OPTIMIZATION OF TESTING FACILITIES FOR LOCOMOTIVES

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Key Words

Locomotive testing; Poisson arrival and service; FIFO; Bottleneck area.

Introduction

A pioneer Indian electrical company started manufacturing locomotives for Indian Railways with the facility for manufacturing 350 HP and 700 HP diesel locomotives. Accordingly, the necessary infrastructure for testing the locomotives was also created. Initially, the plan was for 6–8 locomotives per year and then to increase the annual production to 18–20 diesel locomotives, depending on the demand.

Subsequently, the Railway Board undertook a massive electrification program in Indian Railways, which increased the demand for electric locomotives. Because of the inability of the existing manufacturer of electric locomotives to fulfill this enhanced demand, the Indian Railways had to look for an alternate source of electric locomotives. Eventually, the company at which this study was carried out was entrusted with the additional responsibility of manufacturing electric locomotives.

To start, in addition to the existing demand for 12 diesel locomotives, the Railway Board gave an order for 5 electric locomotives, which was subsequently enhanced to 35 per year. The major stages in the production of locomotives are as follows:

1. Fabrication
2. Assembly
3. Testing

It was felt that with the introduction of the requirement to manufacture electric locomotives, the testing facilities might be a bottleneck due to a space constraint in the test shop. Thus, a study was undertaken to determine the inadequacy, if any, of the existing facilities and to suggest suitable alternatives to meet the demand for increased production.

Objectives

The objectives of this study were to determine the maximum number of locomotives that can be tested in a financial year of roughly 300 working days, consisting of two shifts of 8 h each with the existing testing facilities and to find any bottleneck areas. Another objective of this study was to suggest alternatives in case bottleneck areas are detected, so that the current demand for locomotives could be fulfilled through optimization of testing facilities.

Testing: Sequence and Layout

During testing, each electric locomotive must pass through 10 different activities, whereas each diesel locomotive must pass through only 5 activities. These activities in some instances included a part of manufacturing. The activi-

Table 1. Testing Time and Stations for Electric Locomotives

SL. NO.	ACTIVITIES	TESTING STATIONS	EXPECTED TIME (IN DAYS)
1	Electrical and pneumatic tests (locomotive is on dummy)	5, 6	13
2	Mechanical and rain tests	7, 8, 9	5
3	Painting	10	10
4	Lowering on regular bogeys	1, 2, 3	4
5	Pneumatic and leftover tests	4, 5, 6	5
6	Weighment	4, 5	1
7	Maximum moving dimension and curve tests	11	2
8	Trial run	12	2
9	Attending to miscellaneous problems	4, 5, 6	1
10	Pinking and dispatch	1, 2, 3	7

ties were carried out in the predefined sequence given in the following subsection. Each activity may be performed in a number of testing stations (there are 12 testing stations) and each testing station can perform a number of different activities.

Sequence and Processing Time

The order of activities that must be carried out on an electric locomotive, along with the testing stations and expected processing times (in days), is given in Table 1. The order of activities that must be carried out on a diesel locomotive, along with the testing stations and expected processing times (in days), is given in Table 2.

Layout

The layout of the existing testing facilities is given in Figure 1.

Table 2. Testing Time and Stations for Diesel Locomotives

SL. NO.	ACTIVITIES	TESTING STATIONS	EXPECTED TIME (IN DAYS)
1	Electrical and mechanical tests	7, 8, 9	5
2	Painting	10	3
3	Trial run	12	1
4	Weighment	7, 8, 9	3
5	Pinking and dispatch	1, 2, 3	3

Assumptions

1. Each locomotive must pass through all of the activities in the stated prespecified order. This is in the ascending order of activities listed in Tables 1 and 2 for electric and diesel locomotives, respectively.
2. The production of locomotives was assumed to follow a Poisson distribution with means of 25 days and 8 days respectively for diesel and electric locomotives.
3. Activity times were also assumed to follow a Poisson distribution with mean values as specified in Tables 1 and 2 for electric and diesel locomotives, respectively. One day consisted of two shifts of 8 h duration.
4. The transportation time required to shift a locomotive from one testing station to another is negligible compared to the activity times.

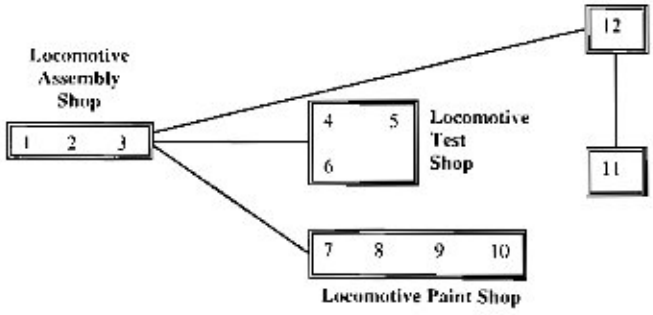

Figure 1. Layout of testing facilities.

