CHAPTER FOUR

STUDY, MODELLING AND ANALYSIS OF A RAILYARD

4.1. INTRODUCTION

Indian Railways is one of the largest railway systems in the world. Railways play a vital role in economic, industrial and social development of the country. Compared to road transport, railway transport has a number of advantages. Railways are more energy efficient, more efficient in land use and significantly superior from the standpoints or environment impact and safety. Railways being the more energy efficient mode of transport are ideally suited for movement of bulk commodities and for long distance travel.

Railways cover the length and breadth of India with 63,140 route kms as on 31.3.2002, comprising broad gauge (45,099 kms), meter gauge (14,776 kms) and narrow gauge (3,265 kms). Indian Railways have a fleet of 2,16,717 wagons (units), 39,236 coaches and 7,739 number of locomotives and run 14,444 trains daily, including about 8,702 passenger trains. They take more than a million tonne of freight traffic and about 14 million passengers covering 6,856 stations daily 1.

Indian Railways now faces many problems especially in the era of globalization. Some of these issues that was presented in Railway Status Paper (2002) are a) High operational losses b) High Costs of Inputs c) Maintenance and Replacement of Assets d) Maintenance of rolling stock e) Surplus Capacity in Production Units

Different aspects of Railway operations have been studied by a number of researchers. These include terminal operations, rail network optimization, freight movement, scheduling passenger trains and freight trains etc. There are many

1 Salient Features of Indian Railways, Website of Indian Railways, http://www.indianrail.gov.in.
studies, which consider intermodal terminals. Models in general include simulation as well as analytical models.

Most of the models related to rail yards described in papers above are oriented towards problem solving for long term facility planning. From the review of literature it can be seen that there have been reports of use of simulation in operational, tactical and strategic decision making for railway systems in separate cases with each case concentrating on one type of problem. In this chapter we examine the possibilities of using simulation models of a railway marshalling yard in three types of decisions i.e. operational, tactical and strategic points of view for the same case and would like to bring out the differences in models when type of decision changes.

4.2. PROBLEM AND OBJECTIVES OF THE STUDY

For the Railways, providing a high level of service to passengers is of utmost importance. This requires a high punctuality of trains and an adequate rolling stock capacity. There should be more running time of its rolling stock than idling at yards. Yard performance measures must be found out under varying conditions of its utilization. This study was done at the passenger rake yard in Ernakulam marshalling yard of Southern Railway Zone of Indian Railway. The study was carried out with the following objectives

1) To create a simulation model of the above yard.
2) To identify and develop yard performance measures.
3) To find out the level of utilisation of major facilities.
4) To study the effect of varying operation times on train schedules.
5) To study different operating strategies for train scheduling at the pit of the yard.
6) To study the problem of finding an optimum inventory level of spare coaches.
4.3. METHODOLOGY

The development and use of simulation models involves specific steps in order for the study to be successful. Regardless of the type of problem and the objective of the study, the process by which the simulation is performed remains almost same. Law and Kelton (1991) have discussed these steps for a simulation study. We have followed similar methodology for our simulation study consisting of following steps.

1. Operational flow charts, data regarding operation times and resource requirement were found out from a system study.
2. Conceptual modeling was done and three classes of models to suit three classes of problems were made.
3. A modelling platform was selected and models were made to get sufficient representation of actual operations. Models developed were verified and validated.
4. Experiments were done on the model by changing various parameters and its effect on utilization of equipments and resources were studied.

4.4. THE ERNAKULAM MARSHALLING YARD AND ITS OPERATION

This work involves simulation modelling of the passenger rake yard of Ernakulam marshalling yard located in South India.

4.4.1. Main Facilities

Figure 4.1 shows a block diagram showing facilities available at the passenger yard. The main facilities here are two pits where the workmen gang does various types of inspection, cleaning, maintenance and overhaul on arriving rakes. Each of the pits has a length of 650 meters and hold 26 coaches. The yard is equipped with required tools, watering and cleaning equipment, a large compressor for adjusting brake power of coaches, various electrical equipment for electrical maintenance are also provided. When a pit schedule starts, the designated engineers and his gang of workmen start their work, simultaneously on various coaches. At the end of the yard there is a coach care center. Here sick coaches
(A sick coach is one that is in need of repairs or maintenance and withdrawn from service for that purpose) are attended. Figure 4.2 shows the operations performed at the yard.

![Diagram of Yard's Facilities](image)

**Figure 4.1:** Facilities at the Ernakulam passenger rake yard

### 4.4.2. Activities at Marshalling Yard

A Marshalling yard is a yard where rakes (consists) for various trains are assembled and disassembled as required; typically contains a huge maze of highly interconnected sidings and tracks, lots of coaches, wagons, tankers, etc. being shuffled around to put together in formations as required, and equipped with lots of shunter locos. The passenger trains scheduled to Ernakulam yard first arrives at the Ernakulam South railway station. From there shunters (Shunter is a person who move shunting locos and others in and out of tight spots on shunting sidings, e.g., to allow the turner to move the main loco to some desired location. Shunter is also used to mean 'shunting locomotive'.) take the rakes to the passenger rake yard.
The overall high-level plan for rake movements is described in a rake link issued by a zonal railway, which has details of the planned rake compositions and rake movements for all trains handled by the zone. This has the details of which trains share rakes with which other trains, how and when rakes need to be formed or split up, and many other details: composition, marshalling order, vacuum or air braked, permissible loads, train watering, postal accommodation, sanctioned runs, locomotive allotment, maintenance stations, lie-over periods, distance (km) earned by a rake in a round trip, instructions for sending sick/defective coaches or coaches due for Periodic Overhauling (POH) to shops. The rake link book contains information regarding the types coaches to be attached to various rakes. The railways have a large variety of coaches. These coaches are understood by looking at their codes.

