Import Storage Yard Layout in Vehicle Terminals

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ABSTRACT

This paper addresses the problem faced by terminal operators in organizing the import storage yard of vehicle terminals. An analytical model is developed to quantify rehandling moves and storage density for each storage layout, characterized by a shape parameter. Afterwards the total cost function of the yard is defined. The target of the paper is to set up the storage layout which minimizes total cost and maximizes terminals’ capacity. A numerical case, based on a real terminal, is tested. Results show the optimal layout is quite sensitive to labor and opportunity costs. Nonetheless, block lines with more than two import vehicles are economically feasible.
1 INTRODUCTION

Automobile industry and its logistic operations in the auto supply chain have included port terminals as strategic nodes, hoping for better economies of scale. At the same time, activities such as component, module assembly or other added value activities are being included in vehicle terminals; hence port terminals are a key part of the global supply chain of vehicles.

On the other hand, the driving strives for efficiency in a highly competitive environment has resulted in creating a net of dedicated port terminals and hubs. Consequently port terminal operators have strengthened their efforts to optimally manage their resources and storage areas in order to increase terminal’s productivity.

Storage yard of port terminals is perceived as one of the main areas; hence their layout should take into account the infrastructural decisions with options to be taken by operational planning of vehicles (1). As it is known, import and export processes differ in the way vehicles are taken into and retrieved from a storage yard. Vehicles for import are stored as a batch but their departure is a subject to stochastically arriving customers’ delivery orders, whereas export vehicles are consolidated according to their final destination in order to warrant an effective loading process in a batch.

Therefore, the layout of storage yards provided for processing batches is distinguished from the layout suitable for stochastic retrieval. Another difference between import and export vehicles is a dwell time in the terminal associated to each one. Import vehicles remain in the terminal longer than export vehicles, and the dwell time in the terminal is defined according to different delivering strategies (2).

This paper will focus on inbound logistics operations and more particularly on those which take place in the storage yard. Moreover, we will give special attention to rehandling moves and their effect on the operational cost. Rehandle is a consequence of storing import vehicles in lines which length is longer than 2 vehicles because its departing patterns are random and unpredictable, as it is demonstrated in (1).

Afterwards, we will propose and analyze economically different storage block layouts in order to maximize the utilization of available space and to minimize operational cost, that is, try to find the trade-off between storage utilization and operational cost due to rehandling moves in economic terms.

This article is structured as follows: first literature is analyzed by reviewing the major contributions in the design of port configuration and rehandling moves. Chapter 3 introduces the problem and Chapter 4 defines and develops the methodology used in this article. The analyzed case study and respective results are presented in Chapter 5 that will allow us to set some conclusions (Chapter 6).

2 LITERATURE REVIEW

Optimization of vehicle terminal operations is a field within transport research which has recently become a subject to explore. Generally, the vast majority of studies have focused on improvement and optimization of processes developed in container terminals.

In the terminal vehicles are moved by drivers organized in gangs, so terminal operations are very cost-intensive. Moreover, if rehandling moves were required to retrieve vehicles from a line, the operational cost would be highly increased. In order to minimize the cost, storage strategies, decision models for manpower planning or deployment scheduling have been analyzed by few authors, although rehandling moves have been studied mainly by De Castilho and Daganzo (3), Kim (4), Huynh (5) and Saurí and Martín (6) just for container terminals.
A multi-agent system for integrated storage allocation and deployment scheduling was developed by Fischer and Gehring (7) to minimize and balance the number of drivers required in the planning period. Similarly, Mattfeld and Kopfer (8) set out a decision planning and scheduling system intended to support automated terminal operations in Bremerhaven. Both studies demonstrate that heuristic tools are suitable to support the current storage allocation problem and deployment scheduling.

Regarding the literature concerned with organization of the storage area of vehicle terminals we should mention the contribution of Mattfeld (1) who stated the efficiency of the operational processes and terminal’s productivity depend on the organization of the storage area.

