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ANALYSIS AND EVALUATION OF DOUBLE ENDED FLAT-SHUNTED YARD PERFORMANCES EMPLOYING TWO YARD CREWS

Marin Marinov, José Viegas
marinov@civil.ist.utl.pt

Instituto Superior Técnico - CESUR at Technical University of Lisbon
Av. Rovisco Pais, 1049-001 Lisboa, PORTUGAL

Key words: *Railway freight transportation, Double ended flat-shunted yards, Yard performances, Analytical queueing models, Event based simulation*

Summary: *The yards are facilities that reassemble freight cars into freight trains. These facilities play an essential role for providing the freight transportation service by rail. However, they are non-revenue producing elements for the railway freight companies and therefore keeping them unutilized is not acceptable. In this paper, a double-ended flat-shunted yard is studied by a two step approach employing G/G/m queues and discrete-event-based simulations. The results obtained demonstrate significantly low utilisation levels of the subsystems of this yard. Therefore, possible improvements through changes in traffic rules and yard work technology are investigated and discussed.*

1. Introduction

1.1. Yards in short

The major function of yards is to reassemble the inbound traffic into outbound freight trains having new destinations. In other words, the yards serve as "*redistributing hubs*" of traffic in the railway network and therefore, they play very important role for the sake of providing the rail freight transportation service. The yards consist of different areas, where different processes with freight trains are fulfilled. According to the available resources (both static and dynamic) the yards may be classified as flat-shunted yards, hump yards or gravity yards.

On rail yard classifications, analyses and evaluations the interested reader is referred to e.g. Nadel and Rover (1967), Konstantinov (1969), Hein (1972), Petersen (1977a), Martland (1982), Turnquist and Daskin (1982), Tasev and Karagyozov (1983), Raikov (1986), Karagyozov et al. (1990a, b), Rhodes (1998, 2003), Kraft

(2002), Harrod (2003), Wegner (2003), Kumar (2004), Shughart et al. (2006), Marinov (2006, 2007).

Generally speaking, regardless of the yard classification the yard throughput line comprises the following consecutive operations: receiving the inbound freight trains, technical and commercial inspections, reassembling the freight trains (i.e., breaking down and making up of freight trains), arriving and putting the road locomotive(s) on the assembled compositions, full break tests as well as operation on freight train departures. The yards can also serve as buffers and storage areas in the railway network, where rolling stock currently not in use can be kept.

However, as Kumar (2004, p. 25.1) states "*for a railroad, the yard process is an essential but non-revenue-producing component … It has been estimated that nearly one-fourth of a railroad's expense is yard-related*". Motivated by a similar situation, in this paper in the shape of case study we deal with a double-ended flat-shunted yard that appears to be inefficiently utilized.

1.2. Paper Organization

The paper includes a case study addressed at evaluating Entroncamento double-ended flat-shunted yard and is organized as follows: Section 2 provides a description of the technical and technological characteristics of Entroncamento yard. In Section 3 the evaluation approach implemented in studying Entroncamento yard performances is discussed. Section 4 entirely concentrates on the estimation and interpretation of the results obtained for both current situation and suggested scenarios. This paper completes with brief summary and conclusions.

2. Object of study

The object of this paper is Entroncamento flat-shunted yard which is situated close to Entroncamento city rail passenger station, 100 km North from Lisbon and is the biggest facility of this type in Portugal. This yard is equipped with 24 tracks. A sketch of Entroncamento layout is given in Fig. 2.1. The operating processes with freight trains are fulfilled on tracks from 1 to 23. Track 24 is a non-electrified lead of Entroncamento freight car workshop. The electrified yard tracks are from 15 to 22. The track 23 is planned to be electrified.

"Entroncamento" yard is the only yard in Portugal equipped with a hump but because of safety reasons (the hump tracks are not equipped with retarders, so the yard crew encounters difficulties to control the freight car speed when it is rolling on a hump track) this device is not in operation any more. The hump is connected with tracks from 1 to 10. These tracks are used for shunting and storage of empty freight cars, when necessary.

Today, Entroncamento flat-shunted yard can be classified as a double-ended yard because there are two separate yard crews in operation at the time at each end of the yard. More precisely, the classification work of the freight cars is fulfilled by two employees, one at each end of the yard. The shunting work is performed by two shunting crews, meaning there are two shunting locomotives at the time in operation within Entroncamento limits. The inspection work after arriving and before departing of freight trains is executed by two employees as well, one at each end of the yard.

And, none of those pair of working resources work simultaneously on the same freight train.