Inspection: Pre-departure inspections for a train include testing the brake system continuity for the entire rake, locomotive inspection by the crew (checking fuel and oil levels, inspecting the traction equipment, the bogies, etc). The guard ensures the availability of safety equipment, last-vehicle indications and warning lamps, etc. En route at important stations where the train stops, the wheels/axles and bogies of the rake are checked: visual inspection to check for defects, trailing or hanging equipment, etc., using a mallet to test the bogie fittings, using contact or non-contact thermometers to detect hot bearings or axles. At many stations, track-side fluorescent or halogen lamps are provided to help in this inspection.

Maintenance and Overhauls: Normal maintenance work at trip termini or intermediate stops (if needed) is done at trip sheds which have facilities for minor repair and maintenance but which normally do not home locos. Primary maintenance is carried out on all coaching stock every 2500km or so, and is a basic maintenance regimen taking around 6 hours. Mail and express coaches are sent to workshops for periodic overhaul once in about 13-14 months. Ordinary passenger train coaches receive periodic overhaul once in about 18-19 months. Passenger coaches are usually sent back to the owning zoning railway for overhaul. Figure 4.2 shows a simplified flow chart of operations at the yard.
ARRIVAL OF TRAINS AT MAIN STATION

SHUNTER ENGINES CARRY RAKES TO MAIN STATION

PIT READY?

no

WAIT IN SPARE ROADS

PIT PLACEMENT

no

WAIT IN SPARE ROADS

RESOURCES AND GANGS READY

no

WAIT IN SPARE ROADS

UNDER GEAR AND BRAKE INSPECTION

ELECTRICAL INSPECTION

TOUCHUP WORK

WATERING

AMENITIES INSPECTION
4.5. MODELS OF THE YARD

Fairly complex simulation models of the yard operations were developed in the simulation package Extend. All models were of the type discrete-event simulation. Data was collected from following documents and time study.
1. Site visits - to understand yard operations, constraints and local traffic.

2. Pit occupancy chart: The Occupancy chart for a station details which platforms and sidings are occupied, and by which trains, at different times. Figure 4.3 shows the pit occupancy chart at the centre.

3. Rake link (A detailed description of the rake compositions and movements for various trains handled by a particular division or zone. It usually covers the movement of stock for about 2500km (the primary maintenance period)). The composition of rakes is different for various schedules. Different types of coaches are used in these formations.

4. Coach registers: These registers give details of incoming rakes, of the coaches attended, the type of maintenance given, the number of coaches made sick, and the plan for train formation and the times at which the specified rakes left.

5. Spare coach register: This register details the position (inventory) of coaches received, available from coach care center, number of sick coaches etc.

6. The railway timetable.

7. Direct observation for getting times of operations.

Our observation on the behaviour of system revealed that performance of such system on short term is highly dependent on time schedules of entities arrival, operations and departure from the system. This aspect lead us to the categorisation of models, i.e.

1) Model the system according to schedules existing (TYPE 1 models)

2) Model the system partly according to schedules (TYPE 2 models)

3) Model the system discarding existing schedules (TYPE 3 models)
Figure 4.3: Pit occupancy chart
4.5.1. TYPE 1 models

When a model is prepared by considering yard elements as isolated from the main station, we call such models TYPE 1 (see Figure 4.4). The yard has to act by given arrival schedule and departure schedules of rakes. The decision maker can use the model for decisions related to changing pit placement schedules. This is usually the task for the yard senior engineer who is in charge of daily operation of the railway yard.

![Figure 4.4: TYPE 1 Model](image)

This type of models behaves strictly according to the time schedule. In the rail yard there are schedules for

1) rake arrival
2) pit placement
3) rake departure

The model generates arrival of rakes in the yard based on the given schedules. The model then receives rakes, holds it if necessary, places it for pit service, completes service and delivers the rake out from the system at the scheduled time. Model has enough flexibility to change operational times, and for viewing various statistics. This type of models is of great help in operational decision
making as it could be used to analyse the impact of actual schedule of a day or week. A major limitation with above model is in case of facility planning for additional capacity. Analyst will be at great difficulty in augmenting the times for rake arrival, pit placement and departure schedules.

4.5.2. TYPE 2 models

If output schedules can be changed, ways to achieve better performance can be investigated. These decisions go to a tactical level, which is carried by zonal managers. He has to prepare the train time tables for trains starting from this station.

This type of models of system behaves partly according to schedules (see Figure 4.5). For rail yard models, this type models have provision for schedules for some of the following: receiving rakes, placement for pit service and exit of rakes at the scheduled time. Model has provision to set a probability distribution for wait time and operation times. Model has enough flexibility to change operational times, and viewing various statistics. Model blocks allow repeated schedules over time. These types of models are of great help in tactical and strategic decision making as it could model actual schedule of that day or week, and these schedules can be changed easily.

![Figure 4.5: TYPE 2 Model](image)

Figure 4.5: TYPE 2 Model
4.5.3. TYPE 3 models

If both arrival and departure schedules and pit placement schedules are flexible (see Figure 4.6), it is possible to investigate the maximum work that can be got out from the railway yard. Also

a) Facility bottlenecks could be detected and alternatives for de-bottlenecking can be investigated.

b) Cases regarding stock of spare coaches, shifting of coach care centre, addition of roads/pits etc are problems that come under this category.

