Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 32 No. 1 (2025)

Development of Probability Distribution Functions for Material Utilization in Road Construction Projects

[1]Gaurav Gautam, [2]Dr. Gaurav Shukla
[1]Research Scholar, Department of Civil Engineering, Maharishi University of Information Technology, Lucknow
[2]Assistant Professor, Department of Civil Engineering, Maharishi University of Information Technology, Lucknow

Article History:

Received: *15-07-2024*

Revised:*28-08-2024*

Accepted:*11-09-2024*

Abstract: Road construction is a major contributor to the country's development, and its development requires more attention than any other construction sector. The dynamic nature of these projects complicates planning and scheduling. There has been considerable research in various countries on supply chain management and its application in construction. However, very few studies have been conducted in the Indian context using real-time data for material usage as input for discrete event simulation modeling as a tool for supply chain management. The present research arrives at a probability distribution function for material usage for all layers of a Road construction project.

Keywords: Road construction, material utilization, simulation model etc.

Introduction

Road building projects greatly contribute to the country's development and require rigorous planning, scheduling, and management. Due to road construction projects' linear and dynamic nature, the quantity of material requirements varies at every stage. This variant causes a more complete analysis of the critical resources in order to reduce delays. Furthermore, the perishable mix must be delivered from the factory within the time range given, reducing the amount of idle time for other project resources. Any project's success depends on identifying and providing the appropriate amount of material and equipment at appropriate time. Delays are one of most serious global challenges that construction industry & project stakeholders confront.

According to Ministry of Road Transport & Highways' AnnualReport (2023-2024), India has world's second-largestroad network,totaling 63.45 lakh kilometres in length. According to a study conducted by Statista's research section, the infrastructure industry contributed around 5% of India's GDP between 2016 and 2024. Road development in India is expected to increase at a rapid pace of 12 kmper day in 2014-15 and 30 km per dayin 2018-19. The Indian government has set a goal of constructing 100 km of road each day by the end of 2025.

India's road network has grown by about 59% from 2013 to 2024. In 2023, the national highway network was 146,145 km long. In FY24, about 12,300 km of national highways were constructed. About 70% of India's roads are paved, while 30% are unpaved. Major projects such as the Golden Quadrilateral connect rural and urban areas to support the country's growing economy. The Ministry ofRoad Transport & Highways supports road safety awareness campaigns and deploys emergency response teams at landslide-prone sites.

These data show how important rigorous planning, scheduling, and resource efficiency are for Indian highway building. Improved planning and scheduling criteria Highway construction projects can be created utilizing real-time data from the job site. This study focuses on micro-level use of equipment & materials. This study used data from 30 highway building projects. The presence of outliers was evaluated using the statistical program SPSS 29.1V to reduce the variability of the raw data collected. After removing any outlier values, the best fit probability distribution function for the material and equipment data is determined. Using the Arena program, the study creates an integrated discrete event simulation model for the highway construction project's many activity layers. The activity layers examined in the current study are as follows:

1. Sub-base course: Granular Sub Base(GSB)
2. Base course: Wet Mix Macadam(WMM)

The simulation model derives the probability distribution function from real-time data. The model takes into account a variety of parameters, including the number of quarry trucks, mix-trucks, the length of work stretch, number ofworking hours each day, and the time it takes to get from mixing plant to site. Unlike the manufacturing industry, Indian construction industry has a set of suppliers, and inventory is often assigned to a distribution facility. The dynamic shift in the location of the road building site complicates the material logistics plan, resulting in material delays, unpredictable productivity rates, and resource constraints (Alvanchi et al., 2021).

Rather than selecting suppliers, supply chain integration in construction focuses on putting distribution centres and mixing plants in the most strategic locations. The Taguchi method is combined with simulation to determine the optimal resource combination. The goal is to determine best combination of characteristics that maximizes the project completion rate.

Construction Industry

Construction is process of constructing abuilding or infrastructure (Merriam- Webster.com, 2016). SCM should not only strive to save costs, but also to emphasize the corporation's talents, expertise, and competences. Today's workers understand the importance of complete client satisfaction. As a result, the supply chain's duties are completely expanded to ensure end-customer fulfillment, allowing intimate relationships to be developed. It remains till the project is constructed and fully equipped for use.

Chitkara (pp. 9-10), states that overall, there are three segments of development such as structures, facilities, and industrial use. Building development is usually divided into residential and non-residential. Infrastructures is habitually so-called heavy civil or heavy engineering, which covers huge public works like dams, bridges, highways, railways, water and utility distribution, and construction in industry includes manufacturing facilities, process chemical, power generation. Construction industries are the pillars of the national economic development (Myers, 2013).

According to Mazhar and Arain (2015), the construction industryplays an important role in global economy as ithas about 15% share in world'sGDP (Gross DomesticProduct). Construction is a one of major sectors in several countries that contribute significantly to the growth and development of the nation.

According to Bureau of Labour Statistics (2016), construction employment increased at an annual rate of 2.3 percent over the period, slightly more than long run job growth for total non-farm industries. In this context, it is noticed that the construction sector plays animportant rolein contributing to growth and employment in countries across the world.

