Journal of Construction Project Management and Innovation Vol. 5 (2): 1196-1210, 2015
ISSN 2223-7852

ELIMINATING ENFORCED IDLENESS OF RESOURCES AND JOB WAITING TIME IN TIME-CONSTRAINED CONSTRUCTION ACTIVITIES USING WAITING LINE THEORY

Oluseye OLUGBOYEGA

Department of Building, Obafemi Awolowo University, Ile-Ife, Nigeria, 220282, PH (+234)08066704465, Email: oolugboyega@oauife.edu.ng, oolugboyega@yahoo.com

ABSTRACT

Waiting of labour on construction site is a waste of energy and has been described as a shortcoming and production waste that can affect work performance and profitability of contractors. Labours are expected to be flowing through the construction site and not to be stationary; but when activities are not well-designed, their capacities are withheld and are forced to be idle. Also, conventional job-design techniques focus on planning of operations and required operatives without considering the elimination of waste related to operatives. Hence, this study explored the application of waiting line theory to eliminating the cost of waiting time of resources using the construction of a hypothetical upper floor slab. The practical application of waiting line theory was demonstrated and conclusions were drawn from the findings of the study. The findings revealed that waiting line theory can be applied in the design of time-constrained construction activities so as to eliminate enforced idleness on construction sites through reduction in the waiting time of resources.

Keywords: Enforced idleness, waiting line theory, idleness of resources, job waiting time, queue discipline.

1. INTRODUCTION

Enforced idleness is a form of waste that exists when specialized resources have been driven out of productive employment (Hutt, 2011). Russel & Wong (1993) observed that labours are forced to wait for the space vacated by others in order to carry out their tasks on construction sites. Devi & Ananthanarayanan (2007) concluded that resource idle time and job waiting time can result in higher costs and possible delay.

Activities with long waiting time are wasting productive time and capacity. According to the United State Environmental Protection Agency (2007), waiting of labour on construction site is a waste of energy. It can also be described as a shortcoming and production waste that can affect work performance and profitability of contractors. Song *et al*. (2010) inferred that waiting of labour is an unnecessary movement of labourers on construction site; together with inefficient sequencing of work procedures, waiting can contribute to schedule delay. Waiting of any resources, especially labour can cause gap and delay between activities and lead to production waste (Ohno, 1998 cited in Belayutham and Gonzalez, 2003; Womack & Jones, 2003). Fagbenle *et al*. (2011) concluded that labour is the major and the most important resource in the construction industry which need to be properly managed if performance is to improve. Hutt (2011) described enforced idleness of resources as the withholding of capacity of resources. He pointed out that when resources are left in a state of 'valuelessness' in respect of any alternative employments, those resources are forced to be idle and their capacities wasted. Sridhar (2000) observed that idleness of resources has a strong negative effect on resource utilization.

It is not part of the construction plan for resources to be idle on site. Many authors have studied the causes of enforced idleness of resources on construction sites. Hutt (2011) noted that the monopolization of a cooperant stage of production may force labours into enforced idleness. Koskela (2000) identified long distance between facilities as a cause of waiting and delay between activities. For example, long distance between concrete batching plant and working area. Devi & Ananthanarayanan (2007) argued that idleness and waiting of resources on construction sites are due to unbalanced production rates and variation during execution. Belayutham & Gonzalez (2003) claimed that defective output, overproduction of other activities and shortage of material may cause waiting of labour on construction sites. Enforced idleness has been observed on construction sites when labours and equipment's are waiting and being idle because the activities were not well-designed (Javkhedkar, 2006). Most of the construction projects result in huge time and cost overruns because of the inability of the construction projects managers to make use of the right management technique or failure to apply the same (Wideman, 2001). Managing construction activities and demands to achieve the maximum efficiency from the available resources is difficult and typically not well done. Time, money and resources are wasted when projects are poorly managed, causing workers to have to wait around (Modular Building Institute, 2010).

