Simulation model for port shunting yards

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Abstract. Sea ports are important nodes in the supply chain, joining two high capacity transport modes: rail and maritime transport. The huge cargo flows transiting port requires high capacity construction and installation such as berths, large capacity cranes, respectively shunting yards. However, the port shunting yards specificity raises several problems such as: limited access since these are terminus stations for rail network, the in-output of large transit flows of cargo relatively to the scarcity of the departure/arrival of a ship, as well as limited land availability for implementing solutions to serve these flows. It is necessary to identify technological solutions that lead to an answer to these problems. The paper proposed a simulation model developed with ARENA computer simulation software suitable for shunting yards which serve sea ports with access to the rail network. Are investigates the principal aspects of shunting yards and adequate measures to increase their transit capacity. The operation capacity for shunting yards sub-system is assessed taking in consideration the required operating standards and the measure of performance (e.g. waiting time for freight wagons, number of railway line in station, storage area, etc.) of the railway station are computed. The conclusion and results, drawn from simulation, help transports and logistics specialists to test the proposals for improving the port management.

1. Introduction

The port shunting yards have an important role in ports activity because connect railway network with maritime network [1]. Some problematic aspects are particular to port shunting yards, like limited access, large volume for cargo flow from territory to maritime ship and opposite, a rigorous schedule for the departure/arrival moments for maritime ships, as well as limited land availability to develop new infrastructure to deserve flows between maritime and land networks [2], [3], [4] and [5]. From this reason it is important to identify proper solution and test it before implementation. In this direction a computer simulation model helps us to find the best choice.

The absence of technical equipment to take over the maximum request, leads to the worsening of operating indicators, making it necessary to adopt constructive or technological measures. Usually, constructive measures involves substantial investments, and if the trackside installations are designed according to the maximum request, then, the most of the time, these, will not be fully used, that represent an unacceptable situation, because there may not be recoverable investments. On the other hand, there may be elements of geographical or juridical nature, which can make difficult the implementation of constructive solutions.

Transit and processing capacity for rail stations depends by topological aspects, number of lines, duration of technological process and specific technologies for shunting process. Last of these have an important role, because using humps train sets are separate on maritime berths destination. Usually a maritime rail station have two humps (one for winter condition, one for summer condition) which can...
be used both with some adjustments at lines breaks for all seasons. In a normally shunting process it is used only one hump, wagons having access to all line from next group lines (lines of group B). This aspect limits transit and processing capacity for all railway station. So it is necessary to find a new technology for shunting process.

2. Improvement of shunting process in maritime railway station

The ports configuration (relief, land availability) in order to double the railway tracks or to expand the receiving group of lines (group A -where the train sets arrives in the station and are prepared to be shunted on the hump) of the shunting yard, are not insignificant factors. Therefore, are preferred technological measures, to ensure a rational and intensive use of maritime railway station capacity. In the case of the marshalling yards, the increase of the processing capacity can be achieved by simultaneous shunting of two train sets. The capacity of railway shunting stations from port area can be limited by capacity of shunting facilities. A solution to improve this last capacity is to change a normal shunting process (who supposes a shunting process with a single freight train sets) to simultaneous shunting process (two train sets are shunting in same time).

This measure may be applied there where exist a shunting hump designed with two lines and where the group of lines (named group B) located after the hump, charged with the accumulation of the groups of wagons after the shunting process, can be divided in two distinct groups ($B_1$ and $B_2$) (Figure 1).

![Figure 1. Simultaneous shunting process, [6]](image)

Wagons of a train set which will be simultaneous shunted with another one, are guided towards one of two groups ($B_1, B_2$). Consequently, each half of group B must provide at least a line to be allocated provisionally for wagons with other final berths destinations (each line of group B are specialized to accumulate groups of wagons for one important group of final berths destinations from port area), which after the shunting process are located in the other half of the group B.

After the shunting process of several train sets, the wagons distributed on these lines are repeated shunted.

