Simple Design Tools for Stockyard Layouts

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Abstract

This article presents some simple design tools which can be used by engineers to understand the operation of the materials handling equipment in a stockyard.

1 Introduction

Most stockyard operations consist of materials handling systems such as conveyors, bins, feeders, hoppers, stockpiles, and materials handling machines. When designing a stockyard, engineers need to decide on a suitable capacity and size for the various components of the stockyard. The under sizing of equipment can lead to excessive delays and decreased annual throughput. Oversizing equipment can be expensive both in capital costs and in operating and maintenance costs. There is a trade-off between service cost and delay time.

Typically, engineers have used experience and engineering judgement to help size components. Also, simulation models have been used to help understand requirements of the stockyard layout. However, simulation models can be quite complex and are difficult to use to help gain an understanding of what is happening in the stockyard.

This paper presents a simple set of equations that can be used for "back of the envelope" calculations; the equations are based on Queuing or Waiting Line Models. A detailed review of Queuing Theory is presented in the excellent textbook by Chase, Aquilano and Jacobs (Chase, Aquilano, & Jacobs, 1998). It is important to understand that the simple equations presented in this paper are not meant to replace engineering judgement or become a substitute for detailed simulation. Rather the equations can help provide a better understanding of the issues and constraints within stockyard operations during the initial stages of development. The use of these simple tools is illustrated by some examples.

2 Queuing Models or Waiting Line Models

Queuing or Waiting Line Models are an important application in operations management – the prediction of congestion, as measured by delays caused by waiting in line for a service. This is a common situation – a business needs to decide on the optimum mix of cost (increased service) versus delays (increasing waiting). Customers arriving at a checkout counter in a store, a theatre ticket office or a fast-food drive-through may feel that they are wasting their time if there are repeated and excessive delays.

The use of Queuing Theory is demonstrated via a truck dump station example (refer to Figure 1). This shows a typical truck dump station for a mine or port stockyard. The trucks take the ore from the pit to the stockyard. If the hopper is full when a truck arrives, then the truck may need to queue, or it may dump its load on the pad, requiring "double handling," and continue back to the pit. Excessive waiting time or "double handling" of the material can lead to reduced overall throughput.

The variables to consider for this example are the number and size of trucks, the size of the hopper and the throughput capacity of the feeder and conveyor. The operators want to understand the influence of each of these variables.

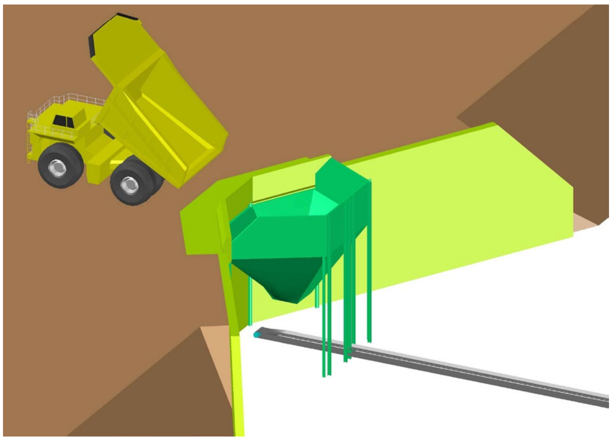

Figure 1. Typical truck dumping station

The queuing system consists of two main components: arrival characteristics and service characteristics:

2.1 Arrival Characteristics

Arrival characteristics have three key features:

1. Size of the arrival population. Arrivals may be drawn from a finite or infinite population. In the truck dump example, the size of the truck fleet is important. An infinite population means that the truck fleet is large enough so as not to have an adverse effect on the service facility.

2. Distribution of arrivals. Queuing formulas require an arrival rate. A constant arrival rate means exactly the same time between successive arrivals. In stockyard applications, the only arrivals that approach a

constant arrival rate are those subject to machine control such as material delivered by a conveyor. Truck arrivals, train arrivals and ship arrivals are commonly variable or have random arrival distributions.

3. Behaviour of arrivals. A patient arrival is one who will wait as long as necessary for the service facility to serve them. In the dump station example, a truck may only be prepared to wait for a certain amount of time. If the waiting time is too long, the truck may decide to dump its load on the pad rather than wait for the dump station to become free.