Figure 4.6: TYPE 3 Model

4.5.4. Simulation related characteristics

Various simulation related characteristics of the above three types of models are given in Table 4.1. The model details, validation procedures, run length and types of analysis were different in each case.
### Table 4.1: Simulation related characteristics of TYPE 1, TYPE 2 and TYPE 3 models

<table>
<thead>
<tr>
<th>MODEL TYPE</th>
<th>MODEL DETAILS</th>
<th>VALIDATION</th>
<th>RUN LENGTH</th>
<th>ANALYSIS</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL: TYPE 1</td>
<td>Operational schedules, arrival and departure schedules</td>
<td>Scheduled times in and out from blocks</td>
<td>One cycle, repeat for confidence interval</td>
<td>Changes in schedules, Operational times</td>
<td>Due to priorities in schedules, little flexibility for studying tactical and strategic decisions</td>
</tr>
<tr>
<td>MODEL: TYPE 2</td>
<td>arrival schedules and wait time distributions</td>
<td>Scheduled times in and out from blocks. Longer term behavior checked on output.</td>
<td>Many cycles, repeat for confidence interval</td>
<td>Changes in schedules, Operational times, Changes in number of some facility</td>
<td>Due to priorities in schedules, little flexibility in some blocks. More flexibility in blocks without specific schedules and priorities.</td>
</tr>
<tr>
<td>MODEL: TYPE 3</td>
<td>interarrival and wait time distributions</td>
<td>Longer term behavior checked on output</td>
<td>Steady state non terminating</td>
<td>Changes in operation times, Changes in number of facility, Changes in key technology</td>
<td>No specific priorities given to study long term behaviour, wait times and inter arrival time distributions based averaged values of present schedules</td>
</tr>
</tbody>
</table>

### 4.5.5. Basic model features

A basic model which represented only the operations at the pit of the yard was developed first. For subsequent analysis, features depending on the type of problem were added. Figure 4.7 shows a block diagram representing the elements in the basic model. The DE (Discrete Event) library of Extend was used for modelling.

![Figure 4.7: Block diagram representing the elements in the basic model](image-url)
4.5.5.1. Modelling periodic nature

When modelling situations like the operations of the yard one faces a peculiar situation when dealing with timing of events. The railway time table indicates the arrival and departure times of trains. These events are repeated periodically i.e. some schedules are daily schedules and some schedules are weekly etc. Simulation usually move forward in time upon each events as depicted in Figure 4.8. The arrival( i-1), pit placement (i), departure(i+1) events of a any train schedule is shown in cyclic as well as linear sequencing.

![Figure 4.8: Cyclic Vs. linear sequencing](image)

This means we can not directly put the times on the railway time table for modelling. For example consider the timing of train number 6310 given below.

<table>
<thead>
<tr>
<th>TRAIN NO</th>
<th>DAY</th>
<th>ARRIVAL TIME</th>
<th>TRAIN NO</th>
<th>DAY</th>
<th>DEPARTURE TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>6310</td>
<td>Sat</td>
<td>18.45</td>
<td>6309</td>
<td>Mon</td>
<td>17.20</td>
</tr>
</tbody>
</table>

This train reaches the railway station at Ernakulam South on Saturday at 18.45hrs. This train turns around as 6309 and departs from above station on Monday at 17.20hrs.
The total time it spends in Ernakulam = ((24-19) * 60 + 15) + 24 * 60 + (17 * 60 + 20) minutes

The first term in above represents the balance time on Saturday in minutes. Second term represents time on Sunday ie 24 hours. And the third term represents time available on Monday. Figure 4.9. Clearly illustrates this concept. Thick dotted line shows the balance time on each day. In short if $A_i$ represent the arrival time and $D_i$ represent the departure time the difference $(A_i - D_i)$ will not represent the time total time the train spends in the yard. This difficulty can be overcome by considering a 10 day schedule starting with first Sunday's beginning as 0.00 hrs and and adding total minutes of a day (1440 minutes) when a day is over. Maximum is $10 * 1440 = 14400$ minutes. All train arrival times, pit placement and departure times changed to times obtained by above conversion method.

Figure 4.9: Illustration of the calculation of time differences

4.5.5.2. Generating rake arrival:

The coaching yard services 33 train schedules. The pit chart shows the train arrival times in the station and pit placement times. For studying problems like pit and other facility utilisation in general, the rake arrivals are scheduled as per their
pit schedules. Upon arrivals, the rakes are set with its attributes like train number, its designated pit, and the type of maintenance i.e. primary or secondary.

4.5.5.3. Routing train units to appropriate pits

Once the rakes start arriving they all go either to the pit for the scheduled maintenance or to the spare lines in case the pit is busy at that time. Modelling was done by filtering rakes as per their attribute of pit. If the pit is busy they wait in the resource pool queue for pits. They will be immediately released when the pit is free.

4.5.5.4. Scheduling the type of maintenance

The rakes coming to the pit were filtered according to type of maintenance ie primary or secondary. The operation times vary accordingly. For primary maintenance it takes about 6 hours and for secondary maintenance it takes about 4 hours. Some of the coaches may be found to be sick here. A uniform random variate (here an integer between 0 and 4) was used for generating the number of sick coaches.