Jobs wait in line to be executed and resources wait in line to be utilized. The time spent by works in the line waiting to carry out their respective tasks could otherwise be spent in productive activities (Waiting Line Management, 2003). Belayutham & Gonzalez (2003) and Koskela (2000) opined that a smooth process flow can increase value to clients by minimizing or eliminating idleness of resources. Production waste could be reduced by analysing and designing the process flow. Song *et al.* (2010) observed that productivity study has been mainly focused on observing and improving construction operation, whereas emphasizes ought to be placed on the eliminating of waste related to construction operatives.

Labours are expected to be flowing through the construction site and not to be stationary and to achieve this a schedule technique for smooth movement of resources is needed for minimizing idle time on construction sites. A pending job and waiting labour can be avoided by proper resource planning. Optimization of resources starts with the determination of the right number of labour for a specific task or activity to obtain minimum project duration with maximum labour utilization (Devi & Ananthanarayanan, 2007). It is imperative that specific time bound tasks are spelled out clearly and allotted to specific labour for execution within that time frame in order to achieve results within a pre-decided time-frame (Wideman, 2001). Sridhar (2000) noted that one of the important of service quality is ease of access, which includes not only location of service facility and its opening hours but also minimum waiting time to receive service.

Contractors are under enormous pressure for continuous improvement to enhance their productivity and competitiveness locally and internationally (Javkhedkar, 2006). The conventional techniques may not be able to smooth the process flow that may create waiting between activities (Belayutham & Gonzalez, 2013). Understanding waiting lines or queues is basic to creating schedules and job design and learning how to manage waiting lines is one of the most important areas in operations management (Waiting Line Management, 2003).

The objective of this study is to balance the cost of waiting time of resources with the cost of adding more resources to a waiting job by applying waiting line theory to resource scheduling for the construction of a hypothetical upper floor slab.

2. LITERATURE REVIEW

The central problem in virtually every waiting line situation is a trade-off decision. The manager must weigh the added cost of providing more resources against the inherent cost of waiting time (Waiting Line Management, 2003). Sridhar (2000) pointed out that waiting line theory is being ignored in the planning of service delivery process. He carried out a study to examine the concepts of service quality and customer satisfaction in waiting line theory and applied it to a typical library situations. In his conclusion, he stressed the need for appropriate studies on the application of waiting line theory. Cernea *et al*. (2010) applied waiting line theory to waiting situations in a fast-food restaurant to highlight the characteristics of a waiting system and concluded that waiting line theory plays a key role in highlighting the operations effectiveness and the need to improve their characteristics. Yang & Ioannon (2001) conducted a research to investigate the existence and influence of idleness on construction sites and proposed the pull-system scheduling system to eliminate idleness. Hutt (2011) maintained that ‘withheld capacity’ arises when the output of a resources is cut down. Withholding the capacity of resources reduces the degree of utilization of those resources. Javkhedkar (2006) studied the application of lean construction in concrete construction projects at both operation and project levels.

He proposed the use of Linear Scheduling Method to identify and eliminate waste of resources on construction sites. Song *et al*. (2010) studied lean construction and its application in concrete construction projects at both the operation and project levels. An actual concrete construction project was observed and problems areas contributing to production wastes were identified. The study recommended the use of 3D animation to train workers and eliminate production wastes. Hutt (2011) argued that the absence of idleness does not imply the absence of waste. According to him, waste of capacity exists when movement of labours does not contribute to productive output of the employed resources. Koskela (2000) concluded that waiting of labour and idleness in the construction processes can be caused by wrong choice of construction method, improper allocation of resources that creates lag between works and improper planning and sequence of work that creates gap between activities. Waiting times may happen due to the delay of a previous activity, inefficient space allocation, low productivity of a crew, deficient or insufficient equipment, delay in information flow, unavailability of material and external situations such as heavy downpour (Belayutham & Gonzalez, 2013). Devi & Ananthanarayanan (2007) attempted the development of an automatic resource-driven construction schedule with which resources can optimally be allocated to the activities. Modular Building Institute (2010) reported the documentation of 25 to 50 percent waste in coordinating labour by studies focusing on construction efficiency. Waiting Line Management (2003) critically pointed out that waiting lines are not a fixed condition of a productive system but are to a very large extent within the control of the system management and design. Modular Building Institute (2010) expressed a belief that an improvement in the efficiency of labour will also improve overall productivity and help individually construction firms become more competitive. Studies on the application of waiting line theory are few and no specific study has applied waiting line theory to time-constrained activities like the construction of upper floor slabs.