There have been many studies on the optimization of the design parameters of storage systems. Berry (9) analyzed the layout of conventional warehouses, Bozer and White (10) suggested an algorithm for designing picking systems, Lee and Kim (11) proposed two methods for optimizing block size and Iranpour and Tung (12), among others, stated that parking areas should be designed according to the storage capacity. They proposed a new design that maximized its capacity and reduced parking moves to the minimum. The implementation of this design has had great success, not only in storage yards but in any parking area.

Additionally, Cassady and Kobza (13) focused their studies on finding the optimal parking slot in order to reduce the access time and the distance to the parking lot, considering two strategies. Other authors who provided a quantitative approach to the design of parking areas which can be adapted to car terminals are Bingle et al., (14). They reduced the turning radius to reduce incidents and vehicle damages.

In short, this paper will combine the design process of a storage block, limited by the terminal capacity, with the restrictions of inbound logistic processes of vehicles. That is, we will consider the stochastic departure process of vehicles and therefore, the required rehandles to retrieve a vehicle from a line with more than 2 vehicles. All studies regarding import vehicles suggest lines formed by only two vehicles, in order to avoid rehandling moves. However, we will try to demonstrate that in particular conditions it will be economically feasible to design block storage with more than 2 vehicles so the capacity of the terminal will be increased without large investments.

3 PROBLEM DESCRIPTION

Let the shape parameter (β) be the reference ratio that will be used to compare the different block layouts which dimensions are \(L_x\) and \(L_y\), length and width respectively. The capacity of each block is \(n\) slots and the main slot dimensions will be \(w\) and \(l\) (see Figure 1).

\[
\beta = \frac{L_x}{L_y}
\]

where:
\[
L_x = w \cdot X
\]
\[
L_y = l \cdot Y
\]

where:
- \(X\): Number of slots (vehicle) per line along the abscissa axis (‘x’)
- \(Y\): Number of slots (vehicle) per row along the ordinate axis (‘y’)

\(L_x\) and \(L_y\) express the total available length and width for the storage block dimensions.
In the layout shown in Figure 1, where vehicles are stored in lines, only the first and the last vehicle can be accessed directly. Since we are dealing with import vehicles, rehandles will be needed for retrievals, due to stochastic departing process. Therefore, as the number of vehicles per line ($Y$) increase, bigger will be the probability of rehandles, but lower will be the storage space per vehicle. Hence, there exists a trade-off between both criteria (rehandles versus storage space per vehicle).

Finally, we will develop an economic analysis where the total cost function of the storage yard will be introduced. Thus, the target will be to minimize total cost.

### 4 METHODOLOGY

#### 4.1 Storage density

Terminal storage areas are organized in blocks, where vehicles are temporarily stored, and in internal paths which help to organize traffic within the terminal. Therefore, the total area available for storage is divided into parking areas and internal paths.

Each layout will have paths arranged in different ways; therefore the distribution of paths and parking slots will depend on each layout. For this reason, storage density will be evaluated and the unit area per vehicle will be assessed ($m^2/vehicle$), that is:

$$\rho_i = \frac{S_{T,i}}{C_i}$$  \hspace{1cm} (5)

where:

- $S_{T,i}$: Storage yard’s overall surface ($m^2$) for layout $i$ (characterized by $\beta$).
- $C_i$: Overall capacity for block layout $i$ (vehicles).

Internal slot width between blocks will be $a_x$ and $a_y$ meters (regarding the associated axis). Also, slot area is ($w \cdot l$) square meters (Figure 1).

Therefore, the analytical expressions that quantify the shaded area in Figure 1, applying to storage blocks ($S_{b,i}$) and internal paths ($S_{v,i}$), are:

$$S_{b,i} = (L_x \cdot L_y)$$  \hspace{1cm} (6)

$$S_{v,i} = (L_x + a_x) \cdot a_y + L_y a_x$$  \hspace{1cm} (7)
Finally, the total block surface \( S_{b+v,i} \) will be:

\[
S_{b+v,i} = (L_x + a_x) \cdot (L_y + a_y)
\]  

(8)

The storage density per vehicle can be divided into two components: storage area \( \rho_{b,i} \) and area traffic path \( \rho_{v,i} \) area, that is:

\[
\rho_i = \frac{S_{b+v,i}}{C_i} = k \cdot \left( \frac{S_{b,i}}{C_i} + \frac{S_{v,i}}{C_i} \right) = k \cdot (\rho_{b,i} + \rho_{v,i})
\]  

(9)

Where the parameter \( k \) determines the total number of blocks in the storage yard.

