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RESOURCE UTILIZATION ANALYSIS OF HIGHWAY PROJECTS USING ARENA

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Abstract

The construction sector is a significant contributor to the Gross Domestic Product of a developing country. Infrastructure improvement plays a vital role in this wherein highway construction is a dynamic sector requiring proper planning and scheduling multiple resources. Appropriate integration among various associated stakeholders is essential for a project's success, aided by supply chain management. Resource planning is one of the basic concepts in supply chain management, with material and equipment management being the critical area. The main objective of this study is to develop a conceptual supply chain simulation model using ARENA, to analyze the equipment idling and utilization rate, keeping inter-arrival time for dispatch, the number of equipment, and working hours as constant. This model employs the real-time 'best fit' material utilization data as input. Material utilization data collected from 62 construction projects are analyzed to arrive at a 'best fit' probability distribution. This study's conceptual supply chain simulation model helps formulate suitable material and equipment delivery plans to lessen risk in construction projects.

Keywords: Highway construction, material utilization, simulation, supply chain management function, material utilization.

1.0 INTRODUCTION

According to the Ministry of Road Transport and Highways, India has the second-largest road network globally, with 5.98 million kilometres (Wikipedia 2020). It is growing at a rate of 76 kilometres per day. These road projects face various technical and managerial problems: material shortage, cost escalation, space restriction, and so on, which directly impact the entire project, resulting in delay and cost overrun. Based on the Indian Construction Industry Development Council study, highway construction materials constitute around 42-45% of the total project cost (Swarup 2007).

In a study by Kiran et al.(2020), material management is prioritized as one of the prime criteria for completing a road project by selecting and stocking materials as per the project's requirement. If the material demand is not met on time, the vendor eventually ends up with high material buffer (Vrijhoef and Koskela, 2000). Thus materials need to be ordered in the project location at the right time based on supplier lead time. In most construction sites, material management happens with minimum communication and no apparent organization between the different parties involved (Hasim et al., 2018). A range of techniques are implemented in construction projects for effective material management, and one among them is Supply Chain Management (SCM).

Supply chain management is a system that was implemented in the manufacturing sector in the Toyota Production System (Shingo 1988) and was later applied to the construction sector. SCM has proven to improve quality in the manufacturing industry, save time, and increase profit (Wisner et al., 2011). Supply chain management is a managerial expert which interlinks all activities in a project, and the worth of this is achieved through optimized resource usage. Vrijhoef and Koskela (2000) have claimed four significant supply chain management roles in their study, and they allege that the centre of attention can be shifted to the supply chain or the site or on both based on the project. Many studies in this area conclude that information sharing and lead time directly impact the supply chain (Lee et al., 2004, Mani et al., 2016, Pillai et al., 2014). It is found that the construction sector is reluctant in implementing SCM; the reasons identified include fear of loss of control, inability to share information between stakeholders, project's complexity, inappropriate knowledge about SCM and its benefits in construction (Love 2000, Hope 2012, Benton and McHenry (2010), Battula et al., 2020)

Highway construction projects are considered in this study, which involves various linear activities compared to projects like high-rise building construction, which has a non-linear nature (Vorster et al., 1992). Similar activities are carried out at various locations along the same highway construction project's alignment, which requires proper resource utilization with minimal idle time. Simulation modelling has been used successfully for highway construction projects by various researchers (Polat and Buyuksaracoglu, 2009; Puri and Martinez, 2013).

The output data of these simulation models are much dependent on the quality of the input data provided (Maio et al., 2000). Hence, choosing an appropriate probability distribution as the input is exceptionally essential. Simulation models need to utilize realistic production rates to plan and develop a realistic construction schedule for highway projects (Chong et al., 2011). And it generally uses the flexible families of probability distributions because of their capability in attaining a wide variety of shapes (Fente et al., 2000).

The probability distribution derived from the goodness-of-fit technique aids in identifying extreme values and levels of the irregularities of empirical distribution for conducting simulation (Law & Michael, 1991). This study arrives at a 'best fit' probability distribution using data collected from 62 different highway construction projects. Thus, the distribution functions were then incorporated as input to the simulation model to analyze the equipment idling and utilization rate. Moreover, the developed model aids in providing the user with first-hand information on the idling and size of equipment to be employed.