2.1 Waiting Line Theory

Waiting line theory is the study of waiting (Wang, 2009). Waiting lines are a part of everyday life and exist wherever the current demand for a service exceeds the current capacity to provide that service, and their adequacy has strong effect on quality of service and productivity (Wang, 2009; Sridhar, 2000). The theory deals with one of the most unpleasant experiences of life – waiting, and its application is about determination of the main performance measures of the system which are the probabilistic properties of the number of customers in the system, number of waiting customers, utilization of the server(s), response time of a customer, waiting time of a customer, idle time of the server, and busy time of a server (Sztrik, 2012). According to Cernea *et al.* (2010), waiting line theory can be applied to determine the most economical strategy to reduce the time spent in waiting systems. Wang (2009) developed a waiting line model (figure 1.0) which shows the waiting line characteristics and observed that the provision of too much service units involves excessive costs and non-provision of enough service units causes the waiting line to become excessively long. The ultimate strategy to achieve an economic balance between the cost of service and the cost associated with the waiting for that service.

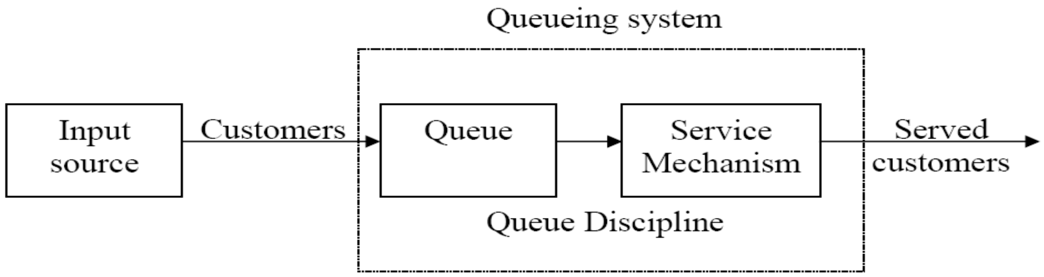

Figure 1.0: Basic structure of waiting line model (Source: Wang, 2009).

2.2 Waiting line characteristics

2.2.1 Queue

The queue is where those in need of service wait before being served. A queue may be infinite or finite based on the maximum permissible number of customers it can contain and it is formed when customers arrive faster than they get served and usually has length and number (Wang, 2009; Waiting Line Management, 2003).

2.2.2 Queue discipline

This refers to the order in which members of the queue are selected for service (Wang, 2009). It can also be referred to as a priority rule or set of rules for determining the order of service to customers in a waiting line (Waiting Line Management, 2003). According to Waiting Line Management (2003), examples of priority rules in queue discipline include: chronological arrival (first come, first served), shortest service first, reservations first, emergencies first, highest-profit customer first, largest orders first, best customers first, longest waiting time in line first, and soonest promised date first.

2.2.3 Service mechanism

This consists of one or more service facilities, each of which contains one or more parallel service channels, called servers (Wang, 2009). It represents the structure of the flow that customers may go through for service; examples include: single channel-single phase, single channel-multiphase, multichannel-single phase, multichannel-multiphase and mixed structures (Waiting Line Management, 2003).

2.2.4 Service time

Usually defined by a probability distribution, it is the time the customer spends with the server once the service has started (Waiting Line Management, 2003).

2.2.5 Arrival/input source

This generates customers for a service system. It has population sizes which are considered unlimited (infinite) or limited (finite) and patterns which are considered random (variable) or constant (periodic) (Wang, 2009; Waiting Line Management, 2003).