Presently, the construction industry is experiencing change across the globe. Speedy expansion of construction industry in world has provided a strong motivation for extensive application of new systems and technology. Prefabrication, innovative technologies, modern construction methodology, modern construction materials, higher capacity automatic equipment's, transformation of the man power driven industry to semi-automatic or fully-automatic industry, green buildings & alliance are trends, leading companies muststay ahead of soon to be prosperous. Construction business will also have to become accustomed to the modifying govt rules and regulations which are geared towardssustainability. Trends are changing shape of industry & companies must adapt tokeep it up. At present, world is strongly pushing its construction industry forward for improving efficiency and lowering cost for those willing to keep up the technological advances. Thefollowing are major contributions of construction industry towards a nation:

- It acts as a premeditated device for accomplishing sustainable development.
- It contributes significantly to GDP.
- It acts as a growth initiator.
- It contributes significantly towards Gross Fixed Capital Formation.
- It helps for revenue generation and re-distribution.
- It generates significant employment.

Review Of Related Literature

Dr. S Kanchana et al. (2018) seek to identify key factors impacting managing the supply chain in the construction sector. Focusing on the survey questionnaire, the variables will be collected and ranked using fuzzy logic. The present market trend encompasses not just competition among enterprises, but also the supply chain. In compared to other sectors of manufacture, the construction industry is notorious for low productivity, severe fragmentation, cost and time overruns, and conflicts. Supply chain oversight is an innovative management style that provides a fresh approach to addressing these difficulties from a systemic perspective.

Utkarsh Yadav et al. (2019) investigated effects of supplychain management on highway building projects. Supplychain management detects challenges that slow down road development. In recent years, supply chainhas emerged as a key area of management study. The report covers the survey's key findings and emphasizes the implications of supply chain governance in highway building that exist inside the construction supply chain.

Abdelmegid et al. (2020) underlined inability of present simulation techniques to replicate reality of building systems. In this study, the lack of sufficient simulation expertise among construction practitioners, as well as the nature of input data necessary for a simulation study, were recognized as significant impediments to use of SCM in construction projects.

Dario Messina et al. (2020) investigate how supply chain decision makers receive, interpret, and apply accessible internal and external information during supply chain interruptions. The study examines relevant supply chain publications to create an information prevention model for disruption management. Following that, three case studies from the vehicle assembly business, namely autos, trucks, and aircraft wings, give empirical insights into the information management strategy. This paper explains the stages of disruption mitigation and shows the data that firms use to recover from a variety of disruptive events. It presents a new information management approach that enhances supply chain visibility and disruption management. Furthermore, it proposes two design concepts to help businesses revamp their disruption investigation and recovery operations.

Mochamad Agung Wibowo et al. (2021) looked at the Small and Medium Classes of Blora Builders. The objectives of this study were to evaluate the beneficial influence of corporate performance as well as to identify the positive aspects of Supply Chain Management in terms of increasing the business's competitiveness and customer satisfaction. The analysis was carried out utilizing processing methods, with path analysis also used to investigate the data. The findings imply that applying SCM can improve construction businesses' performance and competitiveness, as well as their level of customer satisfaction. Project Supply Chain Management (SCM) is an oversight of resource activities and supplier-customer interactions from upstream to downstream in the construction service delivery process.

Abdullah Alsharef et al.'s (2021) results will be useful for industry stakeholders seeking to understand the pandemic's early repercussions on the building sector. Industry stakeholders may also utilize the supplied insights to build best practices for ensuring safe and productive operations. The most often utilized risk management techniques were measures to increase safety and reduce other project dangers. Employees were obliged to wear cloth face masks, social distancing protocols were in place, construction operations were staggered, COVID-19-related training was offered, temperature checks were performed prior to entering the site, and other safety precautions were done. Other project risk management techniques included organizing a task force team to assess the growing pandemic and provide recommendations, advocating for construction companies to be deemed vital in battling delays, and utilizing government relief programs.

Amulya Gurtu et al.'s (2021) study aims to review the existing literature on risk factors in supply chain management in an unpredictable and competitive business environment. The theoretical study focused on papers that had the word "risk" in the title, keywords, or abstracts. Supply chain risk management is a critical component of the supply network. It faces unexpected challenges as a result of national economic policies and globalization, both of which have raised uncertainty and complexity for supply chain organizations. These have a significant influence on the financial performance of businesses and the whole economy. The discussion over supply chain risk management might improve business competitiveness. Risk mitigation methods will reduce the impact of natural and man-made disasters.

According to Roberto Cigolini et al. (2022), from an overall viewpoint that includes the creation of industrial and residential buildings, as well as building construction and infrastructure are provided attempts, a number of major actors must be coordinated in some way to reach ETO decisions, which lead to effective outcomes. The need to synchronize information through the supply chain is a constant and critical challenge for ETO organizations. Procurement helps to provide the conditions for the supply chain to operate smoothly. New technologies are being utilized, including product configurators and cloud manufacturing. Planning and decision-making are important drives. In the future, the challenges of applying supply chain management concepts to the building trade will demand further quantitative study to shed light on some of the potential benefits of improved data handling and the use of digital technologies. Then there's the option of combining explicit upfront planning and sourcing with project delivery methods, as well as choosing the right configurations, emphasis, and relationship kinds. Finally, there is considerable potential for using SMEs' inventive capabilities.