2.0 LITERATURE REVIEW

Material management is one of the vital resource elements in a project, as the cost of materials amount to a significant share of the total project cost (Li and O'Brien, 1999: Tserng et al., 2006). Scarcity of material both at the site and in the market (Mansfield et al., 1994, Love et al., 2005, Rowlinson & Cheung 2008) and inaccuracy of material estimate (Kaming et al., 1997, Enhassi et al., 2009) are some of the reasons for the delay in a project. The correct quantity of material on time is highly essential for the successful completion of a project. Most of the times, it is aided by the Just-In-Time (JIT) methodology (Deng et al., 2018). Material supply needs to be tracked correctly for the easy functioning of a project. A small saving in material cost through efficient management can substantially save total project cost.

Liwan (2015) identified seven components for an on-site material tracking framework: manufacturing, materials delivery, materials arrival, materials storage, materials use, on-site control centre and report generation. A proper plan for procurement and stocking of construction materials needs to be developed at the site to provide materials of the right quality, in the right amount, at the right price, from the right source and at the right time (Ala-Risku and Kärkkäinen, 2006).

Researchers use various material scheduling tools like the simulation model (Polat and Buyuksaracoglu, 2009; Lu and Olofsson, 2009) linear programming model (Lima et al., 2013) for material management. Modelling is simplified using simulation, which assesses the model numerically with the help of computers and provides a realistic picture of the site's activities. Beyond the different modelling techniques, stochastic/probabilistic modelling is recommended for construction activities with a precise and dynamic nature (Hijazhi 1989, AbouRizk and Halpin,1990).

Fitting a particular set of data entails the estimation of unknown parameters, thereby depicting a real-life situation. The selection of an unsuitable statistical distribution can generate wrong probabilities, which can badly affect decision-making and lead to adverse outcomes (Bedford and Cooke, 2001; Anastasopoulos et al., 2009). The literature study by Wang and Halpin (2004) identified simulation as an appropriate tool for planning and scheduling highway construction projects by determining optimal resource usage. Time and resource data are the inputs for the simulation model, and usually, a triangular distribution is assumed for the duration of various activities involved (Polat & Buyuksaracoglu, 2009).

The probability density function (PDF) based on actual field data is a more precise input than assuming a triangular distribution (Nasir et al., 2003). This paper uses the data from 62 construction projects to determine the 'best fit' probability distribution as opposed to the usual trend of taking a triangular distribution. It facilitates a realistic estimate of material utilization.

The construction supply chain integrates activities from the supply of raw material to the final project completion. In the construction industry, trust, commitment, and information sharing were found deficient, and the need for developing a systematic model such as construction supply chain was identified (Xue et al., 2011). The above study defines construction supply chain management as a combination of different processes involved starting from demand, design, and ending in construction involving client/owner, designer, contractor, subcontractor, and supplier.

In a construction supply chain, the next user in the supply chain must be provided with the right resource on which information and resource sharing are essential (Sullivan et al., 2011). Even though information technology has enabled the effectiveness of information sharing among the various stakeholders of a supply chain, model-based CSCM is very much essential for resource management (Lu et al. 2018)

Though supply chain management is gaining importance in the construction industry, its usage is significantly less. To this end, a study was done by Abdelmegid, et al., 2020 and it identified the lack of ability of current simulation tools to capture the reality of construction systems, lack of proper simulation knowledge among construction practitioners and nature of the input data required for a simulation study as some of the major barriers in adoption of SCM in construction projects. The 'best fit' probability distribution developed in this study is employed in developing a conceptual supply chain simulation model using ARENA software. This developed model can be used to formulate suitable material, and equipment delivery plans to lessen the various resources' idling to lessen risk in construction projects.

3.0 METHODOLOGY

The data set obtained from the 62 highway construction projects are used to develop 'best fit' statistical distributions to determine the probabilities of material utilization. The methodology adopted for data collection and analysis are detailed below. This study mainly aims to determine the 'best fit' probability distribution and use it as an input to develop a conceptual supply chain simulation model using ARENA software and thereby to analyze the equipment idling and utilization rate, keeping inter-arrival time for dispatch, the number of equipment, and working hours as constant.