3. RESEARCH METHODOLOGY

The objective of this study is to balance the cost of waiting time of resources with the cost of adding more resources to a waiting job. In order to achieve the objective, a hypothetical 200mm thick upper floor slab of 298 cubic metre in volume with allocated time of one day (8 working hours) which cannot be exceeded was used to illustrate the application of waiting line theory to resource scheduling. Four various types of concrete mixers were considered for hiring with their respective service rates according to their capacities as shown in table 1.0 and profit losses due to waiting time of resources as shown in table 3.0 were calculated according to waiting time of resources as shown in table 2.0 in order to determine the concrete mixer type to be hired which will balance the cost of waiting of resources with the cost of adding more resources to the work.

Table 1.0: Service time of concrete mixers types (See appendix A)

Type of concrete mixer	Service Time (T)
Type 1	One wheelbarrow every 3.5 minutes
Type 2	One wheelbarrow every 2.3 minutes
Type 3	One wheelbarrow every 1.75 minutes
Type 4	One wheelbarrow every 1.4 minutes

(Source: Olugboyega, 2015)

Table 2.0: Waiting time of resources (See Appendix B)

Type of con-crete mixer	No. reqd	Service rate (μ)(labour per 7minutes)	Average no. of workers waiting in line (Lq)	Average waiting time in line by labour (Wq) (min.)	No. of idle labour based on service rate	Time waiting in line if max. time waiting line	No. of Idle labour based on time waiting in line

					(μ - λ)	allowed is 2minutes ($Wq_{max} - Wq$)	($\lambda_n - \lambda$) n=1,2,3,4
1	27	54	5.79	0.12	4	1.88	3
2	19	58	2.70	0.05	8	1.95	7
3	15	60	2.08	0.04	10	1.96	9
4	14	70	0.89	0.02	20	1.98	19

(Source: Olugboyega, 2015)

Table 3.0: Profit loss due to waiting time of resources (See Appendix A)

Type of concrete mixer	Cost of hire of plant (per minute)	Profit loss per minute due to idle time of plant using the values of $Wq_{max} - Wq$	Profit loss per minute due to idle time of labour using the values of $\lambda_n - \lambda$	Total profit loss per minute due to idle time of labour and plant
1	\$0.09	\$0.17	\$0.03	\$0.20
2	\$0.07	\$0.13	\$0.07	\$0.21
3	\$0.01	\$0.13	\$0.10	\$0.22
4	\$0.07	\$0.13	\$0.20	\$0.33

(Source: Olugboyega, 2015)

Table 4.0: Waiting time parameters for concrete mixer type 2 (See Appendix C)

Waiting time parameters	values
Lq	5.39 labours
Ls	6.25 labours
Wq	0.11 minutes
Ws	0.13 minutes

ρ	86%

(Source: Olugboyega, 2015)

Table 5.0: Optimal utilization of skilled labour and concrete mixer (See Appendix D)

Available optimal utilization options	No. Of skilled labour required
Equating the output of skilled labours to the output of the concrete mixer	100
Equating the output of skilled labours to the quantity of work	100

(Source: Olugboyega, 2015)

4. FINDINGS AND DISCUSSION

Table 2.0 shows the number of concrete mixers required for the work based on their service rates, number of labours required, average number of labour waiting in line, average waiting time in line by labours, number of idle labour based on service rate and time waiting in line. The number of concrete mixer type 1 required, if it is to be considered for hiring is 27 with service rate of 54 labours per 7 minutes, 5.79 labours waiting in line, waiting time of 0.12 minutes, 4 and 3 idle workers based on service rate and time waiting in line respectively, waiting time of 1.88 minutes at maximum time waiting in line of 2 minutes. Concrete mixer type 1 gives the highest number of concrete mixer required for the work, closely followed by concrete mixer type 2 which gives 19, and the least is 14 by concrete mixer type 3. Concrete mixer type 3 has the highest service rate of 70 labours per 7 minutes and the least number of labour waiting in line and average waiting time in line by labours. The profit losses due to waiting time of resources as shown in table 3.0 shows that concrete mixer type 1 will cost \$0.09 to hire but the profit losses due to idle time of plant and labour are \$0.17 and \$0.03 respectively. Concrete mixer type 4 will cost \$0.07 to hire which is \$0.03 lesser than concrete mixer type 1, but its profit loss due to idle time of labours is \$0.20 which is higher than that of concrete mixer type 1.