Dunya Sabah Jarallah et al. (2022) employed a concrete bridge in their investigation. According to the data, altering the source and amount of supplies can reduce costs by around 28.2%. Infrastructure projects are time-consuming, complicated, interdisciplinary, require a variety of materials and products, and carry a significant level of risk. These characteristics have an influence on the materials supply chain. The current paper analyzes the prospect of improving supply chain procedures and lowering costs by identifying the factors that impact them. These components are used as variables in the mathematical model, which functions in uncertain scenarios when material consumption rates fluctuate. The data for this model is derived via Building Information Modelling (BIM) and GIS (Geographical Information System) techniques, and the genetic algorithm is used to determine the optimum provider and supply quantities for various items.

The study by Ms. Rupali M. Suryawanshi et al. (2022) compares the cost and time before and after the outbreak. The COVID-19 outbreak has resulted in major detainments and cost overruns in construction systems. The goal of this study is to collect information and identify the key factors that influence SCM, productivity, and their relationship at Moshi Point in Pune. So, a questionnaire check is performed and delivered to the attesters who operate at that location. It is also gathered and processed using SPSS software and the RII system, with the impacted factors being connected and rated. The current findings will assist design directors in the building industry understand the issues of the pandemic and develop effective measures to prevent the Covid-19 outbreak and future extremes. Thus, the Covid-19 outbreak has a substantial impact on critical parameters influencing the oversight of the supply chain.

Siping Wen's (2023) study highlights key findings and advancements in building project supply chain management. With the growing scale and complexities of construction projects, there has been a considerable growth in the number of studies that focus on scientific the oversight of supply chains to enhance performance. To go deeper into this issue, this study used the Bibliometrix R software tool to do a bibliographic assessment and visually exhibit key data on building enterprise supply chain supervision from 1998 to 2021. This article provides an overview of construction project supply chain study utilizing a variety of indices from econometric analysis. Furthermore, keyword content evaluation is used to analyze the current situation, historical progress, and future growth of this topic. The data show that: (1) the number of works on building managing supply chains has increased over time, with a period of significant growth commencing after 2015.

Mohamed Eslam El-Madany et al. (2023) created a model for managing supply chains in developing nations, starting with early planning and moving through materials in demand to on-site storage. The benefit of this technique is that any change to the project (a lot of items, new items, eliminating things, modifying raw material costs, etc.) affects the initial supply request computed. The model's validity was confirmed by including data from a real-world field project, and modifications were made to the design, supply situations, and material requirements.

K.B. Jaisree et al. (2024) investigate evolution of SCM techniques in construction industry, focusing on transition from conventional approaches to modern, technology-based solutions. Thisliterature study also investigates major SCM features such asprocurement, logistics, managing hazards, sustainability, & the implementation of innovative technology into building supplychain. Sustainability appears as a key subject inthis paper, which analyzes the increased emphasis on ecologically responsible SCM techniques in building.

Sunil Shukla et al.'s (2024) study investigates the use of supply chain administration in highway building projects in India, concentrating on material and equipment use at various phases. Using data from 62 Maharashtra highway projects, a probability distribution function for materials and equipment was created, with outliers filtered using SPSS and best-fit distributions established using RiskPal. Using Arena software, a unified discrete event simulation model was constructed that took into account critical aspects such as truck numbers, trip times, and working hours. The Taguchi technique was used to optimize the use of resources and increase construction efficiency. The findings provide useful insights for better resource scheduling and scheduling, reducing delays and improving supply chain management in Indian highway building.

Shrouk Awaad et al.'s (2024) research develops a material supply chain (MSC) architecture for effective operations in road construction projects at all stages. This ensures that contractors receive the commodities they demand at the optimal time, in the appropriate quantities, and at the lowest possible cost. Contractors may boost production, save money, and remain innovative. An assessment was created to evaluate existing MSC practices, identify the most common issues experienced by contractors during project stages, and identify the most important contributors to supply chain coordination in manufacturing. The finished structure was then evaluated by road construction experts, with 90% agreeing that it promotes project participants to share information and data. 80% of respondents agree that the framework improves project completion with the desired quality and promotes issue solving before it occurs.

Objectives OS The Study

- Created real-time probability distribution functions for material usage.
- Developed a simulation model to analyze dynamic road construction situations.

Data Analysis and Results

This study uses data from 30 building projectsto identify best fit probabilitydistribution, as opposed to typical tendency of using a triangular distribution, which results in a more realistic estimate ofmaterial and equipment utilisation. The layers considered are the sub-base layer (GSB) and base course layer, which are formed into an integrated simulation model and analyzed. The probability distribution function built for material and equipment utilisation serves as input for the simulation model developed for the various layers of the road construction project.

Data is analyzed to determine the probability. The data samples produced after box plot analysis of material and equipment utilisation are used to fit the probability distribution using Pallisade Inc's risk management software. The software first fits the given data with the standard distribution functions and then uses the moment matching approach to evaluate its parameters. In the case of continuous operations, the programme ranks all the distribution functions by the root mean square error value.

The Levenberg-Marquardt strategy is used by @Risk Pallisade to find the best fit distribution using maximum likelihood estimators (MLEs). This method makes an initial guess about the distribution function's parameters before modifying each one slightly to achieve the best fit. This strategy fits a distribution function to a data set as closely as possible. To determine goodness-of-fit, use the Chi-square, Kolmogorov S (KS), and/or Anderson-Darling (AD) tests. The outcomes are compared, and the one with smallest goodness-of-fit scores is selected as the best fit. The KS test is more accurate than the chi-square test since it is independent of the number of intervals. The AD test looks comparable to the KS test, except it emphasizes tail values more and is independent of the number of intervals. The A-D test is considered superior and is employed in this study's thesis (Jakauskas and McLafferty 1996).