4.5.5.5. Shunting and pit operations

The sick coaches are to be taken to the coach care center. For this, the unit is to be detached and then pulled out. Further some fit coaches from the coach care center are to be taken and shunted to the designated position of the coach (In actual practice, at times when sufficient number of fit coaches are not available, some coaches of set rakes for other schedules are detached and used. This is not a recommended practice). However the present model has the facility to set a time for shunting operation in proportion to the sick units. The shunter is released immediately after its operation. Once the shunting operations are over each of the rakes are released to destination.

The actual time of operation at the pit is modelled as random variable. Many different gangs starts working on coaches related to inspection, cleaning, checking brake power, electrical maintenance etc. Pit maintenance time to be taken is the largest of each these times.
Pit Maintenance time = Max \{ T_k \} where \( T_k \) represent the operational times of different gangs(k). Delays occur due to a number of reasons like lack of availability of spare parts, major damages on coaches which require more time for repair, failure of equipment etc. Figure 4.10 shows a screenshot of the hierarchical block for setting these time delays.

**Figure 4.10:** Contents of hierarchical block of pit operations

The basic model was modified to study the effect of the pit maintenance delays. A number of parallel operations of random times (a uniform time approximately 10% less and above scheduled times was used) were added and condition is set that the rake is subjected to further operations only after completion of each of gang activities. To study how many rakes left in time, a number of additional simulation blocks were to be added. The purpose of these blocks are to schedule the exit of each rakes from pit according to time table. If time is not up for the rakes to leave they are put on the spare rakes waiting for departure. A Discrete-Event plotter catches the times when the rakes leave.

To study problems like requirement of spare coaches, a modified form of basic model was also developed. For this, more simulation blocks including a 'Coaches resource pool' were added. Coaches were added to the coaches
resource pool when a rake arrives (not everytime - discussed below) and released at the time of rake formation.

When coaches of a rake with all its set composition, is released to the resource pool is a tricky question. This cannot be done in each arrival. For example train number 2617/18 Mangala Express has a departure arrival schedule everyday. This does not mean that this train requires 7*18 coaches for its operation. Instead 6 rakes are required and this number is dependant on the up and down journey time of each of the trains as illustrated in Figure 4.11. The first rake returns on seventh day and released to the pool. Figure 4.12 shows a screen shot of the resource pool for coaches.

![Figure 4.11: Rake arrival and departure pattern](image)

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4.5.6. Some Performance Measures

A measure of operational efficiency of the yard can be the ratio of rakes on time

\[
\frac{\text{number of rakes exited in right time}}{\text{total number of rakes exited}}
\] (4.1)

For example in a particular run, 28 rakes left in time out of 32 rakes. Therefore the percentage rakes sent on time is \( \frac{28}{32} = 87.5 \% \).

Another measure of the operational efficiency is the average time trains are late over scheduled times. This can be found out from the formula of average lateness

\[
\sum (\text{actual times left} - \text{scheduled times}) / \text{number of late rakes}
\] (4.2)

The average time rakes spent in the system (turnaround time) can also be found out. A sensor (Figure. 4.13) added to the leaving point of rakes is connected to rake arrival point. These blocks gives the average time of rakes in the system.
Performance measures such as utilisation of pits and spare roads, average waiting time and average and maximum queue length were also used.

Figure 4.13: Sensor to find average time spent in the system

Figure 4.14: A screenshot of simulation model
4.5.7. Model Verification and Validation

Verification is the process of ensuring that the model does what the developer wants it to do. This is the first stage of quality check of a simulation model. In this case expert opinion was used to understand how the models should behave. We then used facilities in Extend such as information modules to check whether the model behaved as expected. Entities (here rakes) were checked at different blocks in the model like pit arrival, pit selection, type of maintenance as it passes from one block to another. This white box method of verification was used by us.

Sargent (1996) has demonstrated the use of graphical methods for validation of simulation models. We have also validated the simulation models developed using graphical methods which are discussed below.

Models of TYPE 1 were validated by comparing the simulation output (number of rakes exited in model- see Figure 4.15, Plot of rake departure) and rail time table values (Figure 4.16). TYPE 2 models were validated by comparing average number of rakes exited actually per day with the same output of simulation (Figure 4.17). TYPE 3 models were also similarly validated by comparing with average number exited in actual case and in simulation model (Figure 4.18).

![Figure 4.15: Plot of rake departure](image)
Figure 4.16: Validating TYPE 1 model

Figure 4.17: Validating TYPE 2 model

Figure 4.18: Validating TYPE 3 model
The above procedure for validation is a rough method with limited accuracy. The same has been used by us because this work deals with development and demonstration of methodology for use of simulation models for solving some problems related to railway yard. It is worth noting that when the reliability and accuracy of results from the models have to be increased stricter and more formal model validation techniques need to be carried out.

Run length of a single cycle of the schedules was used for most of analysis. The averaged values were obtained after repeating the simulation runs for 5 times (Law and McComas(1997) recommend making at least three to five independent runs for each system design, and use the average of the estimated performance measures from the individual runs as the overall estimate of the performance measure).