The comparative study between the repeated and simultaneous shunting was made based on two models:
- the analytical model, in which the operating conditions are deterministic;
- the simulation model, which takes into account the variation and interaction in time of the considered variables and which allow the reproduction in small details of the dynamics of system status.

For normal case shunting capacity is calculate with relation [6]:
where:
- \( T_{tr} \) is available time from one day for shunting process;
- \( t_c \) is technologic interval for shunting installation;
- \( m \) is mean number of wagons from a train sets.

In case of simultaneous shunting the capacity is [1]:

\[
n_{tr} = \frac{T_{tr}}{t_c} m
\]  

(1)

where:
- \( T_{tr} \) is occupied time of hump yard with simultaneous shunting of two train sets
- \( T_r \) is occupied time of hump yard with repeated shunting process for railways cars from selection line;
- \( t_c \) is technologic interval for shunting installation in case of simultaneous shunting;
- \( t_r \) is technologic interval for shunting installation in case of normal shunting;
- \( t_r \) is time for a repeated shunting process.

The necessary time for simultaneous shunting is:

\[
T^* = \frac{n^*}{2m} t_c^* = \frac{pm_{tr}}{2m} t_c^*
\]  

(2)

where:
- \( n^* \) is number of wagon separated by simultaneous shunting process;
- \( p \) is percent from total number of wagon separated on hump yard, which are simultaneous shunted.

The consumed time for repeated shunting is:

\[
T_r = \frac{n_r}{m_r} t_r = \frac{\alpha n_{tr}}{m_r} t_r
\]  

(3)

where:
- \( m_r \) is number of wagons from train sets which are repeated shunted;
- \( \alpha \) is percent from total number of wagon simultaneous shunted which are repeated shunted \((\alpha = \frac{n_r}{n^*} = \frac{n_r}{pm_{tr}})\).

In this case equation (2) became:

\[
n_{tr} = \frac{T_{tr} m}{t_c (1-p+\alpha p) + \alpha p m_r}\frac{m_r}{t_c} t_r
\]  

(4)

We note with \( y \) the ratio between technologic interval from simultaneous shunting and from normal shunting and with \( k \) next ratio \( y = \frac{t_c^*}{t_c} > 1 \) with \( (y \in [1.2; 1.8]) \) and \( k = \frac{m_r}{m} \).

Because, simultaneously with the repeated shunting process of wagons on the selection line it may be decomposed one more train set, it is desirable that the ratio \( k \) to be the one for which the values for \( t_r \) and \( t_c \) are equal. Substituting \( y \) and \( k \) values in equation (5) is obtained:

\[
n_{tr} = \frac{T_{tr} m k}{t_c [1-p+\alpha p] + \alpha p (y-1)]}
\]  

(5)

which mean that increasing the number of repeated shunting processes, will decrease the processing capacity of the marshalling hump. Obviously, there is a limit value of \( \alpha \) for which the process of repeated shunting cancel the increase obtained by simultaneous shunting of two train sets.

From expression below:

\[
\frac{T_{tr} m}{t_c} \leq \frac{T_r m k}{t_c [1-p+\alpha p] + \alpha p (y-1)]}
\]  

(6)

results:
Supposing that the repeated shunting does not exist then the maximum percent of simultaneous shunting of train sets in relation with the total number of shunting processes is:

\[ p_{max} = \frac{k}{k+a} \]  

These equations can be used for approximate calculations, since disregard the number of wagons which arrives on the selection lines from the train sets which are simultaneous shunted in relation with the train sets which are repeated shunted.

Properly speaking, during the repeated shunting process will be decomposed \( \frac{T_r}{t_r} m_r = n_r \) wagons removed from the reserve lines and \( \frac{T_r}{t_r} m = N'_r \) wagons from the train sets arrived in group A of shunting yards.

The time for repeated shunting is in this case:

\[ T_r = \frac{n_r}{m_r} t_r + \alpha \frac{n_r m}{m_r^2} t_r = \frac{\alpha p n_r}{m_r} t_r + \frac{\alpha^2 p n_r m}{m_r^2} t_r \]

In this equation above, the second term represent the time for repeated shunting process of wagons which arrive on the selection line in the time of simultaneous shunting.