MATERIAL UTILISATION OF THE ACTIVITY LAYERS OF ROAD

The charts below provide a fit comparison of the per-kilometre material utilization of the various layers of a road. The graphic depicts material usage in cubic metres per km on x-axis & probability density on y-axis. The A-D test is used to fit the probability distribution for each activity, and the plots are displayed in Figures 1–5 for material utilisation.

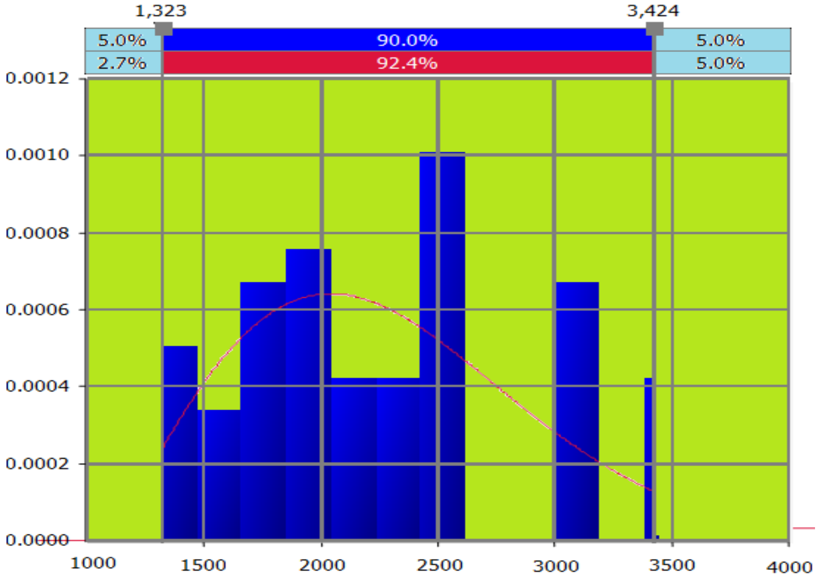

FIG. 1: Utilisation Of Mixing Plant For Sub-Base Course

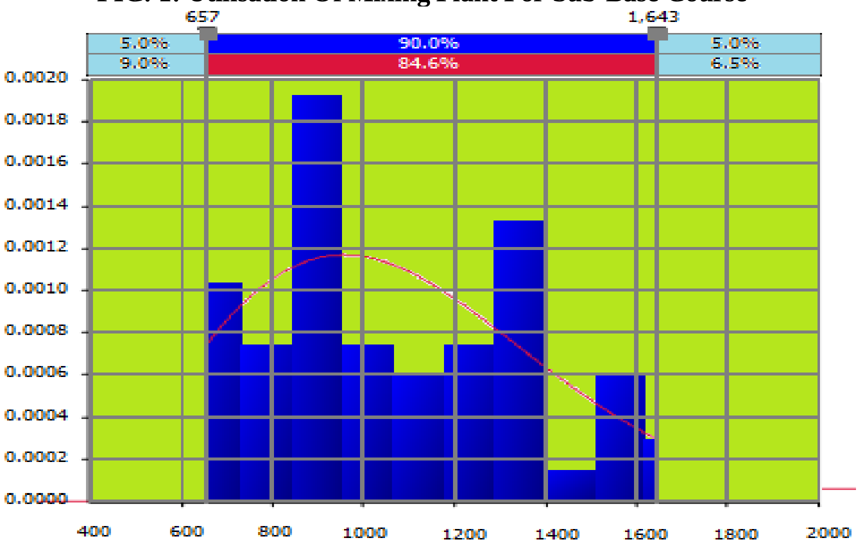

FIG. 2: Utilisation Of 40 Mm Aggregate For Base Course

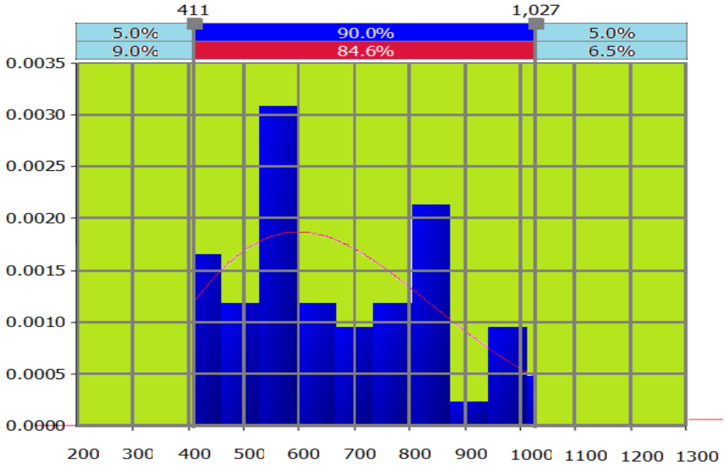

FIG. 3: Utilisation Of 20 Mm Aggregate For Base Course

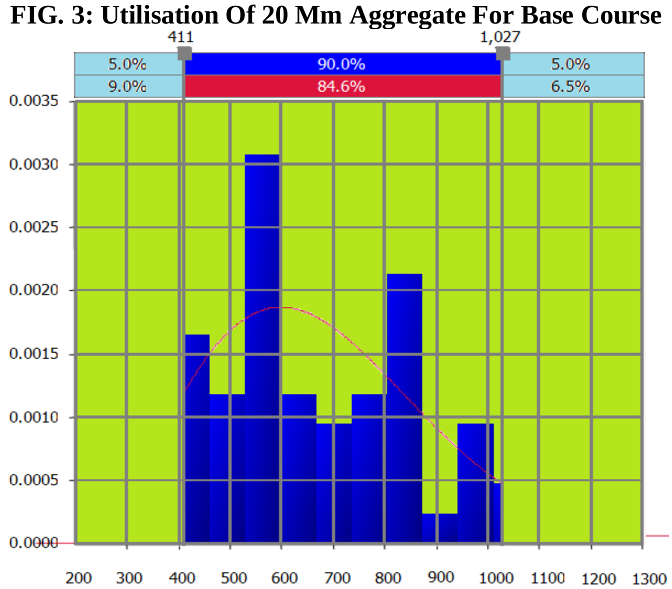

FIG. 4: Utilisation Of 12 Mm Aggregate For Base Course

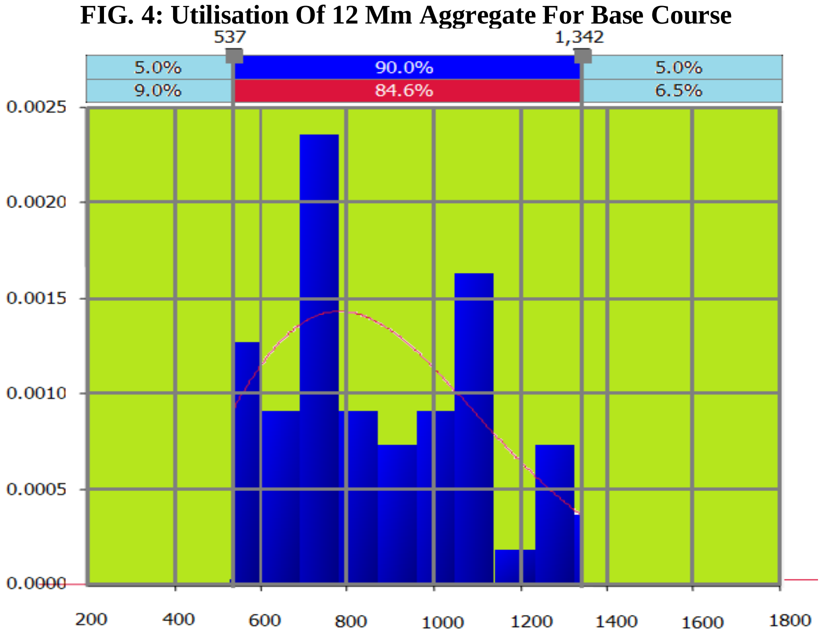

FIG. 5: Utilisation Of Dust For Base Course

SIMULATION MODEL FOR SUB-BASE COURSE AND BASE COURSE

The integrated simulation model uses the user's input data to determine which activity layer the work is carriedout in. Depending on layer of work, quarry trucks deliver material from the distribution centre to the mixing plant. Once the material arrives at the mixing facility, the mix in the needed proportion is made and brought to the site by mix-trucks. The Taguchi method is used to determine the most effective resource combination. It is a realistic optimisation tool that uses a methodical methodology to determine the optimal settings. (Joshaghani et al., 2015).