The primary activities in a highway construction project are preparation of subgrade, laying of sub-base course, laying of base course, applying a prime coat, laying of binder course, application of tack coat, laying of surface course, and application of seal coat. The entire study is based on five phases as shown in Figure 1: data collection, analysis, verification and validation of the probability model, and development of conceptual supply chain simulation model. In data collection, the material utilization in cubic meter per kilometre is calculated from various reports like master schedule, resource utilization chart, bill of quantities and daily progress reports maintained at the site. Thus collected data is first checked to confirm if the sample size is adequate or not by students 't' test. Then by using the software Easy-Fit the 'best fit' distribution was found. Sensitivity analysis is carried out in this data to find the convergence of data. Verification and validation of this arrived distribution are done by calculating the cumulative distribution function's probability. The 'best fit' distribution is then used to develop a conceptual supply chain simulation model using ARENA software. The equipment idling and utilization rate is analyzed, keeping inter-arrival time for dispatch, the number of equipment, and working hours as constant employing a real-time 'best fit' material utilization data.

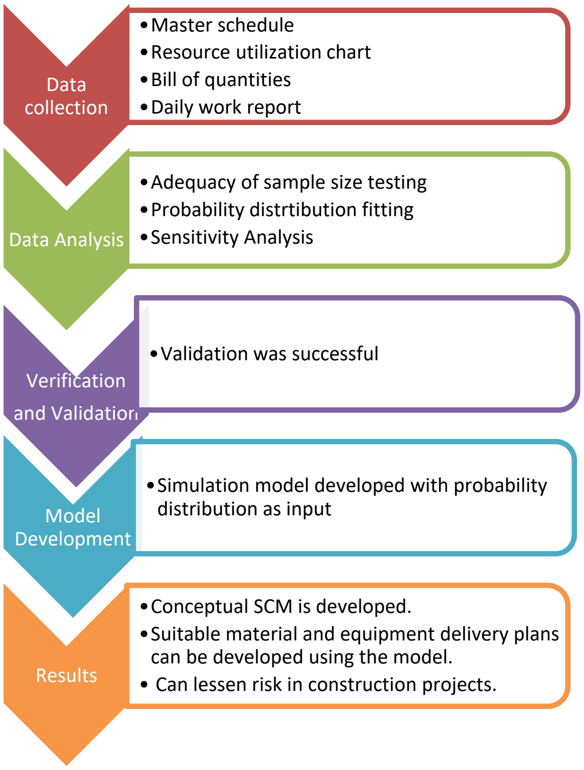

Figure 1. Methodology

3.1 Data Collection And Analysis

The data was collected from 62 highway construction projects, representing diverse geographical, socio-economic, climatic and political conditions. The data collected includes the master schedule, project schedule, resource utilization charts, bill of quantities, and daily progress reports from sites. The quantity of materials used for each activity for each project site was obtained from the daily progress report, and the resource utilization chart is normalized to the material amount per kilometre. The sample adequacy is tested using the student's t-test (Arun and Rao, 2003) given by equation (1). By substituting the median, standard deviation values and the 't' value, the number of samples required is calculated, and the result obtained from this analysis is presented in Table 1. Since the values in the data are very consistent with the median, the sample size requirement is found to be less than one in all the cases.

$$n = \left(\frac{0.3M}{1.25t\sigma}\right)^{2} \quad \text{...............................(1)}$$

Where n - is the sample size

t - The student's 't' value at 95% confidence limit and the corresponding degree of freedom,

M- Median of the sample,

σ - The standard deviation.