2.2 Service Characteristics

The service characteristics have three key features:

1. Length of the queue. For the dump station example, this is equal to the size of the dump hopper plus the number of trucks waiting to dump.
2. Service time. An important feature of the service system is the amount of time that the arrival spends at the system. For example, how long does it take for the truck to dump its load and for the feeder to clear the hopper so that another truck can commence dumping.
3. Line structure. As can be seen in Figure 2, the material may go through a single hopper or through multiple hoppers.

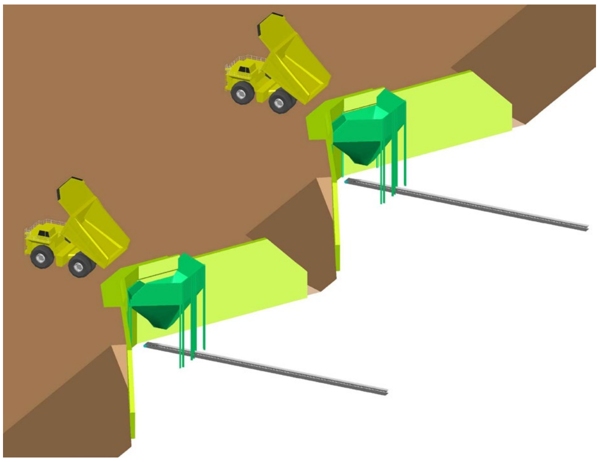

Figure 2. Typical truck dumping station with two hoppers

The equations for waiting line models (Chase, Aquilano, & Jacobs, 1998) can be quite complicated and sometimes it can be easier to solve these problems using computer simulation. However, there is a "quick and dirty" mathematical approximation to the queuing models. All that is needed is the mean and standard deviation of the arrival rate and service time. A stopwatch can be used to measure the arrival times and the service times. The equations for the queuing model are presented below.

Input data required on service time and arrival time:

$\bar{X}_s$ = mean service time

S_s = standard deviation of service time

$\bar{X}_a$ = mean arrival time

S_a = standard deviation of arrival time

The mean and standard deviation is given by:

$$\bar{X} = \frac{\sum_{i=1}^{N} x_i}{N} \quad \text{and} \quad S = \sqrt{\frac{\sum_{i=1}^{N} (x_i - \bar{X})^2}{N-1}}$$

where x_i is the observed value and N is the total number of observed values.

The following values are defined:

Coefficient of variation of service time $C_s = \frac{S_s}{\bar{X}_s}$

Coefficient of variation of arrival time $C_a = \frac{S_a}{\bar{X}_a}$

Service rate $\mu = \frac{1}{\bar{X}_s}$

Arrival rate $\lambda = \frac{1}{\bar{X}_a}$

Number of servers T

Utilisation of servers $\rho = \frac{\lambda}{T \times \mu}$

Expected length of waiting line $L_q = \frac{\rho\sqrt{2 \times (T+1)}}{1-\rho} \times \frac{C_a^2 + C_s^2}{2}$

Expected number of trucks in system $L_s = L_q + S \times \rho$

Expected time waiting in line $W_q = \frac{L_q}{\lambda}$

Expected time in system $W_s = \frac{L_s}{\lambda}$

3 EXAMPLE – TRUCK DUMP STATION

This example presents the results of the problem shown in Figure 2. The mine currently has an annual throughput of 8 MT, and it wants to increase the annual throughput to 12 MT. What options are available to handle the increased throughput at the dump station?

Currently the mine operates for 6500 hours per year and the truck size is 150 tonnes. It is assumed that the size of the truck population is infinite.

The equations for the calculation of the queuing time are presented below.

The mean truck arrival time is calculated by multiplying the number of operating hours by the size of the truck payload and dividing by the annual throughput. For this problem, trucks arrive at an average rate of 8.2 trucks per hour. The mean truck dump time is 4 minutes.