The control and noise factors for the Taguchi analysis are identified from the site for the sub-base and base course activity layer, as shown in Table 1, using data from personal interviews with project managers. Control factors are under management control, whereas noise factors are uncontrollable variables. In this study, the control parameters studied are the number of quarry trucks, the stretch given in kilometres, number of mixtrucks, and number of working hours per day, while the noise component considered is the trip delay from mixing plant to site.

The Taguchi approach considers orthogonal array (OA) & signal-to-noise (S/N) ratio to be two most important instruments for experiment design. The Taguchi approach aims to maximize S/N ratio while minimizing effect of randomnoise sources on process performance. In this study, S/N ratiois analyzed using % completion as the performance metric. To maximize completeness, S/N ratio is determined using the HB (Higher Better) criterion provided by Equation (1).

$$\frac{S}{N} = -10Log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Table 1: Taguchi Experimental Design Factors Andlevels

FACTORS	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4
Number of quarry trucks	7	8	9	10
Stretch assigned in km	0.3	0.4	0.5	0.6
Number of mix-Trucks	3	4	5	6
Working hours per day	8	9	10	11
Travel delay from mixingplant to site (min)	5	10	15	20

To establish the signal-to-noise ratio, a four-level L16 orthogonal array is employed, with four controlled and one noise factor. Table 2 shows the signal-noise ratio produced using Minitab software, with the elements sorted according to their importance. The rating represents the significance of these aspects. In the sub-base course and base course studies, the stretch of work completed on a specific day is given the highest priority, while the noise factor travel time b/w mixing plant & site is the least relevant.