Table 1 Sample size required and available

Activity	**Sample size required (95% confidence level)**	**Available sample size numbers**
Sub base course	0.2	60
Base Course	0.1	60
Binder course I	0.1	40
Binder course II	0.1	55
Surface Course	0.4	54

3.2 Probability Distribution Fitting

Arriving at the 'best fit' distribution is crucial in calculating the realistic utilization schedule. The 'best fit' probability distribution was examined using the 'Goodness of Fit' tests: Kolmogorov–Smirnov and Anderson–Darling. Fitting a particular set of data entails the estimation of unknown parameters, thereby depicting a real-life situation. In construction projects, parameter estimation or data fitting plays a vital role in practical problems. This study carries out data fitting using 'EasyFit Professional' version 5.5 by Math Wave Technology. 'EasyFit' is a data analyzer and simulation software that allows us to adapt probabilistic distributions to given data samples and simulate them. The software selects the best appropriate sample and implements the analytical results to make better decisions.

Sensitivity analysis was carried out for the material utilization of different layers by varying the sample sizes to study the convergence in the probability distribution. The total sample size was split randomly into three sample size categories: 40, 50 and greater than 50 by varying the size of the data for each activity, ensuring randomness for each iteration of the sample. In this analysis, it was found that there was no convergence in the A-D test compared to the K-S test. Each activity's distribution function was found to converge when the sample size is more than or equal to fifty, as shown in Table 2 and Table 3.

While considering both the test, convergence is seen better in the K-S test. However, there is an apparent convergence for material utilization in the base course and the best fit distribution found to be Pearson 6 in the K-S test and Log-Logistic in the A-D test. Binder course is found to follow Nakagami distribution by both tests. Nakagami distribution is directly linked with Gamma distribution having shape parameter and spread control parameter. For binder course-2 the convergence to Weibull distribution is observed in the K-S test. The surface course activity is found to follow Log-Logistic distribution in the K-S test and A-D test.

Table 2 Convergence of distribution function using the A-D test.

Activity	**Material**	**K-S Test**		
		<40	**50**	**>50**
Sub-base course	Quarry waste	Beta	Gamma	Log logistic (3P)
Base Course	40mm Aggregate	Pearson6	Log-Logistic	Pearson5 (3P)
	20mm Aggregate	Pearson5	Log-Logistic	Pearson6 (4P)
	12mm Aggregate	Pearson6	Log-Logistic	Pearson5 (3P)
	Dust	Pearson6	Log-Logistic	Pearson5 (3P)
Binder course I	20mm Aggregate	Weibull	Nakagami	Nakagami
	12mm Aggregate	Weibull	Nakagami	Nakagami
	Dust	Weibull	Nakagami	Nakagami
	Bitumen	Weibull	Nakagami	Nakagami
Binder course II	20mm Aggregate	Gamma	Weibull (3P)	Weibull (3P)
	12mm Aggregate	Gamma	Weibull (3P)	Weibull (3P)
	Dust	Gamma	Weibull (3P)	Weibull (3P)
	Bitumen	Gamma	Weibull (3P)	Weibull (3P)
Surface Course	12mm Aggregate	Log logistic (3P)	Log logistic (3P)	Log logistic (3P)
	Dust	Log logistic (3P)	Log logistic (3P)	Log logistic (3P)
	Bitumen	Log logistic (3P)	Log logistic(3P)	Log logistic (3P)

Table 3 Convergence of distribution function using the K-S test

Activity	Material	A D Test		
		<40	**50**	**>50**
Sub-base course	Quarry waste	Gamma	Log Gamma	Log Gamma
Base Course	40mm Aggregate	Log-Logistic	Log-Logistic (3P)	Log Gamma
	20mm Aggregate	Log-Logistic	Log-Logistic (3P)	Log Gamma
	12mm Aggregate	Log-Logistic	Log-Logistic (3P)	Log Gamma
	Dust	Log-Logistic	Log-Logistic (3P)	Log Gamma
Binder course I	20mm Aggregate	Gamma	Nakagami	Nakagami
	12mm Aggregate	Gamma	Nakagami	Nakagami
	Dust	Gamma	Nakagami	Nakagami
	Bitumen	Gamma	Nakagami	Nakagami
Binder course II	20mm Aggregate	Fatigue Life	Inv. Gaussian	Fatigue Life (3P)
	12mm Aggregate	Fatigue Life	Inv. Gaussian	Fatigue Life (3P)
	Dust	Fatigue Life	Inv. Gaussian	Fatigue Life (3P)
	Bitumen	Fatigue Life	Inv. Gaussian	Fatigue Life (3P)
Sur face Course	12mm Aggregate	Frechet (3P)	Log logistic (3P)	Log logistic (3P)
	Dust	Frechet (3P)	Log logistic (3P)	Log logistic (3P)
	Bitumen	Frechet (3P)	Log logistic (3P)	Log logistic (3P)