It is worth mentioning that, in equation (9) the first component \( \rho_{b,i} \) is the same for all layouts, based on the assumption that all blocks have the same capacity and, thus, the assigned area per vehicle will be equal to \( (w \cdot l) \) m\(^2\). The second component \( \rho_{v,i} \), is particular for each block layout and therefore the criteria will denote the differences between them.

4.2 Calculation of rehandles

Rehandling is another important criterion to assess the suitability of different layouts.

In particular, the objective is to quantify the expected number of rehandles in a row under two different situations: homogeneous rows (each vehicle in a row has the same departure probability or even a gang of 8-10 vehicles with similar properties which will leave the terminal in the same truck) and heterogeneous rows (rows are exclusively made up by vehicles with different departure probability).

4.2.1 Assumptions and notations

The model developed is based on the following assumptions and notations.

Assumptions:

- All vehicles unloaded from the same ship have the same departure probability.
- Ship’s interarrival time is constant (6,15)
- The number of vehicles unloaded per ship is the same in all cases (15)
- Vehicle’s dwell time at the storage yard is similar to the Weibull distribution function (this hypothesis derives from empirical data from vehicle terminals in Port of Barcelona).
- Storage blocks have the same capacity.

Additional notations:

- \( h \): Number of vehicles in half of a row, obtained according to expression (12)
- \( B_{X,Y} \): Storage block with \( Y \) vehicles per row and \( X=n/Y \) vehicles alongside axis ‘X’.
- \( i \): Index that identifies each block layout \( (B_{X,Y}) \).
- \( AT \): Ship interarrival time
4.2.2 Dwell time at the storage yard

Vehicle dwell time in the yard ($t$), or the time vehicles stay in the terminal, is typically considered to be a non-negative continuous random variable, which probability distribution function $F(t)$ might be the exponential (simplest distribution for non-negative random variables) or any other candidate distributions like Weibull, gamma or log-logistic parametric distribution. For this paper, we are choosing the Weibull distribution function ($\alpha$, $\beta$), which includes the exponential one (for $\alpha=1$).

The survivor function, $S(t)$, is defined as the function representing the probability that a vehicle has not left the terminal at the precise time $t$, this is:

$$S(t) = P(T \geq t) = 1 - F(t) \tag{10}$$

Let $h(t)$ be the hazard function and represents the instantaneous rate at which the event of interest (a vehicle leaving the terminal) will occur at time $t$, given that it has not occurred up to this time. That is:

$$h(t) = \lim_{dt \to 0} \frac{P(t \leq T \leq t + dt | T \geq t)}{dt} = \frac{f(t)}{S(t)} \tag{11}$$

The probability of the vehicle leaving at time interval $(t,t+dt]$ is approximately $h(t)\Delta t$, for infinitesimal values of $\Delta t$ (16).

For the particular case of an exponential distribution, the instantaneous rate or hazard function exhibits no duration dependence (hazard rate is constant), which entails that the probability of leaving at the following time interval does not depend on the time the vehicle has been parked in the yard.

4.2.3 Calculation of rehandles for a homogeneous row

This section focuses on the calculation of the rehandling moves of a row made up of same-ship vehicles (therefore, these vehicles have the same probability of leaving the terminal at time $t$). The objective is to obtain the expected number of vehicles in the row needed to be handled in order to retrieve a specific vehicle.

Any vehicle stored in the first or last positions of the row will have zero rehandling moves associated, while a vehicle located on the second or penultimate position of the row will entail $(h-1)$ rehandling moves, where as $h$ is half the number of vehicles in a row, that is:

$$h = \begin{cases} 
\frac{Y}{2} & \text{if } Y \text{ is even} \\
\frac{Y + 1}{2} & \text{if } Y \text{ is odd} 
\end{cases} \tag{12}$$

As vehicles may be retrieved from both ends of the row, a horizontal symmetry within the rows may be found. In the case that the number of vehicles per row is odd, the central vehicle will be assigned to one of the extremities and then the number of vehicles to be retrieved to access to it will be exactly the same.