Table 2: Signal-To-Noise Ratio Obtained From Taguchi Analysis For Sub-Base And Base Course Layer

LEVEL	NUMBER OF QUARRY TRUCKS	NUMBEROF MIX TRUCKS	WOR NGHOURS	STRETCHIN KM	MP2S TRAVEL DELAYIN MIN.
1	35.54	35.83	34.67	37.76	35.51
2	34.78	35.71	36.51	35.85	35.37
3	34.48	34.78	34.66	35.12	34.46
4	36.11	34.61	35.06	32.16	35.57
Rank	3	4	2	1	5

The average (S/N) ratio values for the sub-base and base course layers are shown in Figures 6 to 10.

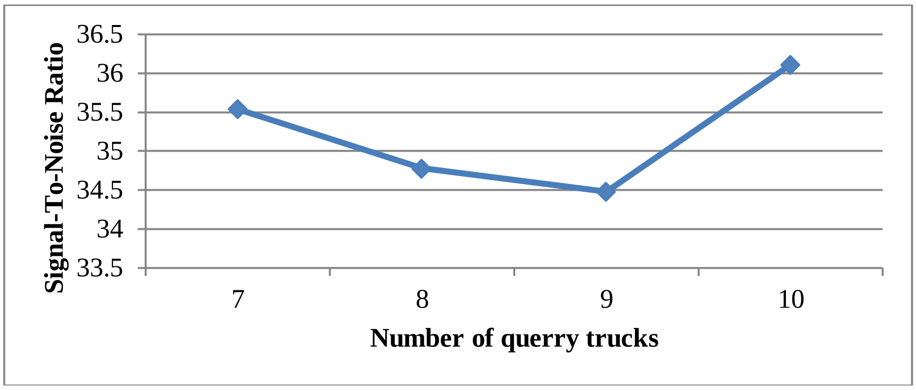

Fig. 6: Variation Of S_i / N_o With Number Of Quarry Trucks

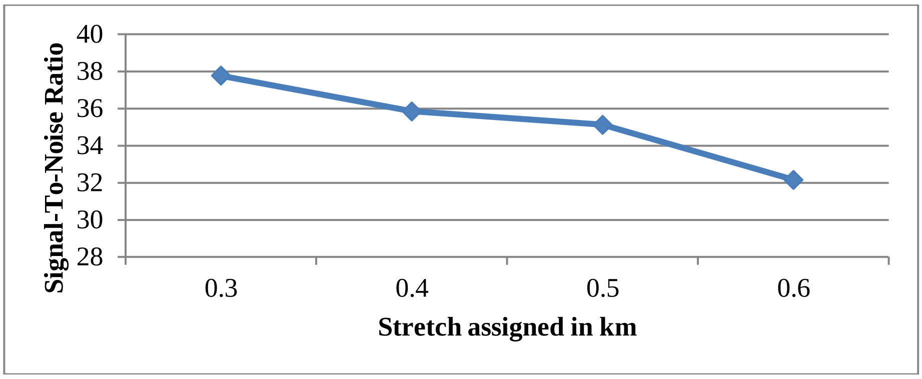

Fig. 7: Variation Of S_i / N_o With Stretch Assigned

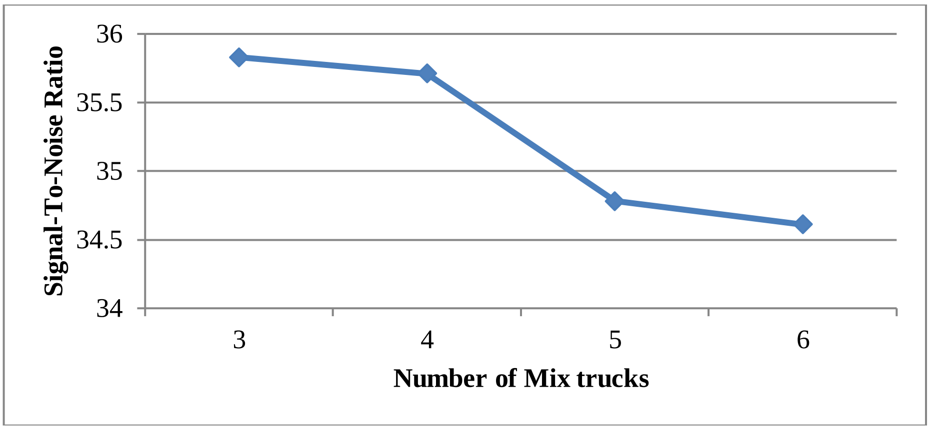

Fig. 8: Variation Of S_i / N_o With Number Of Mix-Trucks

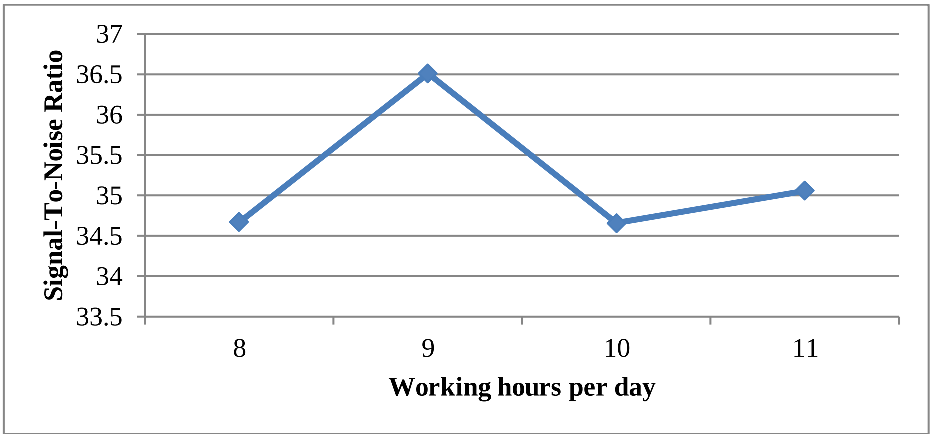

Fig. 9: Variation Of S_i / N_o With The Working Hours Per Day

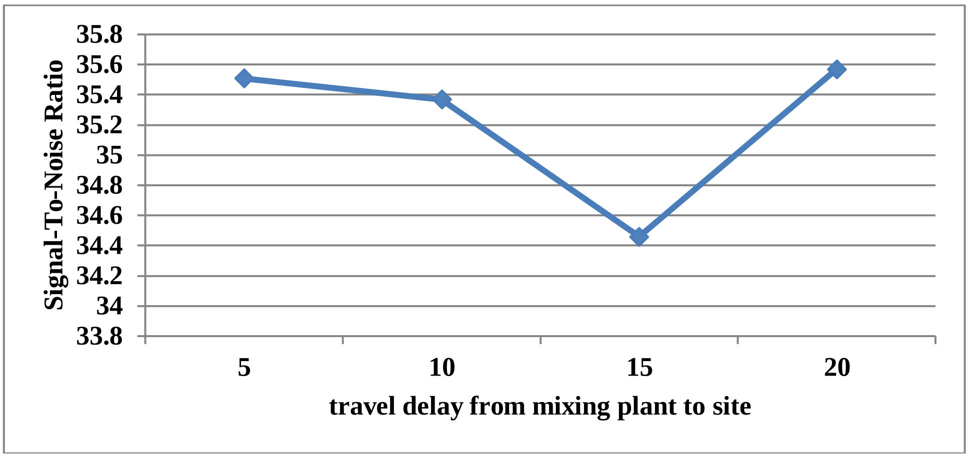

Fig. 10: Variation Of S_i / N_o With Travel Delay From Mixing Plant To Site

The Taguchi method's analysis yields the optimal parameter values depending on the percentage of work completed. In this study, "the larger, the better" characteristic is evaluated because the purpose maximizes the quantity of work completed:

- Number of quarry trucks –10
- Stretch assigned – 0.3km