### 4.5.8. Assumptions And Limitations Of The Model

The models are in general based on certain assumptions

1) It is assumed that work force is available as and when required.
2) The effect resources like compressor, water availability etc are not included in the models
3) The schedules for shunter is not included. Instead it is assumed that shunter is sufficiently available.
4) The availability of spare parts required for maintenance is not considered.
5) The detailed operations at coach care centre is not included.
6) When two rakes are scheduled together for pit maintenance one of them is bypassed.
7) When modelling spare inventory requirements, the individual rake composition, which gives the requirements of different classes of coaches are not considered.
8) When a rake comes to the pit, its set composition can be upset.
9) The severity of sickness of various coaches are considered.
10) Details of train signalling, track maintenance are not considered.
4.6. PROBLEMS AND ANALYSIS

We have developed a modelling and simulation approach for simulation based decision aids for strategic, tactical and operational type decision problems that are typical in terminal systems. We have developed three types of models helpful in such situations depending upon the problems. Some of the problems related to above yard for which simulation modelling was used for decisions support are given in Table 4.2 below. In this section we present use of simulation models described above in analysis of strategic, tactical and operational decision scenarios.

<table>
<thead>
<tr>
<th>DECISION PROBLEM</th>
<th>MODEL TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategic level</td>
<td></td>
</tr>
<tr>
<td>Case 1: Requirement of additional pit</td>
<td>TYPE 3</td>
</tr>
<tr>
<td>Case 2: Deciding number of spare roads</td>
<td></td>
</tr>
<tr>
<td>Tactical level</td>
<td>TYPE 2</td>
</tr>
<tr>
<td>Case 1: Deciding number of spare coaches</td>
<td></td>
</tr>
<tr>
<td>Case 2: Allocation of separate shunter engine to the yard</td>
<td></td>
</tr>
<tr>
<td>Case 3: Comparison of train time tables</td>
<td></td>
</tr>
<tr>
<td>Operational level</td>
<td>TYPE 1</td>
</tr>
<tr>
<td>Case 1: Routing arriving rakes to appropriate pit</td>
<td></td>
</tr>
<tr>
<td>Case 2: Deciding shift timings, preparing pit schedules</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.2: Decision problems and model type used

4.6.1 Strategic level

4.6.1.1 Case 1: Requirement of additional pit

At present, the yard receives about 4.9 rakes on average per day. What will be the scenario if more rakes are coming for service per day? How construction of an additional pit will be helpful provided all other required resources are provided?

By simulation using the TYPE 3 models, one could answer these questions. Such models with two pits and three pits were constructed. Figure 4.19 and 4.20
indicate cases of two pits and three pit respectively. It was seen that the present facility with two pits could handle about 5.5 rakes per day without appreciably increasing the delay for pit's availability. If three pits were provided this number could be improved to about 7 rakes per day without undue delays at pits.

![Chart showing average daily arrivals and departures of rakes](image1)

**Figure 4.19:** Plot of average daily rakes with two and three pits

![Effect of rake arrival rate on average time waiting for pit](image2)

**Figure 4.20:** Plot of average delay at pit for two pit and three pit case
4.6.1.2. Case 2: Deciding the capacity of spare roads

The incoming rakes to the yard wait in spare roads till it is called for placement in the pit. After operations at the pit, the rake is held in spare roads till its scheduled departure time is reached. If sufficient capacity is not available in these lines, incoming rakes will have to wait outside the yard, blocking the system and with no spare roads available rakes will be forced to wait in the pit even after completion of operations. Due to these reasons there would be loss in performance of the system.

Line capacity required for the terminal is dependent upon maximum number of coaches present at a time in the yard rather than the maximum number of rakes present at a time. The reason is that we could put more than one rake in a spare line when length of rake is small (or when number of coaches in rakes are less).

The total number of coaches in yard = Number of coaches waiting in spare lines for service at the pit + Number of coaches getting service at the pit + Number of coaches waiting in spare lines for scheduled departure.

Simulation models of the yard developed in Extend simulation language are capable of giving values of maximum number of coaches in yard at a time (see Figure 4.21) under varied conditions of operational times and schedules. A discrete event plotter (Figure 4.22) shows variation of total number of coaches in the system over time.

Total number of coaches that remains in the system at a time is dependent on

a) Arrival times of rakes to the yard. If rakes come before its pit schedule, it will be put in the spare lines. The earlier the rakes come to pit, the more its wait time in the pit before start of operations.

b) Efficiency of service in the yard. If delays are more in pits, rakes will have to wait more in spare lines.

c) Departure schedule of rake. If rake departure is scheduled at a later time, rakes wait in spare lines after completing operations at pit.

d) Availability of key resources like shunter engine for shunting.
e) Number of services. If more rakes (or coaches) are allotted to the yard for service, more capacity is required.

f) Inventory of spare coaches. Any additional coaches allotted to the yard are kept in spare lines.

Figure 4.21 Maximum number of coaches at a time is obtained from max & min block

Figure 4.22: Showing the number of coaches present in the yard over time
Simulation models developed considers all of these aspects. We have used a simple experiment to assess the levels of coaches present in the yard at a time. We assumed that resources like shunter engines were available on call, and the pits operate with its normal efficiency and no spare coaches. The rakes were scheduled to arrive according to time schedule. The wait times for departure were varied to different levels. Table 4.3 gives values of MAXIMUM number of coaches in the yard at a time averaged over repeated simulation runs each for about two week cycle.

<table>
<thead>
<tr>
<th>WAIT TIMES IN MINUTES</th>
<th>30</th>
<th>150</th>
<th>270</th>
<th>390</th>
<th>510</th>
<th>630</th>
<th>750</th>
<th>870</th>
<th>990</th>
<th>1110</th>
<th>1230</th>
<th>1350</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX NUMBER OF COACHES</td>
<td>72</td>
<td>85</td>
<td>90</td>
<td>91</td>
<td>98</td>
<td>103</td>
<td>111</td>
<td>123</td>
<td>131</td>
<td>142</td>
<td>142</td>
<td>144</td>
</tr>
</tbody>
</table>

Table 4.3: Gives values of MAXIMUM number of coaches in the yard at a time

Figure 4.23 shows the increase in number of coaches due to delays. Maximum number of coaches at a time in the yard doubles (increase from 72 to 144) when each rakes wait time after service in spare lines is increased from 30 minutes to 1350 minutes.