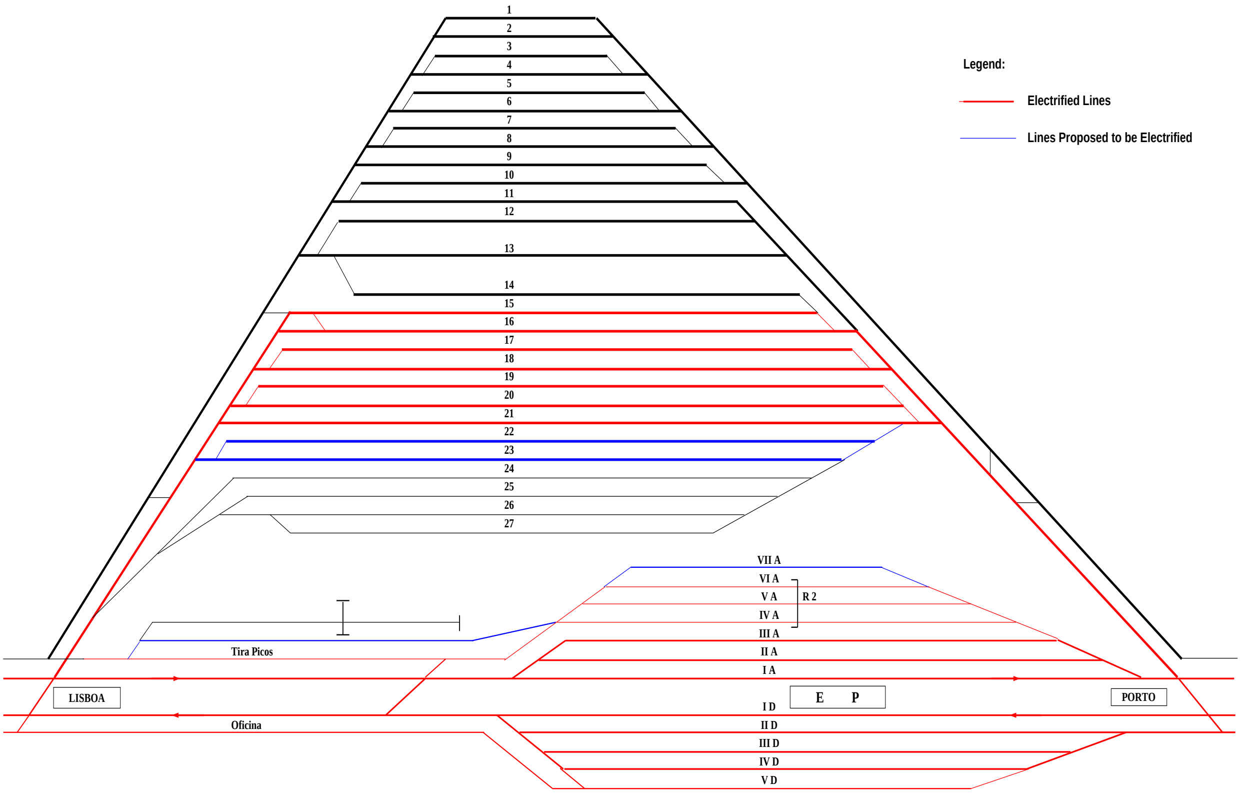


Fig. 2.1 Layout of "Entroncamento" Flat-Shunted Yard
Source: "CP - Carga" Department of Planning and Control

Another specific characteristic that one ought to note is that the road locomotives are kept out of Entroncamento freight yard tracks. More specifically, the road locomotives are usually stored on either track VI A or track VII A, as shown in Fig. 2.1 above. There is no direct access to the specified yard tracks, which requires using the main rail lines in order for road locomotives to enter and/or leave Entroncamento flat-shunted yard. This of course has a negative effect seen in undesirable increase of the average time for waiting a road locomotive by the assembled composition.

Resuming there are two distinguishing features (i.e., there are two yard crews operating at the time separately from each other and the road locomotives are stored to wait for their next assignment far from Entroncamento yard tracks dedicated to the operating processes with freight trains) that we explicitly consider in evaluating this yard performances.

3. Evaluation Approach

The evaluation yard approach implemented here is thought of as a two-step approach that firstly requires the yard in question to be decomposed into its areas (or yard subsystems) such as: Arrival yard, Shunting zone, Locomotive workshop, Departure yard and Car Storage area, if applicable (see for instance Petersen 1977a,b; Tasev and Karagyozov 1983; Shughart et al. 2006; Marinov 2007; Marinov and

Viegas 2008), then employs analytical modelling with G/G/m queues (where m = 1 or 2) followed by event-based simulations. Thus, we obtain measures of yard performances at two stages, firstly by the G/G/m models and secondly by the event-based simulation model.

Looking at G/G/m queues, it should be noted that the formulas for G/G/m queues (for either m = 1 or m = 2) are not exact and that is why for our purposes the approximations provided by *Allen and Cunneen* are used. More specifically, by Allen and Cunneen formulas we are able to compute the Expected freight trains in the queue per yard subsystem ($L_{q,Gi}$) and then the other measures of yard performances (such as: Freight trains in Gi-yard subsystem ($L_{s,Gi}$), Time in the Queue of Gi-yard subsystem ($W_{q,Gi}$) as well as Time in Gi-yard subsystem ($W_{s,Gi}$)) are easily obtained by Little's formulas (Little 1961).

An important yard performance measure that we are able to obtain analytically is the utilisation of single server at each yard subsystem (e.g., the utilisation of single yard crew within the Shunting zone limits). Based on Queueing theory this measure for a single server at the Gi-yard subsystem, say $\rho_{Gi}(Server)$ can be easily computed by the following formula:

$$\rho_{Gi}(Server) = \frac{\lambda_{Gi}}{\mu_{Gi} * S(m)_{Gi}} \rightarrow m = 2 \qquad (3.1)$$

where,

λ_{Gi} – number of freight trains that require service at Gi-yard subsystem per unit time

μ_{Gi} – number of freight trains served by Gi-yard subsystem per unit time

$S(m)_{Gi}$ – number of server employed at Gi- yard subsystem

Furthermore, if we know the number of freight trains that require service at Gi-yard subsystem per unit time (λ_{Gi}) as well as the average dwell time per freight train in Gi-yard subsystem we are then able to estimate the minimum number of tracks required in this Gi-yard subsystem, say $M_{tracks(?),Gi}$ by satisfying the following condition:

$$\frac{\lambda_{Gi} * W_{s,Gi}}{M_{tracks(?),Gi}} < 1 \qquad (3.2)$$

The analytical queueing models provide quick insights into the performances of the yard being examined without requiring detailed data, but they have significant drawbacks. The analytical models cannot provide detailed replication of the dynamic yard behaviour. Therefore, they should be used as a preliminary study in evaluating yard performances.

In order to verify and ameliorate the results obtained by G/G/m queues in evaluating yard performances, process-oriented simulations have been conducted next. The product of event-based simulations is a yard simulation model implemented using SIMUL 8. This computer package for discrete-event simulation allows us to create a visual replication of the yard being examined by drawing appropriate attributes directly on the simulator's screen (Shalliker and Rickets 1997). Typical attributes of SIMUL 8 are:

- Work Entry Point - this is where the work items (i.e., customers) arrive to be served by the system. According to the case being studied there can be more than one Work Entry Point and the customer may enter in any stage of the operation process.
- Work Centre – this is to replicate the server, or in other words this is where work is performed. Depending on the level of replication of the real system being examined there can be many servers configured to different ways.
- Storage Area – this is a buffer or queue, i.e., this is where the customer is held while waiting to be served. The Storage areas can be characterized with limited or unlimited capacities. Their number depends on the real configuration of the system under study.
- Floating Resource – this attribute is used to replicate the existence and the function of a dynamic resource (usually these are: human resources i.e., employee, operator, work crew etc.) that performs work in more than one Work Centre.
- Work Exit Pont – this attribute is used to replicate where the customer leaves the system in question and the service is considered as "completed". There can be more than one Work Exit Point and this allows us to replicate that the customer may leave the system at any stage of the operating process.