- Number of mix-trucks –3
- Working hours per day –10
- Mix plant to site travel delay of 20min

For the sub-base layer, a front-end loader with a bucket capacity of one cubic meter, a motor grader with a 3.35 m blade, and an 8-tonne capacity vibratory roller are used, while for the base course layer, a front-end loader with a bucket capacity of one cubic meter, a paver finisher, and a vibratory roller. The simulation model goes through iterations until a constant utilization rate is obtained. Albright et al. (2011) require at least 440 iterations to provide a mean accuracy of ±5 units (95% confidence). Figures 11 to 13 indicate the utilisation rates of the equipment used for the sub-base layer, whereas Figures 14 to 16 show the utilisation rates for the base course layer.

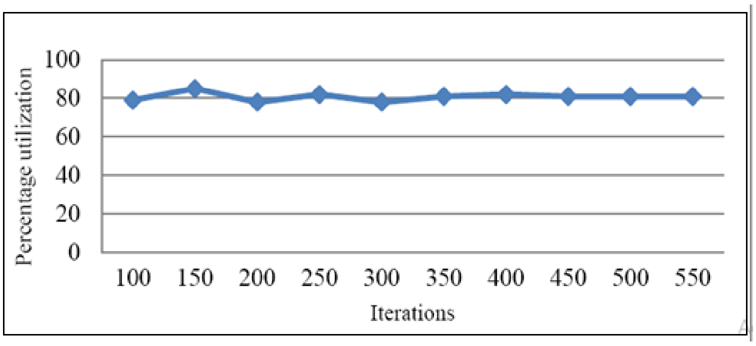

Fig. 11: Variation Of Average Percentage Utilisation Of Front-End Loader

The average percentage utilisation rate of the front-end loader after 550 iterations is 81%.

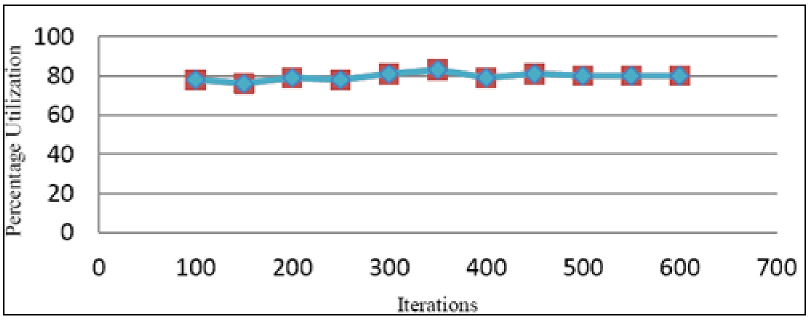

Fig. 12: Variation Of Average Percentage Utilisation Of Motor Grader For The Subbase Layer With The Number Of Iterations

The average percentage utilisation rate of motor graders after 650 iterations is found to be 87%.