We will quantify the number of rehandling moves per row at time $t$ by calculating the probability of each possible number of expected rehandles (per row and for each time $t$), i.e:

$$E[R(t)] = \sum_{R=0}^{h-1} R \cdot P_R(t) \tag{13}$$
where \( R \) is the number of possible rehandling moves associated to each vehicle (function of the vehicle position), taking into account the horizontal symmetry between the parking cells, and \( P_r(t) \) the probability that \( R \) rehandling moves occur at \( t \).

The next step will be to define the probability that \( R \) rehandling moves in a vehicle row \((P_R(t), R \in [1, h-1])\) occur. For example, let’s consider a hypothetical case of a 6-vehicle row, i.e. \( h = 3 \), and we want to calculate the probability of \( R \) rehandling moves, where, in this case \( R = \{1,2\} \).

To determine the probability of \( R=2 \) rehandling moves it is first necessary to define all possible situations where there are two associated rehandling moves. In this case, it will only happen when the vehicle located in the middle position of the row is retrieved at \( t \) and the two vehicles parked in front of it remain at the yard.

Therefore, the probability is determined by the compliance of the events "departure of the vehicle located in the middle position of the row" and the "two remaining vehicles will stay at the terminal." Analytically, this is the result of the probability that a vehicle leaves the terminal at time \( t \) \((F(t))\) and the probability that the two remaining vehicles will stay at the terminal, \( S(t) \), as defined in equation (10).

To get the probability of \( R = 1 \) rehandling moves in a 6-vehicles row for a time \( t \) several conditions must occur at the same time. The first of them is that the vehicle parked in the middle position of the row departs from the terminal \((f(t))\) while the remaining two vehicle stay \((S(t))\). Another condition: one of the three vehicles that formerly made up half of the row has to be retrieved \((F(t))\) and, finally, one more vehicle (having another parked in front of it) departs at time \( t \). The occurrence of these three events will define the probability of \( R=1 \). Here, the density function, \( f(t) \), represents the probability of departure a vehicle at a given time, assuming that it has been stored at the yard until that time. That is:

\[
P_{R=h-1}(t) = f(t) \prod_{r=1}^{h-1} S_r(t) = f(t)(1 - R)^{(h-1)}
\]

\[
P_{R=h-2}(t) = f(t) \prod_{r=1}^{h-2} S_r(t) + \left( \frac{h}{1} \right) f(t)F(t) \prod_{r=1}^{h-2} S_r(t)
\]

\[
P_{R=1}(t) = f(t) \prod_{r=1}^{h-1} S_r(t) + \left( \frac{h}{1} \right) f(t)F(t) \prod_{r=1}^{h-2} S_r(t) + \cdots + \left( \frac{h}{h-3} \right) f(t)F^{(h-3)}(t) \prod_{r=1}^{h-2} S_r(t) + \left( \frac{h}{h-2} \right) f(t)F^{(h-2)}(t) \prod_{r=1}^{h-2} S_r(t)
\]

Once the expected number of rehandling moves in a row of vehicles at \( t \) is defined, by combining expressions (13) and (14a, 14b and 14c), the analytical expression that determines the expected number of rehandling moves for a row consisting of \( n \) vehicles from the same ship (with equal probability of departing the terminal) and for a period of time, \([t_0, \infty)\), is obtained:

\[
E[R] = \int_{t_0}^{\infty} E[R(t)] dt
\]
4.2.4 Calculation of rehandles for a heterogeneous row

The objective is to calculate the number of rehandling moves that occur in a row accommodating vehicles from different ships and, therefore, with different probabilities of leaving the terminal.

In order to do that, the volume of vehicles still parked in a row for a given time \( t \) i.e., the expected number of vehicles at the block, \( E[N(t)] \) will be first determined.

The number of remaining vehicles in each row will depend on the vehicle departing rate. Given that the departure rate approaches a Weibull distribution, characterized by parameters \( \alpha \) and \( \lambda \), we can determine a vehicle’s departure probability and then obtain the average number of vehicles remaining in each block of the terminal.