The software provides appropriate distribution options that allow the user to define which particular distribution is the 'best fit'. Depending on the bounds specified by the software, the distribution is fitted. To further check how well the distribution fits the specific data, the Goodness of fit measure is also available in the software. The software supports the Chi-square test, Kolmogorov-Smirnov (KS) test and Anderson-Darling (AD) test.

The test statistic for each of these test is found and categorized according to the statistic value. In this study, each of the activities in a road construction project is sorted and ranked. For example, if the 40mm aggregate in the base course is taken; Pearson 5 (3P) is the distribution it follows with the following parameters: $\alpha = 8.9672$, $\beta = 14364.0$, and $\gamma = 101.74$ and as per A-D test the best fit is Log gamma distribution with $\alpha = 400.69$ and $\beta = 0.01839$.

The final 'best fit' distribution arrived for material utilization of various highway project activities using 'Easy Fit' software by both the Kolmogorov -Smirnov (K-S) test and Anderson- Darling (A-D) is provided in Table 4.

Table 4 Final probability distribution of material utilization

	Material	KS Test	AD test
Subbase course	Quarry waste	Log logistic(3P)	Log Gamma
Base Course	40mm Aggregate	Pearson5(3P)	Log Gamma
	20mm Aggregate	Pearson6(4P)	Log Gamma
	12mm Aggregate	Pearson5(3P)	Log Gamma
	Dust	Pearson5(3P)	Log Gamma
Binder course I	20mm Aggregate	Nakagami	Nakagami
	12mm Aggregate	Nakagami	Nakagami
	Dust	Nakagami	Nakagami
	Bitumen	Nakagami	Nakagami
Binder course II	20mm Aggregate	Weibull(3P)	FatigueLife (3P)
	12mm Aggregate	Weibull(3P)	FatigueLife (3P)
	Dust	Weibull(3P)	FatigueLife (3P)
	Bitumen	Weibull(3P)	FatigueLife (3P)
Surface Course	12mm Aggregate	Log logistic(3P)	Log logistic(3P)
	Dust	Log logistic(3P)	Log logistic(3P)
	Bitumen	Log logistic(3P)	Log logistic(3P)

3.3 Verification and Validation

Abou Rizk and Halpin (1992) stated that the variability in activity duration in a project is assumed to follow a Beta distribution. Back et al. (2000) alleged that triangular distribution could be adopted by deciding the function parameters. In a study by Hajdu and Bokor (2014), the efficiency of various distributions (uniform, triangular and beta) was studied and concluded that the accuracy of three-point estimation has a significant role in determining project distribution durations. However, minimal studies are carried out on fitting probability distribution to realistic material utilization data. Input data verification and validation is considered critical in the development of a simulation model (Sargent 2010).

In this study, validation was carried out with a different set of material utilization data as given in Table 5. The software Easy-fit was used in finding the usage rate in the cumulative probability distribution function to predict the percentage of material utilization probability. The values in the table 6 are obtained from the cumulative distribution graph obtained from the Easy fit software. It can be seen from the table that the probability of occurrence of these values obtained from this analysis was found to in the more likely range.

Table 5 Validating the probability for material utilization rate

Activity	Material	Per kilometre Utilization rate of material			
		Project 1	**Project 2**	**Project 3**	**Project 4**
Sub-base course	Quarry waste (m^3)	2555	1277	2300	1763
Base course	40mm aggregate (m^3)	1577	985	2365	1360
	20mm aggregate (m^3)	164	102	246	141
	12mm aggregate (m^3)	492	308	739	425
	Dust(m^3)	981	613	1472	846
Binder course 1	20mm aggregate (m^3)	846	535	564	494
	12mm aggregate (m^3)	423	229	282	247
	Dust(m^3)	731	396	487	426
	Bitumen (kg)	97	52	65	57
Binder course 2	20mm aggregate (m^3)	1411	705	330	973
	12mm aggregate (m^3)	705	352	165	486
	Dust(m^3)	1218	609	285	840
	Bitumen (kg)	209	105	49	145
Surface course	12mm aggregate (m^3)	257	151	265	314
	Dust(m^3)	302	177	311	369
	Bitumen (kg)	45	26	46	55

Table 6. The probability of occurrence.