Although, both type 1 and 2 concrete mixers give the lowest profit loss and the number of idle labours, but concrete mixer type 1 gives the lowest profit loss and number of idle labours as compared to concrete mixer type 2; however, the required number of concrete mixer type 2 is lesser, its service rate is higher which makes the average number of workers waiting in line and waiting time in line by labour lesser than that of concrete mixer type 1. Also, the cost of hiring concrete mixer type 2 is lesser than that of concrete mixer type 1 and its total profit loss per minute due to idle time of labour and plant is the 2nd lowest after that of concrete mixer type 1.

As shown in tables 4.0 and 5.0, using the waiting time as criterion for selection because of time-constraint, concrete mixer type 2 is selected to be hired for the work because its cost of hire is lesser than that of concrete mixer type 1, its average time waiting in line is lesser than the maximum time waiting in line, offers the 2nd least total profit loss and optimally utilizes the skilled labour, thereby eliminating enforced idleness of resources and job waiting time. The results in this study are consistent with the earlier studies by Koskela (2000), Javkhedkar (2006) & Hutt (2011) which pointed out that waiting of labour and idleness of resources can be eliminated by proper allocation of resources and that optimizing the movements of labours based on the capacities of employed resources can help to eliminate waste of resources.

5. CONCLUSION AND RECOMMENDATION

Meeting of target rates of construction projects as drawn up in construction programmes and delivering on projects' objectives as required by clients can aid avoidance of cost overruns, reduce profit losses and give values to clients on their investments in the construction industry. Although the method employed for the study is largely based on the construction methods obtained in the Nigerian construction industry; but Waiting Line Theory is a management technique which when applied in designing of construction activities in any construction industry can help in reducing wastage of resources on construction sites. It takes time and money to bring plant and human resources to construction sites; but if these resources are forced to be idle by not utilizing them optimally, more time and money would be lost. It has been established that conventional job schedule techniques may not be adequate in eliminating enforced idleness on construction sites; but the application of waiting line theory to job planning, especially time-constraint activities can help to achieve optimal utilization of resources and meeting of targets as drawn up in the construction programmes by eliminating enforced idleness on construction sites through reduction in the waiting time of resources.

6. REFERENCES

Belayutham, S. & Gonzales, V. (2013). Integrating lean into stormwater runoff management: a theoretical exploration. Proceedings IGLC-21, Fortaliza, Brazil.

Cernea, S. O., Jaradat, M. & Jaradat, M. (2010). Characteristics of waiting line models- the indicators of the customer flow management systems efficiency. Annales universitatis Apulensis Series Oeconomica, 12 (2).

Devi, A. C. & Ananthanarayanan, K. (2007). A model for automated generation of resource-driven construction schedule for housing industry. 24th international symposium on automation and robotics in construction (ISARC, 2007), construction automation group, I.I.T. Madras.

Fagbenle, O. I, Ogunde, A. O. & Owolabi, J. D. (2011). Factors affecting the performance of labour in Nigerian construction sites. Mediterranean journal of social sciences, vol. 2, No. 2.

Hutt, W. H. (2011). The theory of idle resources. 2nd edition, Ludwig Von Mises Institute, Jonathan Cape, London and Toronto.

Javkhedkar, A. (2006) Applying lean construction to concrete construction projects. Unpublished MSc. Thesis, University of Houston.

Koskela, L. (2000). An exploration towards a production theory and its application to construction. Helsinki University of Technology, Espoo, Finland.

Modular Building Institute (2010). Improving construction efficiency and productivity with modular construction. The Modular Building Institute, 944 Glenwood Station Lane, Suite 204, Charlottesville, VA 22901, USA.

Russel, A.D. & Wong, W. C. M. (1993). New generation of planning structures. Journal of construction engineering and management, 119 (2), 196-214.

Song, L., Leang, D. & Aditi Javkhedkar, M. T. (2010). A case study on applying lean construction to concrete construction projects.