Assuming that there were initially \( Y \) vehicles from the same vessel in each row, the probability that there are \( z \) vehicles, \( z \in [0, Y] \), in a row for a given time instant \( t \), will be:

\[
P_y(t) = \prod_{z=1}^{Y} S_z(t) = \prod_{z=1}^{Y} (1 - F_z(t))
\]

\[
P_{y-1}(t) = \left(\frac{Y}{1}\right)F(t) \prod_{z=1}^{Y-1} S_z(t) = \left(\frac{Y!}{(Y-1)!}\right)F(t) \prod_{z=1}^{Y-1} (1 - F_z(t))
\]

\[\vdots\]

\[
P_1(t) = \left(\frac{Y}{1}\right)S(t) \prod_{z=1}^{Y-1} F_z(t) = \left(\frac{Y!}{(Y-1)!}\right)(1 - F(t)) \prod_{z=1}^{Y-1} F_z(t)
\]

\[
P_0(t) = \prod_{z=1}^{Y} F_z(t)
\]

Since a row is made up exclusively of vehicles coming from the same vessel, the distribution function \( F_z(t) \) will be the same for all vehicles in the row. Therefore, for simplicity \( F_z(t) = F(t) \\forall z \), so the above expressions can be summarized as follows:

\[
P_z(t) = \left(\frac{Y}{Y - z}\right)S(t)^z F(t)^{Y-z}
\]

From equation (17), the expected number of vehicles per row at time \( t \), \( E[N(t)] \), will be given by:

\[
E[N(t)] = \sum_{z=0}^{Y} z \cdot P_z(t)
\]

Once the methodology for calculating the probability that there will be \( z \) vehicles in a row, \( z \in [0, Y] \), and thus the expected number of remaining vehicles in the rows making up the storage blocks is defined, the expected number of rehandling moves in a row which is made up by vehicles with different departure probabilities will be quantified.

Since vehicle arrival times at the terminal are different and taking into account that the reference time corresponds to the arrival time of the vehicles unloaded from the first vessel, it will be necessary to evaluate the occupation of each row for each ship arrival time.
Let’s suppose a yard with vehicles from the same ship A. If we consider a specific time, \( t^* \), and if we analyze the terminal occupation at this same time (Figure 2), we will be able to determine the final configuration of the rows in each cell assuming that the vehicles unloaded from the vessel just docked at the terminal, B, are incorporated to them (figure 3: block configuration at \( t > t^* \)). The standard configuration of the rows will be type \((z, Y-z)\) where \( z, z \in [0, Y] \), are the vehicles already stored in the cell (from ship A) and \( Y-z \) is the number of new unloaded vehicles (from ship B).

From the scheme shown in Figure 2, the analytical expression quantifying the expected number of rehandles at time \( t \) in a row with \( z \) remaining vehicles stored at the terminal, and \((Y-z)\) vehicles just unloaded to the terminal will be finally:

\[
E[R(t)] = \sum_{z=0}^{Y} P_z(t = t^*) \cdot E_{z,Y-z}[R(t)]
\]  

Finally, by integrating the expected number of rehandling moves for the time span between \([t^*, \infty)\), the number of rehandling moves resulting from mixing vehicles from two different ships (A and B) is obtained:

\[
E[R] = \int_{t^*}^{\infty} E[R(t)] dt
\]
5 STORAGE YARD LAYOUT

The assessment of each block layout will be carried out by analyzing the rehandling moves and storage density. Both criteria will be related to the shape parameter ($\beta$), as defined in equation (I).

5.1 Block layout and initial data

The block layouts suggested ($B_{x,y}$) are summarized in Table 1, based on the following input parameters: number of vehicles per block ($n$) and number of vehicles per row ($Y$, $Y \in (1, n)$).

Assuming that the slot dimensions are 2.5 meters wide ($w$) and 5.0 meters long ($l$) and the internal paths width of the yard is 6.0 meters ($a_x = a_y$, $a_x = a_y$, is assumed to solve the case study), the dimensions of the block need to be defined. Bearing in mind that $n=300$ vehicles, the settings detailed in Table 1 will be analyzed.

5.2 Results

The results are organized into two different sections: the first one analyzes the main criterion: storage density and rehandling moves; and the second section presents a numerical case, based on a vehicle terminal, where the optimum block layout will be defined.