Furthermore, SIMUL 8 permits us to avoid transient behaviour of the system under modelling by insetting a "Warm-Up" period in the simulation models. Also, we are able to consider phenomena, such as: interruptions (both scheduled and unscheduled) and non-stationary arrivals (by making the arrival pattern "*time-dependent*"), and scrutinize systems' performance under these conditions.

When the system being examined is properly modelled a simulation experiment can be undertaken. The flow of "*customers*" moving over from attribute to attribute is shown by animation so that the appropriateness of the created simulation models can be more easily assessed. When the structure of the model is confirmed a number of trials can be run. Measures of performance are described statistically. Some measures of interest may be number of customers entered/left the system, average time in queue per storage area, number of customers in a storage area on average, number of customers under service, total in system on average, utilisation rates of floating resources, percent of time in which a work centre is either awaiting work, working, blocked or stopped, etc.

In simulating Entroncamento yard operation in SIMUL 8 environment, the program window can look like as shown in Fig. 3.1. There a screenshot of the yard simulation model is presented. The different yard areas are clearly outlined and their attributes properly named. More specifically, e.g.,:

- Arrival Yard replicates the operating processes on receiving freight trains and consists of storage areas to replicate the limited number of track in the Arrival yard and work centres to replicate the operating processes on cutting the road locomotive from the composition as well as operations of technical and commercial inspections;

➢ Shunting Zone replicates the operating processes on reassemble of freight trains and consists of work centres to replicate the operations on breaking dawn and making up of freight trains as well as storage area to replicate the limited number of Shunting zone tracks. Next, it should be noted that within the shunting zone limits the Entroncamento Car Yard is modelled as well by storage areas to replicate the limited capacity of this yard subsystem and work centres to replicate the required time the compositions should dwell in this yard subsystem;

➢ Etc.

Recalling Fig. 3.1., note that there are two independent throughput lines. One line consists of yard subsystems indicated with 1 and another line consists of identical yard subsystems but indicated with 2. Thus, due to the current practice of the operating process with freight trains at Entroncamento yard, freight trains travel through the yard following the basic sequence of operations performed by the subsystems indicated with 1 or the subsystems indicated with 2 (e.g., the subsystems on cutting the road locomotive from the compositions are indicated as Cutting 1 and Cutting 2; the subsystems on breaking down of freight trains are indicated as Breaking Down 1 and Breaking Down 2; the subsystems on making up of freight trains are indicated as Making Up 1 and Making Up 2 respectively; and so on).

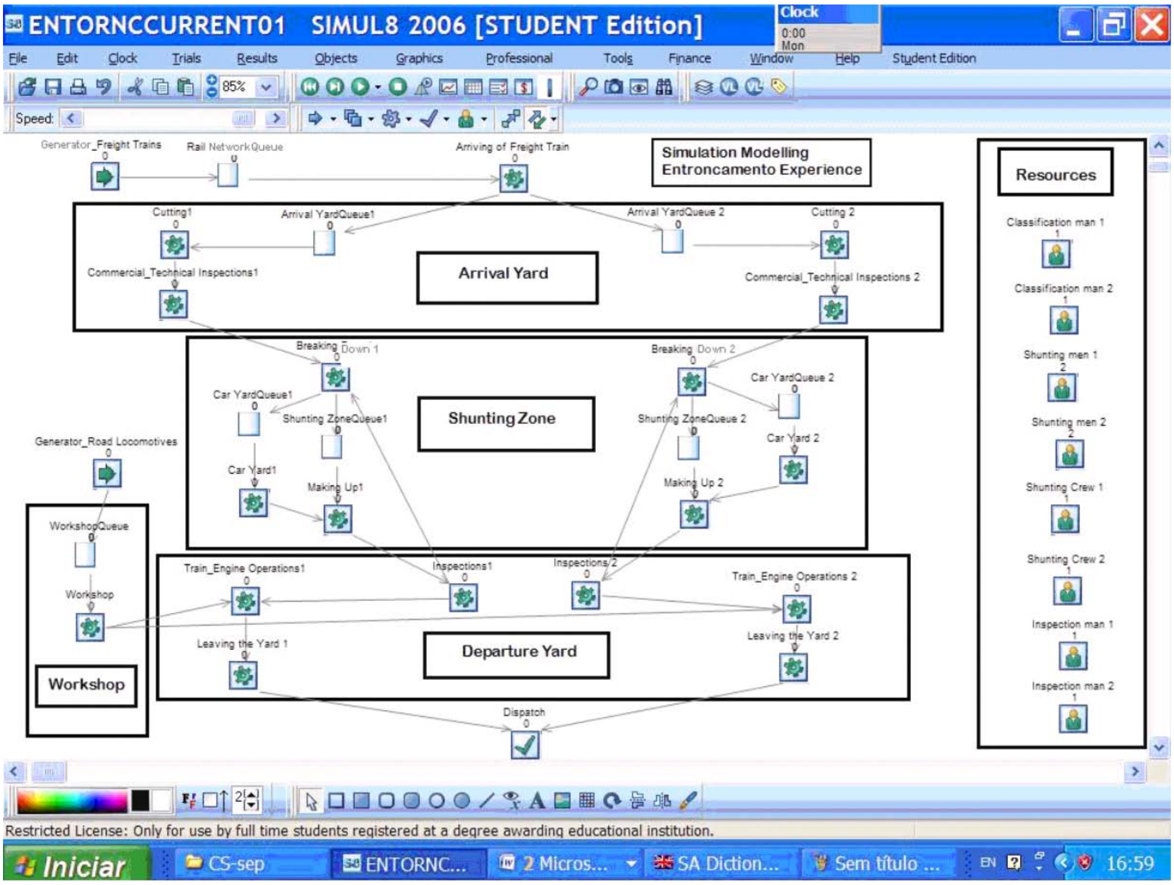


Fig. 3.1 A SIMUL 8' Animation Window in Modelling Operating Processes with Freight Trains at Entroncamento Flat-Shunted Double Ended Yard

By inference, there are one classification man, one shunting crew and one inspection man that work in the relevant subsystems of the one throughput line and there are another classification man, another shunting crew and another inspection man that work in the relevant subsystems of the other throughput line. They are the yard floating resources listed on the left of Fig 3.1., and we will look at their utilization rates in one later stage. Next, for the sake of simplicity and clearness, we named these pairs as Classification man 1 and Classification man 2, Shunting Crew 1 and Shunting Crew 2, Inspection man 1 and Inspection man 2. These names of floating resources are used throughout the simulation experiment.