When deciding capacity of spare roads a long term perspective is required because once a layout is made with a design capacity, it is difficult to change or modify afterwards. In such problems if it is possible to find the boundary levels of input parameters under which the system will perform satisfactorily, designers will be able to correct decisions when allotting facilities. Here we have examined the impact of wait after pit operations which occur in practice on the number of coaches in the yard. Spare roads to accommodate the maximum number of coaches as observed in the simulation for the level of delay likely to occur should be provided at the design stage itself. The above model can be used by modifying the schedules and by increasing operational times or wait times to study the impact of these on facilities. These studies help in determining level of facilities to be provided at layout design stage.
4.6.2. Tactical level

4.6.2.1. Case 1: allocation of separate shunter engine to the yard

Usually Marshalling yards will be attached to corresponding stations itself. In this case the yard is about two kilometers away from the railway station; the loco shed is near the station. There is the second busiest signal point in Southern Railways between the yard and the station, creating hindrance for free movement of rakes and loco between the station and the yard. At present a shunter engine is not allotted exclusively for Marshalling yard operations. Instead this facility is given according to schedules i.e., shunter engine could be utilized by the Marshalling yard only according to time schedules decided by authorities at main station. As a result, re-planning of schedules due to unexpected delays is constrained by availability of shunter engine.

Shunter is utilized for the following tasks

1) Bringing rakes from the Ernakulam South Station to spare roads of the yard.
2) Taking rakes to Pits from spare road, for pit placement
3) Removing sick coaches
4) Attaching new coaches and train formation
5) Transferring rakes from pits (after service) to spare roads
6) Taking prepared rakes to the Ernakulam South Station

A shunter engine is a key resource required at the yard. When a shunter is not available at the requested time it could
a) delay operations and schedules at the pit
b) cause spare roads choked with rakes
c) cause main station lines becoming choked with rakes
d) cause knock-on delays in main station and subsequent stations
e) cause idling of resources in the pit
f) increase turnaround times of rakes from the yard

An investigation was made on the effect of availability of the shunter engine using simulation models.

CASE 1) out of every 45 minutes the shunter was not available for 30 minutes
CASE 2) out of every 60 minutes the shunter was not available for 30 minutes
CASE 3) out of every 75 minutes the shunter was not available for 30 minutes
CASE 4) out of every 90 minutes the shunter was not available for 30 minutes
CASE 5) out of every 105 minutes the shunter was not available for 30 minutes
CASE 6) out of every 120 minutes the shunter was not available for 30 minutes
CASE 7) out of every 135 minutes the shunter was not available for 30 minutes
CASE 8) out of every 150 minutes the shunter was not available for 30 minutes
CASE 9) out of every 165 minutes the shunter was not available for 30 minutes
CASE 10) there was no restriction on the availability of shunter engine

Values of Performance variables maximum number of coaches in the yard and turnaround times (average time a rake spends in the yard) were noted. Simulation answers the question of how much improvement in performance could be obtained by using a separate shunter allotted to the marshalling yard. Table 4.4 shows the average of maximum wait times at various points where this resource was required. We see a reduction in this when the shunter was made more and more available to the yard. The best performance was obtained when the shunter was fully made available to the service in the yard (CASE 10).
Table 4.4: Showing the effect of shunter availability on performance

The rail simulation model could be used by the yard management to convince higher authorities the situations when shunter availability becomes a bottleneck. A shunter engine is a costly resource. Procuring additional shunter is a tactical decision by which the efficiency of service at the base station as well as at the yard gets improved.

4.6.2.2: Case 2: deciding number of spare coaches

The Marshalling yard controls (for full formation of the train as well as primary maintenance) the trains as given in Table 4.5.

<table>
<thead>
<tr>
<th>TRAIN</th>
<th>TRAIN NUMBER</th>
<th>NUMBER OF COACHES</th>
<th>NUMBER OF RAKES</th>
<th>TOTAL COACHES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mangala Express</td>
<td>2617/18</td>
<td>18</td>
<td>6</td>
<td>108</td>
</tr>
<tr>
<td>Patna Express</td>
<td>8309/10</td>
<td>18</td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>Janasadabdi Express</td>
<td>2075/76</td>
<td>9</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Cannoore Express</td>
<td>6307/08</td>
<td>12</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>Milenium Express</td>
<td>2645/46</td>
<td>12</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>Passenger</td>
<td>332/37</td>
<td>12</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>Okha Express</td>
<td>6339/39</td>
<td>21</td>
<td>2</td>
<td>42</td>
</tr>
<tr>
<td>Intercity Express</td>
<td>6305/06</td>
<td>13</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>Varanasi Express</td>
<td>6359/60</td>
<td>18</td>
<td>1</td>
<td>18</td>
</tr>
</tbody>
</table>

Total: 244

Table 4.5: List of trains and rake requirements for schedules under the control of the Ernakulam Yard

At present the yard is allotted about 250 coaches of different categories. A small number of coaches are provided extra to take care of sick coaches and special requirements. Yards like these are always demanding for more coaches. How
many coaches will be required to operate the schedules smoothly? The answer to this question depends upon lot of factors. It depends upon the rake composition, arrival and departure schedules of rakes, management policies regarding rake allotments and priorities, number of coaches getting sick, pit operational times, efficiency of coach care centers, spare line capacity, shunter availability etc.