Development of the Computer Program

Algorithm

Based on the above assumptions, a computer program in QuickBasic was developed using the following algorithm:

1. Find the activities that can be carried out, in the locomotives undergoing testing, at any instant of time.
2. Find the testing stations where these activities can be performed.
3. Find the testing station, among the stations obtained in Step 2, where an activity can first be allocated.
4. Identify the locomotive to be allocated to the selected testing station that minimizes the idle time of the station. In the case of multiple choices, allocate the locomotive with the least number of activities pending at that stage, and in the case of a tie, use the first-in–first-out (FIFO) principle to select the locomotive for allocation.
5. Select the activity for which the identified locomotive is waiting.
6. Generate a testing time from the testing-time distribution of the selected activity and use it to update the time at which the selected testing station becomes idle (i.e., to determine the time when the selected testing station is ready for the next allocation).
7. Repeat steps 1–6 until all the locomotives are tested or the time exceeds the maximum allowable time.

Input and Output

The matrix of testing stations for each activity and the corresponding processing time is the primary input to the program. Diesel and electric locomotives are available for testing as per the Assumption 2.

The program was designed to find the number of diesel and electric locomotives that could be tested in a span of 300 days. The program was run several times and the 90-percentile point was taken as the representative output to be used for subsequent analysis. An additional output is the average waiting time for the start of each activity.

Analysis and Results

The program was run taking into account the existing testing facilities first. The number of locomotives that can be fully tested in a year is given as follows:

Diesel locomotive: 12
Electric locomotive: 25

Thus, in the existing service facilities, at most 37 locomotives could be tested. However, this was much less than the target production of 47. A sample output of the program giving allocation of activities to different testing stations along with respective start times corresponding to the existing testing facilities is given in the Appendix.

Table 3 provides the average waiting time for each activity. From Table 3, it is clear that *painting* is the main bottleneck area (marked with asterisk). To overcome the bottleneck in painting, it was decided to increase the painting facility by the introduction of another set of painting equipment at station 9. In this case, the number of locomotives that could be tested in a year was determined to be as follows:

Diesel locomotive: 12
Electric locomotive: 33

Table 4 gives the estimated average waiting time for the different activities. In this case, activity 1 for electric

Table 3. Average Waiting Time in Existing Facilities

	AVERAGE WAITING TIME (IN DAYS)	
ACTIVITY NO.	DIESEL LOCOMOTIVE	ELECTRIC LOCOMOTIVE
1	0.00	0.64
2	1.92	0.48
3	0.58	12.08*
4	3.08	0.00
5	0.67	0.08
6		0.28
7		0.12
8		0.16
9		0.28
10		0.20

Table 4. Average Waiting Time

	AVERAGE WAITING TIME (IN DAYS)	
ACTIVITY NO.	DIESEL LOCOMOTIVE	ELECTRIC LOCOMOTIVE
1	0.00	4.94*
2	1.67	0.18
3	1.50	1.27
4	2.17	0.30
5	1.42	0.64
6		0.36
7		0.15
8		1.36
9		0.55
10		0.82

Table 5. Average Waiting Time

ACTIVITY NO.	AVERAGE WAITING TIME (IN DAYS) DIESEL LOCOMOTIVE	ELECTRIC LOCOMOTIVE
1	0.00	2.00
2	0.67	0.03
3	0.50	0.79
4	1.50	0.09
5	0.17	0.85
6		1.35
7		0.56
8		0.09
9		0.59
10		1.03

locomotives (electrical and pneumatic tests) appears to be the only bottleneck. Consequently, a decision was taken to carry out the electrical and pneumatic tests for electric locomotives in station 4 also. In this case, the number of locomotives that could be tested in 1 year was determined to be as follows:

Diesel locomotive: 12
Electric locomotive: 34

The estimated average waiting time for the different activities in this case is found in Table 5. This table indicates that with the enhanced testing facility, there are no bottlenecks.

Summary of Results

1. Painting is the main bottleneck area, especially in case of electric locomotives.
2. By increasing the facilities so that the painting activity can be carried out in two testing stations, namely stations 9 and 10, in the Paint shop, it is possible to test 33 electric locomotives, which is sufficiently close to the corresponding targeted value of 35.
3. Further, by enhancing the facility of electrical and pneumatic tests for electric locomotives, it is possible to test 34 electric locomotives.