In completing this section, it should be noted that the two-step approach for analyzing and evaluating yard performances is discussed in greater detail elsewhere (Marinov 2007) and shall not be repeated here. In the following section a discussion on some of the results obtained from our evaluation approach in terms of Entroncamento Double-Ended Flat-Shunted Yard are presented.

4. Results

4.1. Results obtained by G/G/m queue

In Table 4.1 the achieved calibration of the analytical queueing model is presented. One observes a comparison between the observed means and the estimated means of the throughput times per specified yard areas i.e., Arrival Yard (WG1), Shunting Zone (WsG2), Waiting for a Road Locomotive (WsG3) and Departure Yard (WsG4). It should be noted that for yard analytical modelling purposes the average time for waiting a road locomotive is assumed as given. Its value is obtained through observations and timing, and this time is explicitly considered as a waiting time of already assembled compositions.

4.1 Comparison between Observed and Estimated means, Entroncamento Experience

Time in Yard Areas		
Subsystems	Observed Means	Estimated Means
Arrival Yard (WsG1)	20 min/train	20.74 min/train
Shunting Zone (WsG2)	30 min/train	30.41 min/train
Waiting for a Road Locomotive (WsG3)	20 min/train	20 min/train
Departure Yard (WsG4)	25 min/train	25.77 min/train

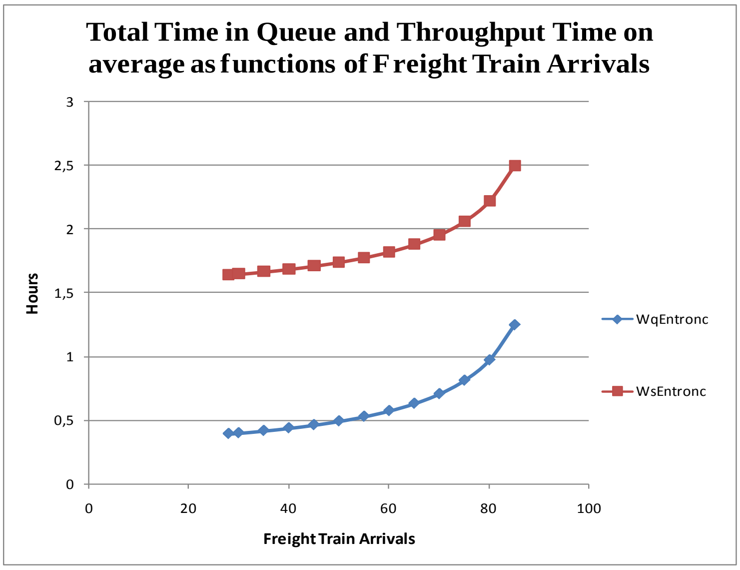
Next, the characteristics of the current situation and the necessary inputs for the analytical queueing modelling, together with some of the estimated measures of Entroncamento subsystems' performances are given in Table 4.2. Note that according to the current situation there are 28 regular inbound freight trains to be served in Entroncamento yard per 24 hours. The regular outbound freight trains, however, come up to 29 (meaning in the shunting zone 28 freight trains are broken down and 29 freight trains are made up). Therefore, because of this phenomenon the arrival rate from the Shunting Zone to the next area (i.e., Waiting for a Road Locomotive) is increased.

Table 4.2 Current Situation, Inputs and Outputs, Entroncamento Experience

G/G/m queue – Inputs and Outputs				
Definitions	Arrival Yard	Shunting Zone	Waiting for a Road Locomotive	Departure Yard
Arrivals-Gi	28 trains/24	28 trains/24	29 trains/24	29 trains/24
λ_{Gi}	1.167	1.167	1.208	1.208
Service Time-Gi	20 min	29.71 min	-	25.26 min
μ_{Gi}	3	2.019	-	2.375
$S(m)_{Gi}$	2	2	-	2
$\rho_{Gi}(Server)$	0.194	0.289	-	0.25
$L_{q,Gi}$	0.014 number	0.045 number	-	0.01 number
$L_{s,Gi}$	0.4 number	0.623 number	0.39 number	0.52 number
$W_{q,Gi}$	0.012 hours/train	0.039 hours/train	-	0.008 hours/train
$W_{s,Gi}$	0.35 hours/train	0.53 hours/train	0.33 hours/train	0.429 hours/train

Looking at the results in Table 4.2, the straightforward conclusion is that the level of server utilizations of Entroncamento yard areas (i.e., ρ_{Gi}(Server)) is relatively low (less than 30%). Low levels of server utilizations means a significant percentage of idle times which has a negative effect seen in higher capital costs for the company. One of the reasons for such a situation is that the yard is not fed enough traffic and therefore the yard subsystems experience such low levels of utilization. Thus, one possible way to increase the utilization levels of yard servers is to search for increases in the arrival rate. However, one should remember that increases in the number of freight trains to be processed, due to limited yard capacity, fluctuations and other external factors cause undesirable increases in the time in queue and hence in the throughput time per freight train on average. On Fig. 4.1 Total Time in Queue, indicated with "W_qEntronc", and Throughput Time in Entroncamento yard per freight train on average, indicated with "W_sEntronc", as functions of Freight train arrivals are studied. Note that if there are 85 freight trains to be served by Entroncamento yard, then the average throughput time per freight train is estimated to come up to approximately 150 minutes, which is an awkward situation. Therefore, in dealing with yard production levels we would suggest that one better specifies an upper bound to reliably replicate the processing capability of the yard in question. As a preliminary observation and relying upon Fig. 4.1 in terms of Entroncamento double-ended flat-shunted yard we would suggest that this upper processing capability bound is between 65 - 70 freight trains to be processed per 24 hours.