The TYPE 2 model developed was run for a period of 12 weeks. The balance of coaches at various instances are given in Figure 4.24. The initial part of this plot is the situation when the coaches of all trains operated by the yard were made available as initial inventory of coaches. Once these rakes leave from the yard, that many coaches get depleted from initial stock and the stock gets refilled upon each arrivals. Steady state on the coaches balance position is only achieved after the first two weeks where we see the effect of initial inventory. This plot provides some interesting insight for planners.

![Figure 4.24: shows how the balance number of coaches varies in time](image)

Maximum level: Information regarding the maximum level is useful in designing spare road capacity. Above chart shows that, there are peaking levels of coaches at many points. If the roads in the pits cannot hold this many, operational delays are expected. This information is also useful when the management plans for additional schedules.

It is difficult to manage the yard without sufficient number of coaches. If required numbers of coaches are not available, it will naturally affect train schedules (even
A 10 minutes late train at some station can bring cascaded effects in the entire network. Models clearly indicate the effect of spare coach availability on train schedules. See Figure 4.25a-c and Table 4.6. We know that average number of rake waiting for availability of coaches is related to number of coaches getting sick and number of coaches getting repaired and the number of spare coaches available. The coach care centre should be supplying repaired coaches efficiently. The desired number of spare coaches could decided by a level whereby operations at care centre is set at normal pace and at the same time the average number of rakes waiting is not excessive.

![Figure 4.25a](image)

Spare Coaches = 5, Mean Time for Repairs = 500 minutes

**Figure 4.25a**
Spare coaches = 0, Mean Time for Repairs = 200

**Figure 4.25b**

Spare coaches = 0, Mean Time for Repairs =100

**Figure 4.25c**

*Figure 4.25a-c*: Plot of effect of spare coaches on average number waiting
Table 4.6: Effect spare coaches on average number waiting

4.6.2.3: Case 3: Comparison of train time tables

We had mentioned that TYPE 1 model could also be used for tactical problems in addition to operational problems for which it is normally used. This case deals with the tactical problem of preparing railway time tables. The TYPE 1 model was used to compare the impact of 2 different time tables, the first with equi-spaced train arrival and the other the actual one in use today. The model was run with these two schedules and performance measures of the railyard were noted. The same is presented in table 4.7.

From the table it can be seen that the performance in both case is more or less the same. However the current schedule is a slightly better one.
<table>
<thead>
<tr>
<th>Schedules</th>
<th>Turnaround (excluding wait time at spare roads)</th>
<th>PIT 1 Average wait of rake</th>
<th>PIT 1 Maximum wait of rake</th>
<th>PIT 2 Average wait of rake</th>
<th>PIT 2 Maximum wait of rake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equi-spaced</td>
<td>444.59</td>
<td>53.37</td>
<td>284.44</td>
<td>79.2</td>
<td>281.3</td>
</tr>
<tr>
<td>Actual</td>
<td>421.96</td>
<td>66.9</td>
<td>301.48</td>
<td>64.68</td>
<td>296.63</td>
</tr>
</tbody>
</table>

(All times in minutes)

Table 4.7: Comparison of Train time tables

4.6.3. Operational level:

4.6.3.1. Case 1: Routing arriving rakes to appropriate pit

Suppose an unscheduled rake is to be accommodated for some day in coming week. Questions like which pit is to be utilized and when the schedule for maintenance is to begin etc are to be answered. The simulation models are helpful in visualizing the effect of such additional schedules. The analyst can test the simulation model for his proposed time schedule and pit. This is done by assigning a schedule generator (See Figure 4.26) for proposed schedule and inputting its attributes of pit (PIT 1 or PIT 2).

![Program block for scheduling a new train](image)

Figure 4.26: Showing a program block for scheduling a new train
Simulation could be used to generate and compare alternate rake schedules. Use of simulation in such situation reduces chances of unnecessary delays. Alternative schedule times can be compared using a suitable performance measure.

An obvious rule commonly used in scheduling problems is the Earliest Due Date (EDD) rule. This rule schedules work according to the preference of due dates i.e., the one which has earlier due date is scheduled first. Trains arriving from various places go to the pit with the condition that priority will be given to those trains which are scheduled to depart from the station first. This model discards pit placement schedules already existing. Table 4.8 shows the performance of EDD rule with FIFO rule (In this case the rakes are placed on pits on a FIFO basis disregarding existing priorities). It is found that the average lateness is less under EDD rule, as is expected from theory.

<table>
<thead>
<tr>
<th>PERFORMANCE MEASURE</th>
<th>EDD RULE</th>
<th>FIFO RULE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of late trains</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Average lateness in minutes</td>
<td>15.6</td>
<td>24.9</td>
</tr>
</tbody>
</table>

Table 4.8: Comparison of EDD and FIFO rules

4.6.3.2. Case 2: Deciding shift timings, preparing pit schedules

The Railway time table changes occasionally and according to this, the pit schedules also changes. The simulation models developed were helpful in preparing the pit schedules. A variant of the basic model was developed to study the effect of changing the pit placement schedules. The advantage of such a model is that such investigation reveals potential benefits of work rescheduling.