Activity	Material	Probability			
		Project 1	**Project 2**	**Project 3**	**Project 4**
Sub-base course	Quarry waste (m^3)	0.32	0.97	0.45	0.78
Base course	40mm aggregate (m^3)	0.50	0.90	0.14	0.66
	20mm aggregate (m^3)	0.45	0.91	0.14	0.66
	12mm aggregate (m^3)	0.50	0.91	0.14	0.66
	Dust(m^3)	0.50	0.90	0.14	0.66
Binder course 1	20mm aggregate (m^3)	0.11	0.45	0.41	0.52
	12mm aggregate (m^3)	0.11	0.58	0.41	0.52
	Dust(m^3)	0.11	0.58	0.41	0.52

	Bitumen (kg)	0.11	0.59	0.41	0.52
Binder course 2	20mm aggregate (m^3)	0.17	0.64	0.99	0.40
	12mm aggregate (m^3)	0.18	0.64	0.99	0.4
	Dust(m^3)	0.174	0.641	0.988	0.398
	Bitumen (kg)	0.17	0.64	0.99	0.4
Surface course	12mm aggregate (m^3)	0.66	0.99	0.62	0.40
	Dust(m^3)	0.66	0.98	0.62	0.39
	Bitumen (kg)	0.67	0.99	0.64	0.41

3.4 Model Development

The simulation model developed in this study utilizes the equipment available with the contractor, which are two water tankers of nine kilolitre capacity, one grader, one excavator, seven rear dump trucks and a vibratory roller. The software Arena (version 14.70.00) by Rockwell Automation was used for developing the simulation model. The equipment available with the contractor and the sub-activities in sub-base construction is listed below.

- A grader, an excavator, seven rear dump trucks, a smooth wheel roller and two water tankers.
- Transporting the mix from distribution centre to site using trucks and returning empty trucks to the distribution centre.
- Leveling the mix at the site using a grader.
- Compacting the mix using a smooth wheel roller.

The inventory at the distribution centre is assumed to be infinite and is pulled as and when required. The probability distribution arrived in the material analysis is used as an input to the simulation model. Seven dump trucks of capacity 14 m^3 were used at the site with a mean inter-arrival time of 8 min. The model architecture is presented in Figure 2, representing the below listed physical sequence of operation at location:

- Mix transported from mixing plant to the site using dump trucks.
- Mix dumped and levelled at the site using a motor grader.
- Compaction using a smooth wheel roller.

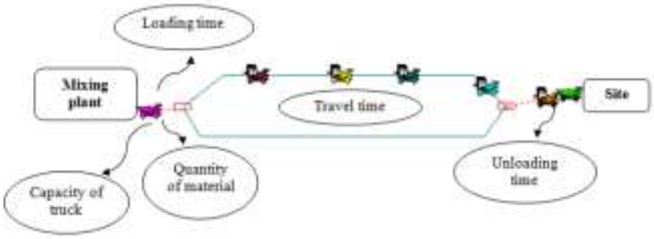

Figure 2. Model Architecture

The simulation model in this study compares the queuing formation of trucks, thereby calculating the idle time, keeping some parameters constant while others are varying. The truck capacity, inter-arrival time for dispatch, the number of equipment and working hours are hard coded based on the site requirements and hence are constants for this study. The variable parameters based on the probabilistic analysis carried out are the mix utilized daily, the distance between the mixing plant and site, the grader's processing time, and the roller's processing time. The values of the constant and varying parameters are presented in Table 7 and Table 8.

Table 7. The constant parameters used.