Fig 4.1 "Effect" on Total Time in Queue and Average Throughput Time due to Increases in Freight Train Arrivals, Entroncamento Experience



The results presented above are based on the current operational practices within the yard under study. Generally speaking, ameliorating yard performances is not an easy task. When a given yard encounters difficulties to qualitatively serve freight trains one of the possible ways to ameliorate that is by adding a new server (e.g., it could be a new yard crew or a new shunting engine). However, such a decision should be very well thought of before to be made, because of the fact that if there are no changes in the work technology, adding new server is expected to have a positive effect seen in a reduction of total time in queue per freight train on average, but it is not expected to decrease significantly the service times of freight trains. Furthermore, considering the limited yard capacities if there is no infrastructure for two shunting engines to operate simultaneously at the time, adding a second shunting engine will not lead to a breakthrough but just on the contrary, more conflicts within the yard limits will be created. Consequently, in searching for improvements one of the first places where one should look at is in the work technology within the yard. In other words, one should look for possible changes in the service processes with the purpose of increasing the rate at which the freight trains are processed. A reduction of service times decreases the throughput time per freight train on average and further creates operating capacity.

Recalling Entroncamento yard, let us be reminded that this flat-shunted yard is classified as a double-ended yard because there are pairs of working resources employed as single servers that operate separately from each other at one end of the yard only, i.e., the one shunting crew operates at the left end of the yard, the other shunting crew operates at the right end of the yard, the one classification man serves the fright trains assigned North, the other classification man serves the freight trains assigned South, and so on. The pair of working resources can work simultaneously on the same train independently of the assignment of this train because the layout of Entroncamento yard allows it. And, that is where amelioration can be found. If the pair of working resources serves the same freight train simultaneously, a reduction of service times will be experienced. If the two shunting crews break down the same freight composition on the same time, this process is expected to be fulfilled faster than if there is only one shunting crew in operation; if the two classification men work simultaneously on the same freight trains, the classification process is expected to be executed faster than if it is only one classification man in operation and so on.

In order to provide a simple proof, let us look explicitly at aggregated measures of Entroncamento yard performances estimated according to the current situation (i.e., one crew works on one freight train) and the suggested scenario (i.e., two crews on the same freight train). Fig. 4.2 clearly shows the proof required. In implementing the suggested scenario, Entroncamento yard appears to experience a reduction of approximately 25 minutes in average throughput time per freight train served by Entroncamento double-ended flat-shunted yard.

Fig. 4.2 Visualization of the Average Throughput Times estimated in "One crew works on one freight train" and "Two crews on the same freight train", Entroncamento Experience

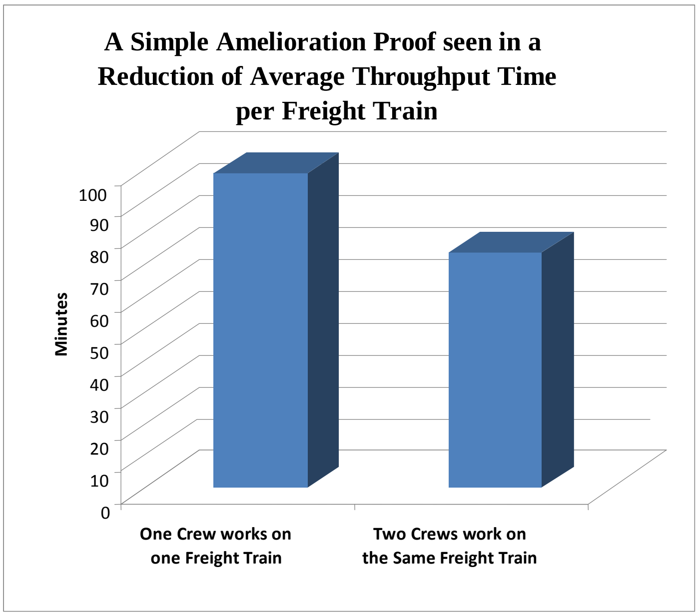
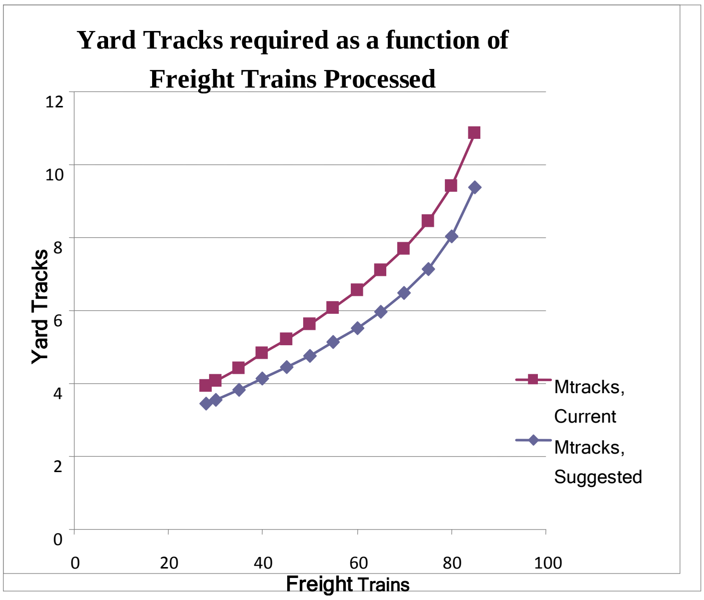


Fig 4.3 Absolute Minimum Number of Entroncamento Yard Tracks required in the Current Situation and the Suggested Scenario



Moreover, the suggested scenario seems to have a positive effect on the absolute minimum number of Entroncamento yard tracks required according to the number of freight trains to be processed. The absolute minimum number of yard tracks required is computed by multiplying the throughput flow in number of freight trains by the average throughput time estimated per freight train plus two further tracks to ensure a standing capacity for the seamless flat-shunting operation. The curves obtained for both the current situation (i.e., $M_{tracks,}Current$) and the suggested scenario (i.e., $M_{tracks,}Suggested$) are given in Fig.4.3.. The effect that the current situation requires a greater number of yard tracks than the suggested scenario is apparent.