Implementation

The findings of the study were presented to the top management of the organization and the following decisions were made:

1. Extensions for facility of painting to station 9, in addition to the existing facility at station 10
2. Extensions for facility of electrical and pneumatic tests for electric locomotives to station 4, in addition to the existing facility at stations 5 and 6

Subsequently, implementation took place, and by the end of 1 year, 12 diesel and 35 electric locomotives were manufactured and tested successfully.

Appendix: Sample Output of the Software Developed for Optimal Allocation

LOCO-MOTIVE	ACTIVITY NUMBER																			
	1		2		3		4		5		6		7		8		9		10	
NO.[a]	STN[b]	ST[c]	STN	ST	STN	ST	STN	ST	STN	ST	STN	ST	STN	ST	STN	ST	STN	ST	STN	ST
D-01	7	0	10	7	12	11	8	13	1	16										
D-02	9	20	10	27	12	29	9	31	3	32										
D-03	7	49	10	54	12	60	8	61	3	66										
D-04	9	70	10	74	12	76	9	77	3	80										
D-05	9	90	10	95	12	97	7	117	3	121										
D-06	8	113	10	124	12	127	8	129	1	130										
D-07	9	136	10	145	12	149	8	152	2	154										
D-08	7	166	10	173	12	177	8	182	1	192										
D-09	9	187	10	198	12	203	7	215	3	217										
D-10	7	209	10	215	12	219	7	220	1	224										
D-11	8	237	10	249	12	251	8	256	1	257										
D-12	7	255	10	263	12	268	8	269	3	272										
E-01	5	0	7	16	10	17	2	24	4	25	5	31	11	32	12	34	4	38	2	39
E-02	6	9	8	22	10	29	1	37	6	41	4	44	11	45	12	48	4	49	2	50
E-03	5	16	7	28	10	37	3	44	4	50	4	54	11	57	12	61	5	63	2	64
E-04	6	23	8	36	10	44	1	52	4	57	4	63	11	64	12	68	4	69	3	70
E-05	5	34	8	51	10	60	1	67	4	74	4	76	11	77	12	79	4	82	2	83
E-06	6	44	7	57	10	67	1	74	7	78	4	83	11	84	12	87	4	89	2	91
E-07	5	51	7	66	10	76	1	84	4	94	4	97	11	99	12	100	4	104	3	108
E-08	6	57	8	76	10	84	3	95	4	101	4	108	11	110	12	112	5	116	1	118
E-09	5	68	7	79	10	97	1	108	4	113	4	118	11	119	12	120	4	121	3	123
E-10	6	76	8	89	10	119	1	124	5	129	4	134	11	135	12	137	4	140	1	141
E-11	5	79	7	90	10	108	2	119	4	129	4	133	11	134	12	135	4	137	2	138
E-12	6	89	7	109	10	127	2	130	5	134	4	139	11	140	12	143	4	146	2	147
E-13	5	95	9	116	10	130	1	138	5	139	5	140	11	143	12	146	6	149	3	150
E-14	6	110	8	124	10	138	3	145	4	147	5	154	11	157	12	159	5	162	2	163
E-15	5	118	7	127	10	149	1	156	4	159	5	167	11	169	12	170	5	171	3	172
E-16	6	124	8	137	10	156	3	167	4	169	4	172	11	173	12	174	5	178	1	179
E-17	6	137	8	149	10	167	1	173	4	176	4	179	11	180	12	182	5	183	3	184
E-18	5	141	9	152	10	175	2	188	4	194	4	197	11	200	12	202	4	203	3	204
E-19	6	151	8	160	10	188	1	198	6	202	4	204	11	205	12	206	5	208	2	212
E-20	6	163	8	178	10	199	2	208	4	212	4	219	11	221	12	223	4	224	3	225
E-21	5	173	8	185	10	208	1	215	6	218	4	221	11	223	12	224	4	227	1	229
E-22	6	182	8	194	10	219	2	230	4	234	4	236	11	237	12	238	4	241	2	242
E-23	5	191	9	208	10	230	3	240	4	242	4	248	11	249	12	250	4	251	3	253
E-24	6	205	9	218	10	240	1	249	4	255	5	263	11	264	12	266	4	268	2	269
E-25	5	215	7	230	10	251	2	263	4	266	4	269	11	270	12	274	4	277	2	278

[a] D-xx: diesel locomotive number xx; E-xx: electric locomotive number xx.
[b] STN: Station number to which the activity is allocated.
[c] ST: Start time (in days) of the activity.

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