By introducing this value of \( T_r \) in equation (2) is obtained:

\[ n_{tr} = \frac{T_r m k}{k t_r c [k(1-p)^2 + \alpha p(1+\frac{\alpha}{k})(t_r-t_c)]} \]

Comparing this equation with (1) shows that:

\[ \alpha_{max} = -\frac{k}{2} + \frac{k^2}{2} \frac{t_r-2 t'_r + 3 t'_c}{t_r-t'_c} \]

The maximum percentage of simultaneous shunting is:

\[ p_{max} = \frac{k^2}{k^2 + \alpha k + \alpha^2} \]

that is to say, the simultaneous shunting of all train sets is possible only in the situations when the repeated shunting are missing (\( \alpha = 0 \)).

With all these possibilities, simultaneous shunting of two train sets is limited not only by repeated shunting, but also by the existence in the same time, in group A of two train sets which can be simultaneous shunted.

Thus, if from even direction arrive \( N_2 \) train sets which are stationing on the lines of group A (for technological process) for a time interval \( t_2 \), then the probability that in the station to be found a train set of this type is:

\[ p_2 = (1 - e^{-\frac{N_2 t_2}{24}}) \]

It is considered a similar situation for the odd direction (the case of Poisson type arrivals [6]).

This means that the probability of finding simultaneously train sets in the station of both, even and odd directions is:

\[ p_{1,2} = (1 - e^{-\frac{N_1 t_1}{24}})(1 - e^{-\frac{N_2 t_2}{24}}) \]

To further increase of the processing capacity of the shunting hump, each half of groups A and B must work as an independent system, served by two locomotives. In this case, by synchronization of activity for each pair of locomotives is possible to achieve \( t'_c = t''_c = t_r \) so as to reach a capacity:

\[ n_{tr} = \frac{T_r m}{t_c(1-p)} \]

3. Simulation model

Using Arena 12 simulation software a simulation model is developed to analyse the shunting process in maritime railway stations [7]. This simulation is made taking in consideration an entering flow of trains from land railway network with wagons for different berths from a maritime port. The
simulation model has two structures. One when shunting process is normal with activities on a single hump (Figure 2) and one with simultaneous shunting process with activities on two humps (Figure 3).

**Figure 2.** Simulation model for normal shunting process

For simulation model with simultaneous shunting process destination berths are split in two set and are allocated to shunting humps. If a wagon for second set is shunted on first hump is routed on a collector line and then re-shunting on second hump.
Figure 3. Simulation model for simultaneous shunting process

The relevant variables statistics (expressed as average) provided by Arena simulation software that can be used to evaluate the port shunting process (normal and simultaneous) performance are:

- $N_{\text{engines, out}}$ – the number of locomotives;
- Waiting time of wagons for free shunting hump;
- Waiting time of wagons in Collector line 1 and 2;
- Number of waiting wagons in queue for free shunting hump;
- The number of wagons that are waiting to be batched on collector lines;
- The utilization of shunting humps.

The simulation has 6 experiments differentiated by alternatives used in model’s input data such as:
- The inter-arrival time distribution of trains: Exponential distribution (E) with mean 0.2, 0.25, 0.35, 0.45 hours and Normal distribution with mean 0.4 hours, standard deviation 0.06 hours;
- \( N_w = 60 \) wagons/train;
- Duration of technologic process in lines group A is 50 minutes;
- Duration of shunting process is 25 minutes;
- Duration of wagon transfer from collector line to shunting hump is 10 minutes;
- 12 destination berths;
- 6 railway lines in lines group A.