4.2. Results obtained by the virtual yard simulation model implemented using SIMUL 8

It should be noted that G/G/m queue assumes stationary arrival patterns for a certain period of time. This is a drawback. Most rail freight operators tend toward strict fixed schedules, thus the freight train operations is planned and scheduled long in advance, meaning in the real world the freight train operations are subordinated to "*predictable variability*" in which the arrivals of freight trains at the yards are hardly ever stationary, but vary over time.

The situation under examination is no different and according to the current schedule the arrival pattern of freight trains at Entroncamento yard is defined as a time-dependent distribution given in Table 4.3. Note that there are periods of time in which no freight train arrivals are scheduled.

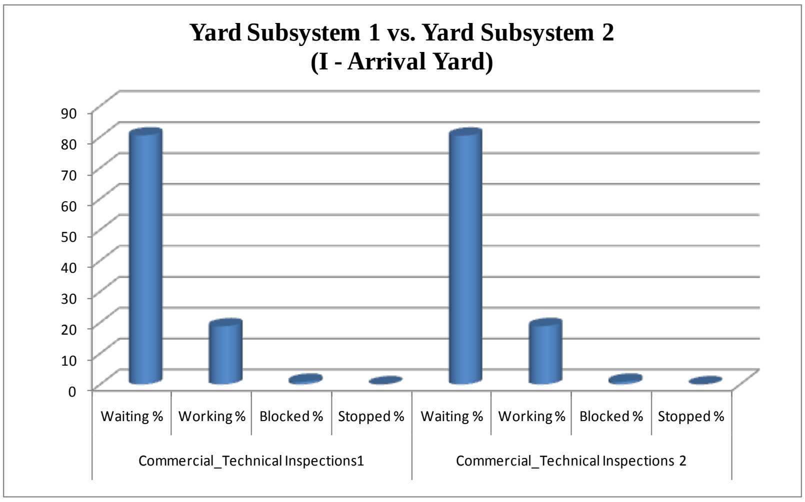
On the other hand, however, it appears that Entroncamento yard may suffer a *predictable queue* problem. By definition, a predictable queue occurs when the arrival rate is known to exceed the service capacity over finite intervals of time. Consequently, the question concerning the operating process with freight trains at Entroncamento should be brought into: *whether the processing yard capacity is consumed over some of the defined time intervals or not?* But, let us be reminded that based on the results obtained by the foregoing analytical model we got the intuition that according to the current practice and available resources involved, Entroncamento yard is able to process from 65 to 70 freight trains per 24 hours before reaching its upper processing capability bound. If so the straightforward conclusion is that this yard bears a rather high percentage of unutilized capacity.

Table 4.3 Time-Dependant Freight Train Arrivals, Entroncamento Experience
Source: **"CP Carga"- Department of Planning and Control**

Time-Dependent Distribution	
Periods	Scheduled Arrivals of Freight Trains
From 0:00 to 01:00	0
From 01:00 to 04:00	5
From 04:00 to 08:00	0
From 08:00 to 10:00	3
From 10:00 to 11:00	0
From 11:00 to 13:00	4
From 13:00 to 15:00	0
From 15:00 to 20:00	8
From 20:00 to 24:00	8

This is the only facility in Portugal of such a dimension and keeping it inefficiently utilized is not acceptable. We wish to verify this result through simulation, because if our analytical model strikes true, a reduction of dynamic resources might be of interest. Needless to say, the fulfilment of the frontline freight train operation is a hard work and therefore employees such as shunting men, inspection men, classification men, shunting engine drivers are by all means needed. However, the railway freight system needs to use its employees effectively. In this way the system could make a profit and the company would keep the jobs and pay its employees well. There is no point to keep idle shifts doing nothing.

Fig. 4.4 States of Subsystems on Commercial and Technical Inspections, Current Situation, Entroncamento Experience



After having conducted simulation trials that consist of 1000 runs, plausible measures of Entroncamento yard subsystem performances for evaluating the current satiation in this yard have been obtained. More precisely, the results estimated for the percent of time in which Entroncamento yard subsystems (i.e., subsystem for commercial and technical inspections, subsystem for breaking down of freight trains and subsystem for inspections of freight trains before departure) are either awaiting work, working, blocked and/or stopped are shown in Fig. 4.4 – Fig 4.6. Note that the percent of time in which these subsystems are awaiting work is more than apparent.

Fig 4.5 States of Subsystems on Breaking Down of Freight Train, Current Situation, Entroncamento Experience