5.2.1 Storage Density and rehandling moves

Table 1 shows the results from the application of expressions as defined in Section 4.1 and 4.2. As regards the storage density ($\rho_t$), and particularly its components (blocks and internal paths), it should be noted that blocks storage density ($\rho_{bi,t}$) is equal for all block layouts: 12.50 ($m^2$/vehicle).

On the other hand, Table 1 also shows the expected number of rehandles per block considering two different scenarios: homogeneous and heterogeneous row. In both cases, it has been assumed that vehicle dwell time follows a Weibull distribution which parameters are $\alpha=1.5$ and $\lambda=0.04$ as the average dwell time is assumed to be 10 days.

In the second scenario (heterogeneous row) we have considered a row made by vehicles from the first ship and vehicles from a ship which have arrived at the terminal 3 days later. It should be stand out; vehicles arriving earlier are more likely to leave the terminal before those arriving later.
### TABLE 1 Storage Density (m²/vehicle) and Expected Rehandles per Layout

<table>
<thead>
<tr>
<th>Block Configuration</th>
<th>X</th>
<th>Y</th>
<th>β</th>
<th>ρᵢ (m²/vehicle)</th>
<th>ρᵥ,i (m²/vehicle)</th>
<th>E[R]ₜ₉っております</th>
<th>E[R]ₜ₉ ([%])</th>
<th>ΔE[R]ₜ₉ ([%])</th>
</tr>
</thead>
<tbody>
<tr>
<td>B₁₅₀,₂</td>
<td>150</td>
<td>2</td>
<td>37.5</td>
<td>20.30</td>
<td>7.80</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>B₇₅,₄</td>
<td>75</td>
<td>4</td>
<td>9.40</td>
<td>16.80</td>
<td>4.30</td>
<td>37.50</td>
<td>45.00</td>
<td>20.00</td>
</tr>
<tr>
<td>B₆₀,₅</td>
<td>60</td>
<td>5</td>
<td>6.00</td>
<td>16.10</td>
<td>3.60</td>
<td>55.80</td>
<td>67.20</td>
<td>20.40</td>
</tr>
<tr>
<td>B₅₀,₆</td>
<td>50</td>
<td>6</td>
<td>4.20</td>
<td>15.70</td>
<td>3.20</td>
<td>75.00</td>
<td>90.50</td>
<td>20.70</td>
</tr>
<tr>
<td>B₃₀,₁₀</td>
<td>30</td>
<td>10</td>
<td>1.50</td>
<td>15.10</td>
<td>2.60</td>
<td>150.00</td>
<td>180.40</td>
<td>20.30</td>
</tr>
</tbody>
</table>

Let there be a block with 8 vehicles per row, all from the first ship. At the arrival time of the second ship (ΔT = 3 days) we will note that, on average, 5-6 vehicles from the first vessel remain in that row and therefore there will be 2-3 empty slots. As can be appreciated, the number of rehandles (ΔE[R]ₜ₉) will be increased by 21% over the ones that would have been required for a homogeneous 6-vehicles row with the same departing probability. For the specific case in study, the increase in the percentages will be around 20% for all analyzed configurations, as it is shown in Table 1.

From the above results it is observed that:

- The storage density decreases as the shape parameter (β) decreases, that is, the more compacted the block geometry is, the smaller the area needed for internal circulation paths will be.
- Data shows that given two blocks with the same storage capacity (number of slots), the required total area can be 34% higher in one case than in the other (comparison between configurations B₁₅₀,₂ and B₃₀,₁₀). Thus the application of configuration B₃₀,₁₀ would achieve a better utilization of the storage area.
- The expected number of rehandles per row increases more than proportionately (to square) to the number of vehicles per row. Similarly the labor costs will rise.
- Finally, it can be seen that the expected number of rehandles increases with the decrease of the storage density. Hence there exists a trade-off between both criteria.

#### 5.2.2 Numerical case

Once both parameters are analyzed, the next step is to analyze a hypothetical terminal with a storage area of 50Ha and a block capacity of 300 vehicles (i.e: automobile terminals in Port of Tacoma (WA) or Port of Zeebrugge (Belgium)). In this case, we will try to find the block layout which minimizes total cost.