Sl. No.	Parameter	Range
1.	Capacity of truck	14 m^3
2.	Total working hours per day	14 hour
3.	Number of truck utilized	7
4.	Number of graders	1
5.	Number of smooth wheel roller	1
6.	Mix dispatch inter-arrival time	8 min

Table 8. The varying parameters used.

Sl. No.	Parameter	Range
1.	Quarry waste	Log Gamma
2.	Distance between mixing plant and site	5 km – 40 km
3.	Processing time for grader	4 + Weibull (4.74, 2.3)
4.	Processing time for roller	7 + Weibull (3.16 , 1.65)

A single day conceptual supply chain simulation model, to determine the operation and quantity of work was developed and is presented in Figure 3.

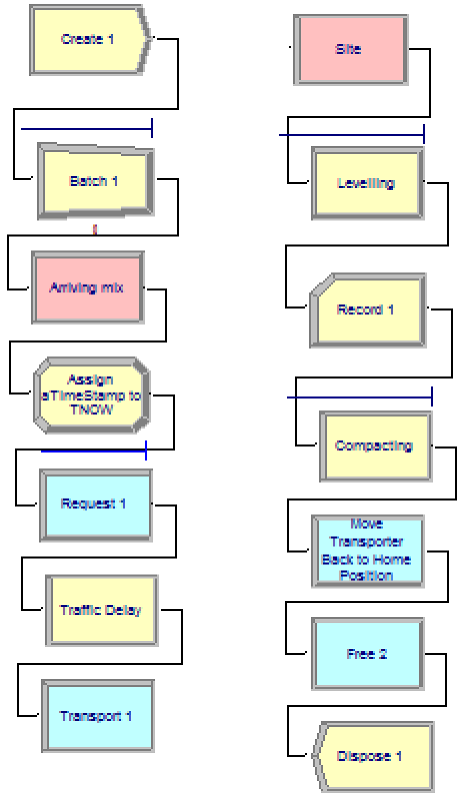

Figure 3. Developed ARENA model

4.0 RESULTS AND DISCUSSION

Material utilization data collected from 62 construction projects are analyzed to arrive at a 'best fit' probability distribution. Utilizing this real-time 'best fit' material utilization data as input, a conceptual simulation model is developed for the sub-base activity in this study. The model examines the waiting time and utilization of various equipment in the project by varying specific parameters.

An increase in the number of trucks reduced the request queue, but this did not increase the outturn. Therefore, it was observed that a near-optimal case is obtained when the quantity of mix processed a day is 700m^3, at a travel distance of 40km employing simulation modelling for a 14-hour workday. Seven trucks are used for completing this job, each making ten trips with the aid of one grader and one smooth wheel roller. The above conditions helped achieve the sub-base activity's completion in a planned duration of 37 days with minimum idling of resources intended by the contractor for a 50-day work. Thus, by applying the real-time probability distribution in the simulation model, a much realistic picture of the actual work is achieved.

The results indicate that an increase in the number of trucks did not improve the project's productivity, whereas an increase in the number of graders from one to two increased productivity by 14 percentage.

5.0 CONCLUSION

In this study, data collected from 62 highway project sites with varying terrain and climatic conditions were analyzed and fitted with a realistic probability distribution. These distributions vary for different activities and based on the results obtained, sensitivity analysis was carried out by changing the sample sizes. The distribution was found to converge when the Goodness of fit test was carried out by the K-S test rather than the A-D test.

It is concluded that the material utilization of the activities predominantly tends to follow Pearson 6 Distribution, Nakagami (a particular case of Gamma distribution), Weibull, Fatigue Life and Log-logistic distribution. Currently, there is no standard probability distribution fit available for material utilization in highway projects. These distributions provide a realistic variation of material utilization in the site since it uses the actual location data and can be integrated as an input for simulation modelling. Moreover, the distribution provides the project team with more realistic data for resource planning and aids in developing a practical supply chain network.

The model developed aids in determining the utilization of resources and supports the project manager to reduce the idling of resources. It also helps in formulating suitable material and equipment delivery plans to lessen risk in construction projects. Further study needs to be carried out to establish probability distribution for equipment utilization. These can be integrated to develop a total supply chain model for simulating highway construction projects.

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