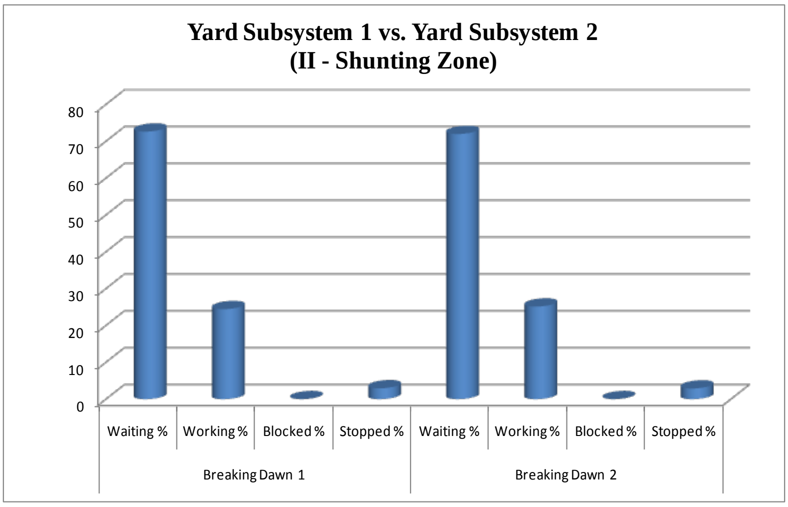
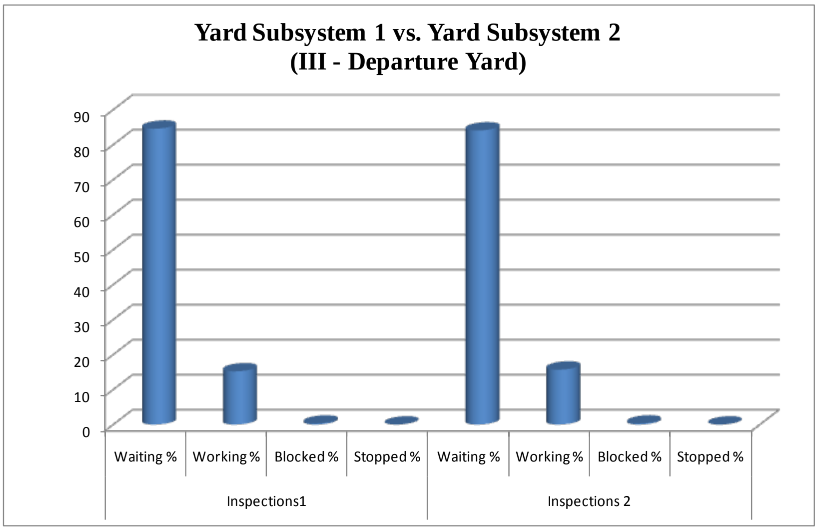


Fig. 4.6 States of Subsystems on Inspections in Departure Yard, Current Situation, Entroncamento Experience



Next, we analyze yard queue lengths and time in yard queues and the results estimated for the queues in the Arrival Yard and Shunting Zone of Entroncamento are given in Table 4.4..

Table 4.4 Queue Yard Estimates, Simulation Trial, Entroncamento Experince

Queue Lengths and Time in Queues		
Yard Subsystem	Performance Measure	Estimate
Queue in Arrival Yard 1	Average queue size in numbers	0
	Average queueing time in minutes	0
Queue in Arrival Yard 2	Average queue size in numbers	0
	Average queueing time in minutes	0
Queue in Shunting Zone 1	Average queue size in numbers	0.03
	Average queueing time in minutes	2.16
Queue in Shunting Zone 2	Average queue size in numbers	0.04
	Average queueing time in minutes	2.42

Note that the sizes of the queues in the Arrival yard come up to 0 (zero) meaning the freight trains would not experience any waiting on the receiving tracks of the yard. Consequently, time in the arrival yard queue should not occur. The estimates for the two queues in the Shunting Zone are 0.03 and 0.04, accordingly, and roughly speaking, due to these queue lengths the average times in Shunting Zone Queues are predicted to be between 2 and 3 minutes.

Table 4.5 Levels of Utilization of Entroncamento Floating Resources, Current Situation

Utilization Rates of Floating Resources in %	
Floating Resource	Estimates
Classification man 1	18.72
Classification man 2	18.79
Shunting Crew 1	34.70
Shunting Crew 2	35.63
Inspection man 1	33.91
Inspection man 2	34.48

Therefore, we have examined whether or not the current demand to be processed by Entroncamento yard (i.e., 28 – 30 freight trains per 24 hours), can be processed by only one classification man, only one shunting crew as well as only one inspection man, meaning a 50 % reduction of flouting resources. No other changes are made. And, our virtual simulation model of Emtroncamento yard shows that a 50% reduction of floating resources is possible without loss of performance (see Table. 4.6 below). Note that the percent of time in which Entroncamento subsystems are awaiting work is reduced and the utilization rates of yard floating resources are increased.

In this scenario the highest utilization rate is experienced by the shunting crew and is estimated up to approximately 70 % at production level up to 31 freight trains per 24 hours, where the time in yard comes up to approximately 110 minutes per freight train on average.

Generally speaking, we believe that the rate at which the shunting crew should work in terms of yard operation (especially flat-shunted yard) is between 60 % and 80 %, bearing in mind the daily demand fluctuations. Then, an adequate level of utilization is achieved. If a shunting crew is shown to have a utilization rate higher than 80 %, so then adding second shunting crew might be of interest, if the yard layout permits it. If a shunting crew is shown to have a utilization rate lower than 60 %, so then most likely the yard in question is not fed enough traffic and indicates for unutilized capacity.

Table 4.6 Estimates Obtained for Entroncamento Yard Performance, after having reduced the Yard Floating Resources

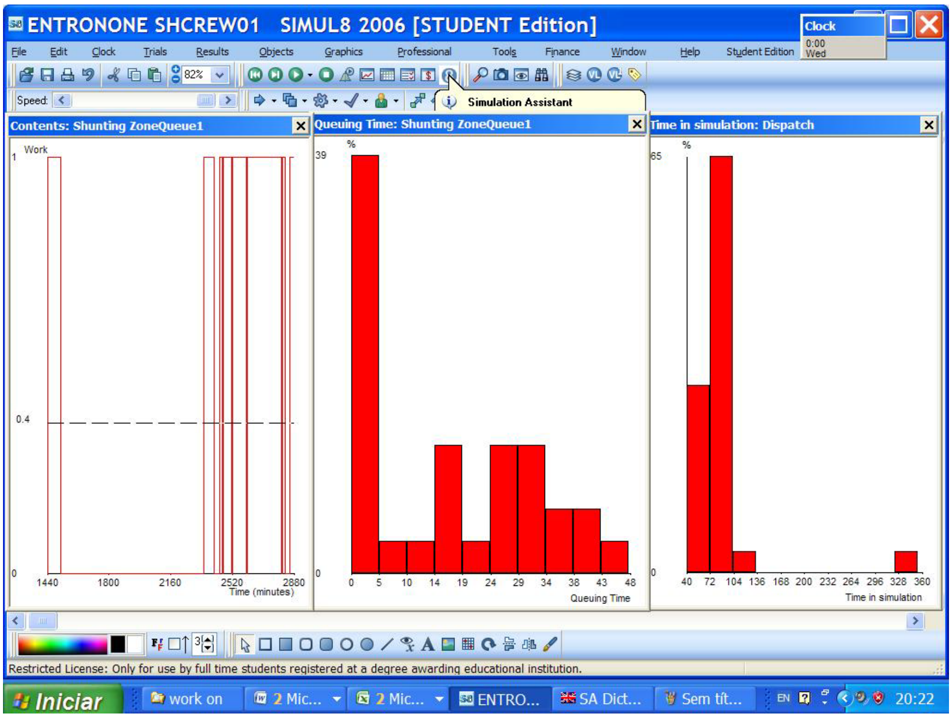
Measures of Yard Performances estimated at a 50 % reduction of Floating Resources	
Yard Attribute	Estimate
Queue in Arrival Yard	0.004 Average queue size in numbers
	0 Average queueing time in minutes
Queue in Shunting Zone	0.33 Average queue size in numbers
	12.39 Average queueing time in minutes
Yard Subsystem on Commercial/Technical Inspections	59.27 % Awaiting work
	37.53 % Working
	3.18 % Blocked
	0 % Stopped
Yard Subsystem on Breaking Down of freight trains	47.41 % Awaiting work
	49.64 % Working
	0 % Blocked
	0 % Stopped
Yard Subsystem on Making Up of freight trains	69.21 % Awaiting work
	18.51 % Working
	9.34 % Blocked
	2.93 % Stopped
Yard Subsystem on Inspections before departure	67.93 % Awaiting work
	30.90 % Working
	1.16 % Blocked
	0 % Stopped