Input data for truck dumping service time and truck arrival time:

Mean truck service time $$X_s = 4\ minutes$$

Truck service time standard deviation $$S_s = 2\ minutes$$

Mean truck arrival time $$\overline{X}_a = \frac{6,500\ hours \times 150\ tonnes}{8,000,000\ tonnes} = 7.3125\ mins$$

Truck arrival time standard deviation $$S_a = 2.7\ minutes$$

The following values are calculated:

Coefficient of variation of service time $$C_s = \frac{2\ mins}{4\ mins} = 0.5$$

Coefficient of variation of arrival time $$C_a = \frac{2.7\ mins}{7.3125\ mins} = 0.3692$$

Service rate $$\mu = \frac{1}{4\ mins} = 15/hour$$

Arrival rate $$\lambda = \frac{1}{7.3125\ mins} = 8.2051/hour = 0.1368/min$$

Number of trucks $$T = 1$$

Utilisation of servers $$\rho = \frac{8.2051/hour}{1 \times 15/hour} = 0.55$$

Expected length of waiting line $$L_q = \frac{0.55^{\sqrt{2\times(1+1)}}}{1-0.55} \times \frac{0.3692^2 + 0.5^2}{2} = 0.1276$$

Expected length of trucks in system $$L_s = 0.1276 + 1 \times 0.55 = 0.6746$$

Expected time waiting in line $$W_q = \frac{0.1276}{0.1368/min} = 0.933\ mins$$

Expected time in system $$W_s = \frac{0.6746}{0.1368/min} = 4.933\ mins$$

The system characteristics of the truck dump station show that the dump station is utilised for 55% of the time. The average time in the system is about 5 minutes and the time spent queuing is about 1 minute.

What is the average truck queue length and waiting time if the annual throughput is increased to 12MT and all the other input parameters remain the same? The queuing model equations can be updated based on the new parameters. The truck arrival rate increases from 8.2 trucks per hour to 12.3 trucks per hour.

Input data for truck dumping service time and truck arrival time:

Mean truck service time $$X_s = 4\ minutes$$

Truck service time standard deviation $$S_s = 2\ minutes$$

Mean truck arrival time $$\overline{X}_a = \frac{6,500\ hours \times 150\ tonnes}{12,000,000\ tonnes} = 4.875\ mins$$

Truck arrival time standard deviation $$S_a = 2.7\ minutes$$

The following values are calculated:

Coefficient of variation of service time $$C_s = \frac{2\ mins}{4\ mins} = 0.5$$

Coefficient of variation of arrival time $$C_a = \frac{2.7\ mins}{4.875\ mins} = 0.5538$$

Service rate $$\mu = \frac{1}{4\ mins} = 15/hour$$

Arrival rate $$\lambda = \frac{1}{4.875\ mins} = 12.3077/hour = 0.2051/min$$

Number of trucks $$T = 1$$

Utilisation of servers $$\rho = \frac{12.3077/hour}{1 \times 15/hour} = 0.8205$$

Expected length of waiting line $$L_q = \frac{0.8205 \times \sqrt{2\times(1+1)}}{1-0.8205} \times \frac{0.5538^2 + 0.5^2}{2} = 1.0442$$

Expected length of trucks in system $$L_s = 1.0442 + 1 \times 0.8205 = 1.864$$

Expected time waiting in line

$$W_q = \frac{1.0442}{0.2051/min} = 5.09\ mins$$

Expected time in system

$$W_s = \frac{1.8647}{0.2051/min} = 9.09\ mins$$

The average queuing time is now 5 minutes and the average time in the system is over 9 minutes. This may be unacceptable for the mine because more trucks may be required.

Some of the other options that can be investigated include upgrading the trucks to 200 tonne payloads, increasing the efficiency and reliability of the mining operation so that the operating hours can be increased and increasing the feeder rate on the hopper to decrease the truck dumping time.

Table 1 presents a summary of the results of various options. As can be seen from the results, there can be a significant difference between the different options. The results demonstrate that this “quick and dirty” calculation can help provide a better understanding of some of the issues and constraints within stockyard operations.

Table 1. Summary of Average Time in System for Different Options

Option	Description	Average time in the system (minutes)
8MT per annum		
1	Current system	4.9
12MT per annum		
2.1	Current system	9.1
2.2	Change to 200 tonne trucks	5.2
2.3	Increase to 7,000 operating hours per annum	7.3
2.4	2 dump stations	4.3
2.5	Decrease average truck dump time to 3 minutes	4.5

4 CONCLUSIONS

It is important to note that the equations presented in this paper are not intended to replace simulation studies or sound engineering judgement. Rather they should be used as simple tools to help engineers understand the constraints and issues associated with stockyard layout and design.

5 References

[1] R. B. Chase, N. J. Aquilano and F. R. Jacobs, Production and Operations Management, Irwin/McGraw-Hill, 1998.