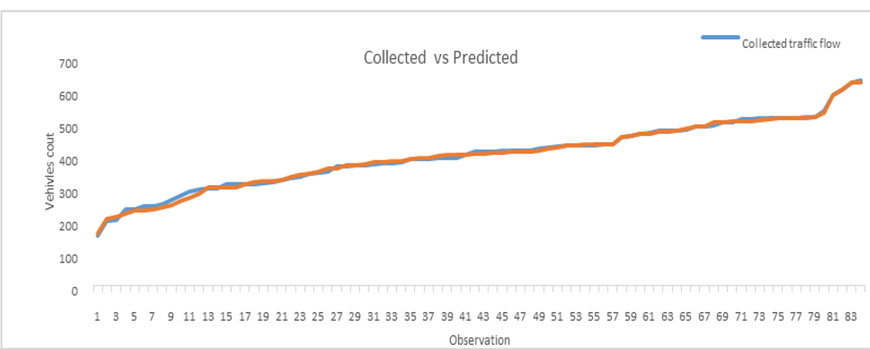

Figure 4: The Collected vs Predicted traffic flow.

Using the MATLAB toolbox with probability distributions, the normal and lognormal distribution lines are fit over the collected and predicted traffic data, hence most of the data points are much near the normal distribution line as compared to the lognormal distribution line, while for the lognormal distribution line is far from the data points. Hence for both the collected and predicted values, the most fitted distribution is normal distribution which means the both data collected and predicted are normally distributed.

Now as the predicted and collected data is normally distribution which guaranteed for the use of Monte Carlo simulation. The MCS is based on the number of iterations and also the iterations depend on the data points in the collected/observed data, as the number of data points is distributed into week form with time intervals of 12 on each day, so for the complete week the total data points are 84. Therefore, for the use of MCS the standard normal variate is 1.96, the variance of the observed/collected data set is 9969.8 percentage error of the mean is 1.390981, and the mean of the observed data set is 400.0476, so the total number of iteration for MCS to estimate/predict the random number as traffic flow is 8400, as the per iteration is allowed to predict into the 100 iteration for a single number. The number of iterations (N) was calculated using the equation (1), Driels, et al. (2004). and Hasnat, et al. (2019).

$$N = \left[\frac{100 Z_c E^2}{e\bar{x}}\right] \tag{1}$$

Where z_c is the Standard Normal variate, E^2 is the variance, e is the percentage error and $\bar{x}$ is the mean of the data.

For the consideration of predicted traffic flow, the mean percentage error was calculated using the equation (2), for consideration of the total volume of traffic flow by week-wise from 7:00 to 18:00 in Table 5. While Figure 4 shows the analysis of traffic flow for collected and predicted data.

$$MAPE = \left(\frac{1}{N}\sum_{i=1}^{N}\frac{(u_i - u'_i)}{u_i}\right)\text{x100} \tag{2}$$

Where $u_i$is the collected value of data is, $u'_i$is the predicted value of data, $N$is the total number of observation.

Conclusion

This study developed the Monte Carlo simulation model for the traffic flow prediction over the section of the road to capture the stochastic traffic flow situation of the road. The data was collected using the manual method and then analyzed for statistical measurement. Then statistical measures were used to predict the traffic flow data prediction using

MATLAB. The main purpose of this study was to predict the future state of the traffic for the section of the road. The predicted data can be used to manage the traffic and to make updates to the travelers for the expected situation of the road traffic using an intelligent transport system. Monte Carlo simulation nowadays is a powerful tool to use for prediction and is used in many real-life problems that involve uncertainty because the simulation is used for forceful traffic flow prediction. This study may be more effective by considering the prediction of a special type of vehicle on the section of the road. This study is carried out to predict the new region by considering the algorithm of Monte Carlo simulation. The study can be carried out more efficiently by adding the stochastic factors, the ramps in and out.

Table 5: Mean Percentage Error between Collected and Predicted flow.