Sridhar, M. S. (2000). Waiting lines and customer satisfaction. Library science documentation and information studies, Vol. 40 (4).

Sztrik, J. (2012). Basic queueing theory. University of Debrecen.

United State Environmental Protection Agency (2007). The lean and environment toolkit.http://www.epa.gov/lean/environment/toolkits/environment/resources/leanEnviroToolkit.pdf

Waiting Line Management (2003). Technical note six. Pp. 242-271, Robert H. Smith School of business, University of Maryland, Maryland, USA.

Wang, J. Y. (2009). Operation research II. College of management, NCTU, chapter 17-1.

Wideman, R. M. (2001). Total project management of complex projects improving performance with modern techniques. Acres International Limited, Vancouver, B. C, Canada.

Yang, I. and Ioannon, P. G. (2001). Resource-driven scheduling for repetitive projects: a pull-system approach.

APPENDIXES

Appendix A: Assumption of requirements

- Concrete mixer type, outputs and costs

Concrete mixer type	**Output/ capacity**		**Cost of hire**
	M^3 per hour	M^3 per minutes	Per hour
Type 1	1.4	0.02	$0.20
Type 2	2.0	0.03	$0.22
Type 3	2.5	0.04	$0.26
Type 4	2.8	0.05	$0.28

- Output for placing concrete in upper floor slab = $3m^3$/man day

Therefore, number of skilled labour to complete the work in a day = $\frac{298}{3}$ = 100 skilled labours.

Output for placing concrete per hour = $\frac{3}{8}$ = $0.38m^3$/hour (using 8working hours per day)

Output for placing concrete per day = $\frac{0.38}{60}$ = $0.0063m^3$/minute.

- Output for transporting concrete within 100m haulage cycle = $6m^3$/man day

Therefore, number of unskilled labour to complete the work in a day = $\frac{298}{6}$ = 50 unskilled labour

Output for transporting concrete per hour = $\frac{6}{8}$ = $0.75m^3$/hour (using 8working hours per day)

- Ratio of skilled labour to unskilled labour = 1:2 (i.e., two skilled labour attending to one unskilled labour).
- Assume Poisson arrival rate and exponential service rate.
- Equipment for transporting concrete is wheelbarrow with $0.07m^3$ capacity.
- Allocated time for the is 1 working day
- Distance from the concrete mixing plant to the work station is 20m.

- Cost of skilled labour per day = \$12.76
- Cost of unskilled labour per day = \$5.10 (\$0.67 per hour and \$0.01 per minute)
- Estimated arrival rate (λ) for unskilled labour to the mixing plant to load their wheelbarrows.

Assuming the travelling time to the mixing plant as 20 seconds (0.3 minute),
Assuming the travelling time from the mixing plant as 25 seconds (0.4 minute),
Assuming that one unskilled labour will supply one wheelbarrow full of concrete to two skilled labour,

The time taken for one unskilled labour to be attended to = $\frac{0.07}{2(0.0063)}$ = 5.4minutes

Allow waste time of 0.9 minutes,

Therefore, total arrival time (λ) for unskilled labour = 0.9 + 0.3 + 0.4 + 5.4 = 7minutes (50 labours per 7 minutes).

- Estimated time taken (T) for the mixers to serve the unskilled labourers (Service time).

  Mixer type 1 = $\frac{0.07m^3}{0.02m^3/minute}$ = 3.5 minutes

  Mixer type 2 = $\frac{0.07m^3}{0.03m^3/minute}$ = 2.3 minutes

  Mixer type 3 = $\frac{0.07m^3}{0.04m^3/minute}$ = 1.75 minutes

  Mixer type 4 = $\frac{0.07m^3}{0.05m^3/minute}$ = 1.4 minutes

Appendix B: The type of concrete mixer to be hired

- Mixer type 1:

  Number of mixer type 1 required for the work, N = $\frac{298m^3}{8hrs\ per\ day \times 1.4m^3\ per\ hour}$ = 27

  Service rate of mixer type 1 in terms of number of labourers,

  $$\mu = \frac{\lambda}{T} \times N \quad (1)$$

  μ = $\frac{7}{3.5} \times 27 =$ 54 labourers per 7 minutes.