Example: Chart (Figure 4.27) below shows the busy times of pit activity (indicated by thick dark line) based on a simulation run of EDD rule. We see a heavy concentration of activity times during the hours 8.00 to 20.00. So if EDD rule is implemented for pit schedules, the employee shift timings are to be adjusted accordingly.
Preparing pit schedules:

The information blocks (see Figure 4.28) attached just before and after the entry of rakes into and from each of the pits would reveal the times of arrivals to the pit and departure from the pit. Typical timings for each of the pits obtained from using the EDD model is shown in Table 4.9. Based on this information detailed pit schedules could be prepared.

Figure 4.27: Chart showing pit busy time based on EDD rule

Figure 4.28: Contents of information blocks related to pits in the rail yard simulation model
Table 4.9: Time of rakes entry and exit from each of the pits

<table>
<thead>
<tr>
<th>TRAIN NUMBER</th>
<th>ARRIVAL TIME</th>
<th>DEPARTURE TIME</th>
<th>TRAIN NUMBER</th>
<th>ARRIVAL TIME</th>
<th>DEPARTURE TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>2075</td>
<td>780</td>
<td>1031</td>
<td>2978</td>
<td>780</td>
<td>1171</td>
</tr>
<tr>
<td>7029</td>
<td>1440</td>
<td>1681</td>
<td>2618</td>
<td>1440</td>
<td>1821</td>
</tr>
<tr>
<td>2075</td>
<td>2220</td>
<td>2469</td>
<td>1097</td>
<td>2220</td>
<td>2618</td>
</tr>
<tr>
<td>6305</td>
<td>2760</td>
<td>3105</td>
<td>7029</td>
<td>2880</td>
<td>3129</td>
</tr>
<tr>
<td>2618</td>
<td>3105</td>
<td>3470</td>
<td>5623</td>
<td>3360</td>
<td>3739</td>
</tr>
<tr>
<td>2075</td>
<td>3660</td>
<td>4014</td>
<td>2618</td>
<td>3780</td>
<td>4140</td>
</tr>
<tr>
<td>2075</td>
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<td>5450</td>
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<td>6305</td>
<td>5640</td>
<td>5888</td>
<td>2618</td>
<td>5640</td>
<td>5888</td>
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<tr>
<td>6308</td>
<td>6540</td>
<td>6927</td>
<td>2075</td>
<td>6540</td>
<td>6880</td>
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<tr>
<td>5221</td>
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<td>7438</td>
<td>2075</td>
<td>7980</td>
<td>8211</td>
</tr>
<tr>
<td>6338</td>
<td>7980</td>
<td>8346</td>
<td>6305</td>
<td>8520</td>
<td>8882</td>
</tr>
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<td>7029</td>
<td>8640</td>
<td>8998</td>
<td>2618</td>
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<tr>
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<td>2075</td>
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<td>9655</td>
<td>10020</td>
<td>6360</td>
<td>9679</td>
<td>10047</td>
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<td>10020</td>
<td>10263</td>
<td>7029</td>
<td>11530</td>
<td>11868</td>
</tr>
<tr>
<td>2618</td>
<td>11530</td>
<td>11794</td>
<td>6310</td>
<td>12000</td>
<td>12254</td>
</tr>
</tbody>
</table>

4.7. CONCLUSION

The work presented in this chapter was carried out to improve the performance of a railway yard using computer simulation models. For the above a study of the Ernakulam marshalling yard was carried out and conceptual model of the Marshalling yard was made. The conceptual model was translated into a working simulation model using Extend simulation package. The model was verified and validated. Performance measures such as turnaround time for rakes, number of rakes handled, waiting time for pit etc were identified and means of their collection made in the simulation models.

The simulation models were also used to find the level of utilization of major facilities. It was found that pit and waiting lines were facilities with high utilization and tended to be bottleneck facilities. A comparison of two train time tables to
ascertain its impact on yard performance using the simulation model showed that
the current time table was slightly better than an equi-spaced time table tried out.
In order to study the effect of different operating strategies, scheduling at pit
according to EDD and FIFO rules were tried out and it was found that EDD rule
gives 3 number of trains late and average lateness of 15.6 minutes while the FIFO
rule gives 3 number of late trains and 24.9 minutes of average lateness which is
higher. Hence it is recommended that EDD rule be used for pit scheduling.
Similarly other rules can be checked using the model.

Rakes with different coaches are put into service. Normally these coaches
require only water servicing and minor electrical, mechanical and AC
maintenance. These can be done without detaching the coach from the rake.
However, at times when major work is required, the coach has to be detached
from the rake and sent to the coach care center. In such cases, the coaches so
detached have to be replaced, by spare coaches from the stock of extra coaches
with marshalling yard. The simulation model was used to find how many such
extra coaches are required in the yard. It was found from our experiments that at
least four sleeper coaches should be provided to ensure no shortage.

Some other highlights of the the work presented in this chapter are that in
Section 4.5 a modelling approach was developed for dealing with the cyclic
nature of events in railyard models. The essence of designing the models was in
deciding the inputs to be given to the model, the decision variables involved and
the constraints imposed on the system. When deciding capacity a long term
perspective is required because once a layout is made with a design capacity, it
is difficult to change or modify afterwards. Overall it could be seen that the level
of constraints became tighter as we moved from models for strategic to
operational problems. The level of flexibility of the model (in terms of decision
rules, facilities, and schedules) however decreased for models from strategic to
operational problems. The validation, run length and type of analysis of each of
these models were different.