Time	Collected traffic flow/one hour	Predicted traffic flow/one hour	MAPE (%)
7:00-8:00	1647	1639	0.486
8:00-9:00	2449	2493	1.79
9:00-10:00	2804	2810	16.67
10:00-11:00	3079	3032	1.526
11:00-12:00	3337	3332	0.159
12:00-13:00	3496	3486	0.287
13:00-14:00	3428	3439	0.32
14:00-15:00	3126	3137	0.32
15:00-16:00	2873	2893	0.697
16:00-17:00	2388	2279	4.56
17:00-18:00	2026	2018	0.395

References

Alaye, Q. E. A., Ling, X., Dong, Z., & Bambou, G. (2020). Evaluation of mixture performance recycled asphalt pavement materials as base layer with or without rejuvenator into the asphalt. *Journal of Wuhan University of Technology-Mater. Sci. Ed*., 35, 579-597.

Alimohammadi, I., Nassiri, P., & Hosseini, M. B. M. (2005). Reliability analysis of traffic noise estimates in highways of Tehran by Monte Carlo simulation method. *Journal of Environmental Health Science & Engineering*, *2(4), 229-236*.

Althoff, M., & Mergel, A. (2011). Comparison of Markov chain abstraction and Monte Carlo simulation for the safety assessment of autonomous cars. *IEEE Transactions on Intelligent Transportation Systems*, *12*(4), 1237-1247.

Bhutto, A. A., Harijan, K., Hussain, M., Shah, S. F., & Kumar, L. (2022). Numerical simulation of transient combustion and the acoustic environment of obstacle vortex-driven flow. *Energies*, *15*(16), 6079.

Bhutto, A. A., Hussain, M., Shah, S. F., & Harijan, K. (2022). Computation of vortex driven flow instability through unsteady rans and scale resolving simulation. *Institute of Space Technology*, *12*(1), 14-22.

Bhutto, A. A., Memon, S., Bhutto, I. A., Khokhar, R. B., & Shaikh, A. A. (2023). Numerical simulation of combustion chamber film cooling mechanism. *Balochistan J. Eng. Appl. Sci.*

Canaud, M., Mihaylova, L., Sau, J., & El Faouzi, N. E. (2013). Probabilty hypothesis density filtering for real-time traffic state estimation and prediction. *Networks and Heterogeneous Media (NHM)*, *8*(3), *825-842*.

Cheslow, M., Hatcher, S. G., & Patel, V. M. (1992). An initial evaluation of alternative intelligent vehicle highway systems architectures. *The National Academies of Sciences, Engineering, and Medicine. 92(63)*

Ci, W. X., Ahmed, S. K., Zulkifli, F., & Ramasamy, A. K. (2009, November). Traffic flow simulation at an unsignalized T-junction using Monte Carlo Markov Chains. In *2009 IEEE International Conference on Signal and Image Processing Applications (pp. 346-351).*

Demos, G. P. (2006). Life cycle cost analysis and discount rate on pavements for the Colorado Department of Transportation. *The National Academies of Sciences, Engineering, and Medicine*.

Deshpande, V. P., Damnjanovic, I. D., & Gardoni, P. (2012). Effects of overlay designs on reliability of flexible pavements. *Structure and Infrastructure Engineering, 8(2), 185-198*.

Driels, M. R., & Shin, Y. S. (2004). Determining the number of iterations for Monte Carlo simulations of weapon effectiveness. *Monterey, California. Naval Postgraduate School.*

Du, Y., Geng, Y., & Sun, L. (2009). Simulation model based on Monte Carlo method for traffic assignment in local area road network. *Frontiers of Architecture and Civil Engineering in China, 3, 195-203.*

Gidlewski, M., Prochowski, L., Jemioł, L., & Żardecki, D. (2019). The process of front-to-side collision of motor vehicles in terms of energy balance. *Nonlinear Dynamics, 97*, 1877-1893.