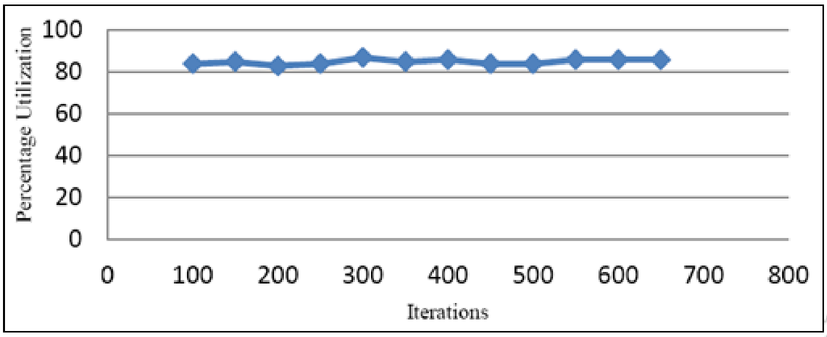

Fig. 13: Variation Of Average Percentage Utilisation Of Vibratory Roller With Number Of Iterations For The Sub-Base Layer

The average percentage utilisation rate of vibratory roller after 700 iterations is found to be 85%.

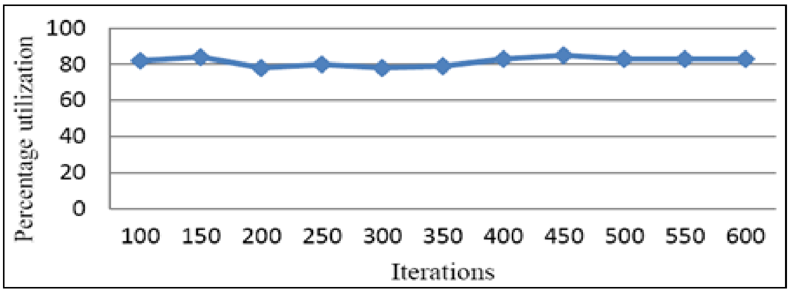

Fig. 14: Variation Of Average Percentage Utilisation Of Front-End Loader For The Base Course Layer With A Number Of Iterations

The average percentage utilisation rate of the front-end loader utilised for completing the base course layer work is 83% after 600 iterations.

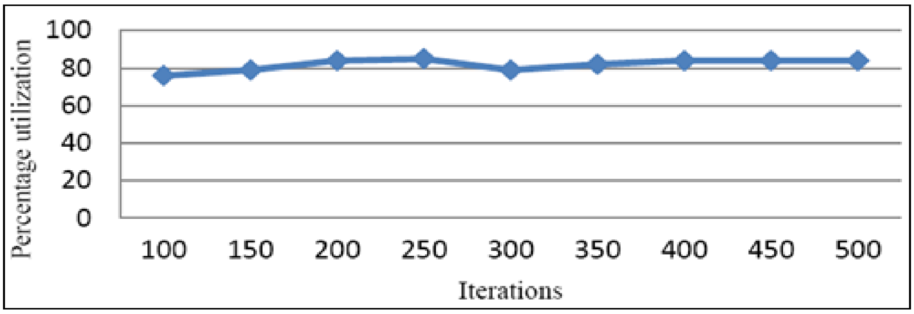

Fig. 15: Variation Of Average Percentage Utilisation Of Paver Finisher With Number Of Iterations

The average percentage utilisation rate of paver finisher after 500 iterations is found to be 84%.

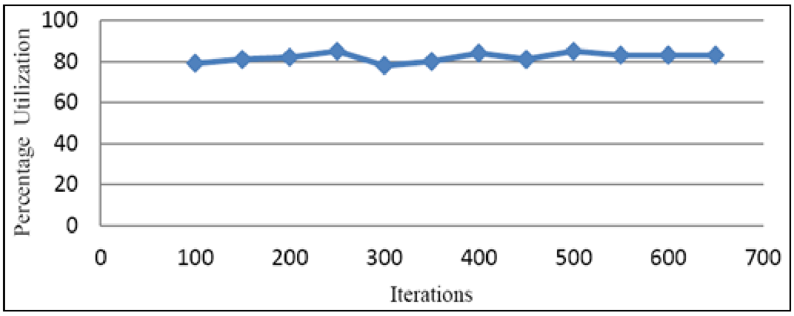

Fig. 16: Variation Of Average Percentage Utilisation Of Vibratory Roller With Number Of Iterations For The Base Course Layer

After 650 iterations, the vibratory roller has an average utilisation rate of 83%. As a result, the average utilisation rate of the equipment placed for the sub-base layer is 81 to 87%, and for the base course layer it is 83 to 84%. The Project Manager can utilize this utilisation rate to keep track on idle equipment. The equipment used in the aforementioned sub-base and base course layer activities appears to be fully engaged, with no idling.

Conclusions

The resources used in a highway building project account for alarge amount of entire construction cost. These projects collapse as a result of improper resource utilisation. Proper resource allocation is critical to success of highway construction projects. Planning resources for a highway building project include identifying the resources and their productivity. This study focuses on the utilization rates of major resources in a highway construction project. The study included data collection on the materials used in a roadway project. In the following stage of the investigation, the acquired data was analyzed and fitted using the best-suited probability distribution function. These distributions were then used as input data for simulation models created.

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