Classification man	37.53 % Utilization
Shunting Crew	70.31 % Utilization
Inspection man	68.43 % Utilization
Freight Trains Entered	31 Number/24 hours
Freight Trains Completed	31 Number/24 hours
Time in Yard	110.38 Minutes on average per train

Next, in analysing the queues one observes that the queue in Arrival Yard of Entroncamento does not materialize. The queue length in Shunting Zone shows size of 0.33 freight trains on average. Hence, the queuing time in Shunting Zone adds up to 12 minutes on average per freight train. *Is that the queue that requires pairs of floating resources acting within Entroncamento yard limits at the time?*

In order to better understand the queuing phenomenon in Entroncamento we drew Fig. 4.7 that consists of three graphs. All graphs but the third concern the yard shunting zone queue. In the first graph (from left to right) the queuing pattern is shown; in the second graph the queuing time in the shape of histogram is shown; and in the third graph the throughput time also in the shape histogram is shown. For our objectives, the first graph is of prime interest where we observe how the shunting zone queue has been materialized and has been vanished over the daily cycle. Note that the queue is not permanent. Also, note that the periods of queue materialization are tied to the periods in which the number of freight trains to arrive is significantly increased (for four hours, eight arrivals, e.g.), which is due to the non-stationary arrival pattern. This confirms the hypothesis made earlier that Entroncamento yard may suffer a predictable queue problem. But the estimated queue size is still too small to be specified as a real problem.

Fig. 4.7 (left-right) Queuing Pattern, Queuing Time and Throughput Time in Entroncamento Yard



If Entroncamento double-ended flat-shunted yard would experience significant increases in the arrivals and if there are finite periods of time in which the arrival rate is known in advance to exceed the processing yard capacity and the shunting crew (we refer to shunting crew because this is the floating resource with highest utilization rate) may encounter difficulties to seamlessly breaking down and making up freight trains, then only in these periods of time adding a second shunting crew might be of interest.

According to the current situation, when Entroncamento yard malfunctions, it appears that the factors causing this situation are not related to “availability of resources”, but other reasons are involved.

In general, it is well known that a high level of variability in the arrival process is the fundamental external reason for malfunctioning of yard, if the yard buffer size cannot handle it. This is not a yard-related problem that can be resolved through changes in yard processing rules and yard work technology. This is a major problem at the overall system level, having a negative effect all over the railway network and if the railway operator under study wants to experience sustained freight transportation service of good quality, the way to proceed is through scheduled and strictly controlled fixed railway freight operations. This is another question whether the schedules are reliable or not as well as whether the road locomotive movements and the freight car capacities are optimized or not; we do not touch these subjects here.

Internal factors that cause yard to malfunction may be such as: disorganization, lack of motivation, lack of control, lack of precision, lack of understanding between labour categories, lack of professionalism in fulfilling the frontline freight train operation in the yard. Such factors force the company to experience heavy inefficiencies and diseconomies of scale i.e., a huge amount of long term accumulated average costs. This is also a system problem, much graver in fact, but of another sort and if the railway freight operator can do something to resolve it, that would be a good thing.

5. Conclusions

In this paper a two step approach employing G/G/m queue and event-based simulation has been implemented in evaluating Entrocamento Flat-Shunted yard performances. This yard is classified as a Double-Ended yard in which pair of working resources is employed. The working resources act within the yard limits independently of each other. This raises an important issue for the plausible replication in modelling Entroncamento yard behaviour and further generation of new scenarios to be tested.

In general, the results obtained for the current situation in Entroncamento indicated significantly low utilisation levels of Entroncamento subsystems. Therefore, increases in freight train arrivals have been examined. Thus, based on the results obtained by the G/G/m queue we got an intuition that Entroncamento yard has a service potential of 65 - 70 freight train per 24 hours according to the yard static and dynamic resources currently employed. (Note that the current situation deals with about 30 freight trains per 24 hours). Next, we have studied whether Entroncamento would experience improvements seen in reduction of total service time if the working resources work together on the same freight train in fulfilling the service. G/G/m model showed that in such a situation Entroncamento would experience a reduction of approximately 25 minutes in throughput time per freight train on average.

In order to enlarge and enrich the scope of our experiment Entroncamento yard performances have also been studied by visual modelling simulations conducted in the environment of discrete-event-based simulator SUMIL 8. The results obtained by the simulation models of Entroncamento confirm that the subsystems of this yard experience a significant percentage of time awaiting work and utilization rates of floating resources below 35%, meaning the yard processing capacity is utilized inefficiently. Therefore, a 50 % reduction in Entroncamento floating resources has been explored and our simulation model shows that such a reduction is possible without loss of performances.

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