Hasnat, A., & Rahman, F. I. (2019). Traffic flow prediction performance comparison between ARIMA and Monte Carlo simulation. *Transport and Logistics the International Journal, 19(46), 12-21.*

Jatoi, M. A., Kamboh, S. A., Abro, O. A., Rajput, S. A., & Zardari, L. A. (2024). Investigation the Stochastic behaviour of the Traffic Flow: A Case Study of a Section of a Road. *VFAST Transactions on Mathematics, 12(1), 189-201.*

Jones, A., Stovin, V., Guymer, I., Gaskell, P., & Maltby, L. (2008, September). Modelling temporal variations in the sediment concentrations in highway runoff. In *Proceedings of the 11th International Conference on Urban Drainage, Edinburgh, UK (Vol. 31).*

Khokhar, R. B., Bhutto, A. A., Bhutto, I. A., Sheikh, F., & Solangi, M. A. (2023). Numerical Analysis of Newtonian Fluids in Channel Flows using Semi-Implicit Time Stepping Taylor-Galerkin/Pressure Method. *The Sciencetech*, *4*(3).

Khokhar, R. B., Bhutto, A. A., Bhutto, I. A., Mengal, A., Shaikh, F., & Shaikh, A. A. (2023). Numerical analysis of non-newtonian fluid flows through an annulus occupied with or without porous materials. *Balochistan Journal of Engineering & Applied Sciences (BJEAS).*

Kumar, K., Parida, M., & Katiyar, V. K. (2013). Short term traffic flow prediction for a non urban highway using artificial neural network. *Procedia-Social and Behavioral Sciences*, *104*, 755-764.

Kumar, S. V., & Vanajakshi, L. (2015). Short-term traffic flow prediction using seasonal ARIMA model with limited input data. *European Transport Research Review*, *7*(3), 1-9.

Li, J., Xiao, F., Zhang, L., & Amirkhanian, S. N. (2019). Life cycle assessment and life cycle cost analysis of recycled solid waste materials in highway pavement. *A review. Journal of Cleaner Production, 233, 1182-1206.*

Mai, T., Ghosh, B., & Wilson, S. (2012). Multivariate short-term traffic flow forecasting using Bayesian vector autoregressive moving average model. *The National Academies of Sciences, Engineering, and Medicine* (No. 12-3728).

Mishraa, R., Singhb, A. P., Sharmac, A., & Sarkard, A. K. (2015, December). Short term traffic prediction using Monte Carlo simulation. In *3rd conference of Transportation Research Group of India (pp. 1-14).*

Nam, L. T., Kaito, K., Kobayashi, K., & Okizuka, R. (2012). Modeling pavement deterioration processes by poisson hidden markov models. *Journal of Japan Society of Civil Engineers, Ser. F4 (Construction and Management)*, *68*(2), 62-79.

Salling, K. B., & Leleur, S. (2006, December). Assessment of transport infrastructure projects by the use of Monte Carlo simulation: The CBA-DK model. In *Proceedings of the 2006 Winter Simulation Conference* (pp. 1537-1544).

Sau, J., El Faouzi, N. E., Ben Aissa, A., & de Mouzon, O. (2007). Particle filter-based real-time estimation and prediction of traffic conditions. In *Recent advances in stochastic modeling and data analysis (pp. 406-413).*

Shengda, Z., Lurong, W., Lin, J., & Bizhi, W. (2013). Study on Monte Carlo simulation of intelligent traffic lights based on fuzzy control theory. *Sensors & Transducers*, *156*(9), 211.

Singh, A. P., & Ghosh, S. K. (2003). Uncertainty analysis in river basin water quality management. *Integrated water resources planning and management,* 260-268.

Stathopoulos, A., & Karlaftis, M. G. (2003). A multivariate state space approach for urban traffic flow modeling and prediction. *Transportation Research Part C: Emerging Technologies*, *11*(2), *121-135.*

Sun, S., Yu, G., & Zhang, C. (2004, June). Short-term traffic flow forecasting using sampling Markov Chain method with incomplete data. *IEEE Intelligent Vehicles Symposium, 2004 (pp. 437-441).*

Ullman, G. L., Finley, M. D., Pike, A. M., Knapp, K. K., Songchitruksa, P., & Williams, A. A. (2008). Studies to improve temporary traffic control at urban freeway interchanges and pavement marking material selection in work zones. *Research Rep. 0-5238, 2*.

Zhang, H. (2009). Sustainable pavement asset management based on life cycle models and optimization methods (Doctoral dissertation, University of Michigan).