The replication parameters for all experiments are:
- number of statistically independent replications is 10;
- warm-up period is 10 hours;
- replication length is 7 days;
- working hours per day is 24 hours.

| Trains inter-arrival time distribution | \( E(\lambda=0.20 \text{ h}) \) | \( E(\lambda=0.25 \text{ h}) \) | \( E(\lambda=0.35 \text{ h}) \) | \( E(\lambda=0.40 \text{ h}) \) | \( E(\lambda=0.45 \text{ h}) \) | \( N(0.4,0.06) \) |
|---------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| No locomotives out                    | 380             | 379             | 379             | 379             | 346             | 379             |
| No Wagons                            | 22800           | 22740           | 22740           | 22740           | 20760           | 22740           |
| Waiting Time Group A                  | 0.1             | 0.03            | 0               | 0               | 0               | 0               |
| Waiting Time SH                       | 46.3            | 36.31           | 16.54           | 6.22            | 1.9             | 3.82            |
| No waiting Group A                    | 0.49            | 0.12            | 0               | 0               | 0               | 0               |
| No waiting SH                         | 235.9           | 146.36          | 48.02           | 15.72           | 4.25            | 9.64            |
| SH Utilization                        | 1               | 1               | 1               | 0.99            | 0.9             | 1               |

**Table 1. Simulation result for normal shunting process**

| Trains inter-arrival times | \( E(\lambda=0.20 \text{ h}) \) | \( E(\lambda=0.25 \text{ h}) \) | \( E(\lambda=0.35 \text{ h}) \) | \( E(\lambda=0.40 \text{ h}) \) | \( E(\lambda=0.45 \text{ h}) \) | \( N(0.4,0.06) \) |
|---------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| No locomotives out        | 759             | 624             | 450             | 420             | 357             | 400             |
| No Wagons                | 45896           | 37694           | 27332           | 25446           | 21778           | 24296           |
| Waiting Time Group A      | 0.08            | 0.03            | 0               | 0               | 0               | 0               |
| Waiting Time SH 1         | 6               | 0.58            | 0.21            | 0.16            | 0.14            | 0.03            |
| Waiting Time SH 2         | 5.98            | 0.55            | 0.21            | 0.18            | 0.13            | 0.03            |
| Collector line 1          | 0.41            | 0.48            | 0.69            | 0.76            | 0.93            | 0.78            |
| Collector line 2          | 0.4             | 0.48            | 0.68            | 0.8             | 0.93            | 0.81            |
| No waiting Group A        | 0.42            | 0.12            | 0               | 0               | 0               | 0               |
| No waiting SH 1           | 15.11           | 1.16            | 0.31            | 0.2             | 0.15            | 0.04            |
| No waiting SH 2           | 15.06           | 1.12            | 0.31            | 0.23            | 0.14            | 0.04            |

**Table 2. Simulation result for simultaneous shunting process**
In all scenarios waiting time for a free shunting humps are decreased. So capacity of transit through maritime railway station is increased when is used simultaneous shunting process. In scenarios when interarrival times between trains are large, like in last four scenarios from simulation, number of wagons who transit through railway station are same indifferent by shunting process used. But for the first two scenarios number of transit wagon over shunting humps are increased (over 100% in first scenario and over 60% in second). So the benefits of this shunting method are reveal when we have a large volume flow through shunting rail station, like in case railway station from port area.

### 4. Conclusion

The location of the railway station inside the seaports allow the access of the freight trains inside the port, the splitting of the wagons in relation with the berth where were destined and their transfer to the port quays. Transit and processing capacity of the station is limited in relation with the technological processes made in the groups of lines and processing installations. Of these, the shunting capacity of the station is of particular importance.

To develop new shunting capacities in the station is difficult to achieve given the space limitation inside the port area. In these circumstances it is appropriate to develop and implement new shunting technologies such as simultaneous shunting process. It has the advantage of using the both shunting humps in the separation process of freight wagons towards the berth where were destined.

However, there is also the disadvantage of repeated shunting process for a number of wagons but it is counterbalanced by the increase of the processing capacity obtained by the implementation of the simultaneous shunting process.

The discrete event simulation software allows the evaluation of these new technologies for shunting in maritime rail station in comparison with actually shunting process. The result promotes these technologies to be used in shunting process in rail station from port area.

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