  Average number of labourers waiting in line, Lq = $\frac{\lambda^2}{2\mu(\mu-\lambda)}$ (Waiting Line Management, 2003) (2)

Lq = $\frac{50^2}{2(54)(54-50)}$ = 5.79

Average waiting time in line,

Wq = $\frac{Lq}{\lambda}$ (Waiting Line Management, 2003) (3)

Wq = $\frac{5.79}{50}$ = 0.12 minutes

- Mixer type 2:

N = $\frac{298}{8(2.0)}$ = 19

μ = $\frac{7}{2.3} \times 19$= 58 labourers per 7 minutes

Lq = $\frac{50^2}{2(58)(58-50)}$ = 2.70

Wq =$\frac{2.70}{50}$ = 0.05 minutes

- Mixer type 3:

N = $\frac{298}{8(2.5)}$ = 15

μ = $\frac{7}{1.75} \times 15$= 60 labourers per 7 minutes

Lq = $\frac{50^2}{2(60)(60-50)}$ = 2.70

Wq =$\frac{2.08}{50}$ = 0.04 minutes

- Mixer type 4:

N = $\frac{298}{8(2.8)}$ = 14

μ = $\frac{7}{1.4} \times 14$= 70 labourers per 7 minutes

Lq = $\frac{50^2}{2(70)(70-50)}$ = 0.89

$Wq = \frac{0.89}{50}$ = 0.02 minutes

- Using maximum waiting time in lines (Wq_{max}) of 2minutes due to unforeseen circumstances.

$Wq = \frac{Lq}{\lambda} = \frac{\lambda}{2\mu(\mu-\lambda)}$; $\lambda = \frac{2Wq\mu^2}{1+2Wq\mu}$ (Waiting Line Management, 2003) (4)

When μ = 54; $\lambda_1 = \frac{2\times2\times54^2}{1+(2\times2\times54)}$ = 53 per 7minutes

When μ = 58; $\lambda_2 = \frac{2\times2\times58^2}{1+(2\times2\times58)}$ = 57 per 7minutes

When μ = 60; $\lambda_3 = \frac{2\times2\times60^2}{1+(2\times2\times60)}$ = 59 per 7minutes

When μ = 70; $\lambda_4 = \frac{2\times2\times70^2}{1+(2\times2\times70)}$ = 69 per 7minutes

Appendix C: Waiting time for loading

(Using the parameters of concrete mixer type 2 to determine the number of labourers waiting to load their wheelbarrows and how long they have to wait to load their wheelbarrows)

- Average number in the waiting line, $Lq = \frac{\lambda^2}{\mu(\mu-\lambda)} = \frac{50^2}{58(58-50)}$ = 5.39 labourers
- Average number in the system, $Ls = \frac{\lambda}{\mu-\lambda} = \frac{50}{58-50}$ = 6.25 labourers
- Average waiting time in line, $Wq = \frac{Lq}{\lambda} = \frac{5.39}{50}$ = 0.11minutes
- Average waiting time in the system, $Ws = \frac{Ls}{\lambda} = \frac{6.25}{50}$ = 0.13 minutes
- Average utilization of the mixer, $\rho = \frac{\lambda}{\mu} = \frac{50}{58}$ = 0.86 = 86%

Appendix D: Balancing the outputs of plants and skilled labours in order to ensure that the selection of concrete mixer type 2 would eliminate idleness of resources

- Option 1: equating the output of skilled labours to the output of the concrete mixer

Nr. Of mixer required = 19
Output of mixer per hour = 2.0m^3
Quantity of concrete available per hour = 19×2.0m^3/hour = 38m^3/hour

Output of skilled labour for placing concrete in upper floor slab= $3m^3$/man day =$0.38m^3$/hour

Nr. Of skilled labour required = $\frac{38m3/hour}{0.38m3/hour}$ = 100

- Option 2: equating the output of skilled labour to the quantity of the work

Nr. Of skilled labour required for the work = $\frac{298m3}{3m3/manday}$ = 100