Table 2 shows the organization of the storage yard: storage density, number of blocks, and the number of vehicles that can be stored in the terminal (in terms of capacity).
TABLE 2 Storage Density and Overall Capacity for each Layout (S_T=50Ha)

<table>
<thead>
<tr>
<th>Block Configuration</th>
<th>β</th>
<th>k</th>
<th>C_i (vehicles)</th>
<th>ρ_b+v,i (m^2/vehicle)</th>
<th>S_b,i (%)</th>
<th>S_v,i (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B_{150,2}</td>
<td>37.5</td>
<td>82</td>
<td>24,600</td>
<td>20.3</td>
<td>62%</td>
<td>38%</td>
</tr>
<tr>
<td>B_{75,4}</td>
<td>9.4</td>
<td>99</td>
<td>29,700</td>
<td>16.8</td>
<td>75%</td>
<td>25%</td>
</tr>
<tr>
<td>B_{60,5}</td>
<td>6.0</td>
<td>103</td>
<td>30,900</td>
<td>16.1</td>
<td>78%</td>
<td>22%</td>
</tr>
<tr>
<td>B_{50,6}</td>
<td>4.2</td>
<td>106</td>
<td>31,800</td>
<td>15.7</td>
<td>80%</td>
<td>20%</td>
</tr>
<tr>
<td>B_{30,10}</td>
<td>1.5</td>
<td>110</td>
<td>33,000</td>
<td>15.1</td>
<td>83%</td>
<td>17%</td>
</tr>
</tbody>
</table>

The table above shows the difference in the use of the allocated space for vehicle storage in a terminal. Considering a block layout of two vehicles per row, 62% of the total area will be useful for storage; while if the blocks are formed by rows of 6 vehicles, surface profitability will be increased by 18% (40Ha used for storage purposes and only 10Ha for internal circulation paths). Additionally, the terminal capacity also depends on the shape parameter (β). Hence, 34% more capacity can be achieved if rows with 10 vehicles (B_{(n/10),10}) are used instead of 2-vehicles rows (B_{(n/2),2}).

These results validate the suggestion stated by Mattfeld (1), who proposed a storage strategy for stochastic output (import) of two vehicles per row in order to avoid rehandling moves although this will require more space for paths in order to ensure direct access to these vehicles.

Following the study case, the expected number of rehandles that would be required a block of 300 vehicles from the same vessel and with a dwell time of 10 days are shown in Figure 3, where the results from the Table 2 are also included.

FIGURE 3 Capacity and expected rehandling moves regarding shape parameter (β)

Analyzing the expected number of rehandles per block layout, it can be observed that no additional vehicle move is required when there are 2 vehicles per row (β=37.5). However, if configurations of 4 vehicles per row are applied, moves increase by 12.5% compared to the
previous configuration. Moreover, if storage blocks of 10 vehicles per row are designed \((\beta = 1.5)\), vehicle moves per block will increase by 50 %, i.e., one on three moves within the terminal will be for rehandling purposes. From Figure 3 it can be stated that, when \(\beta\) increases, storage yard capacity decreases linearly (as an approximation) and the total expected number of rehandles drops also but with factor 2.

### 5.3 Cost analysis

To carry out the economic analysis annual operating costs for a terminal with storage area of 50 Ha will be quantified. The considered costs correspond with concession fees (composed of a fixed part based on the surface occupation and a variable part depending on the number of vehicles handled by the terminal), the cost of additional manpower to perform rehandling moves and the opportunity cost of not being able to answer all possible demand (will be calculated as the price charged by the terminal for the pass of each vehicle and taking into account the difference in configuration capacity of the storage area with more capacity, \(\beta = 1.5\), depending on the configuration considered in each case).

Another cost to consider is related to the value of the time required for transfers from the vessel to the storage area. Different block layouts require placements in different distance in relation to pier line, meaning a decrease in labor productivity when the shape parameter (\(\beta\)) increases. However, this difference in productivity translated into costs will be disregarded due to its low importance compared to other cost components.

First of all, it is necessary to define the potential demand of the terminal. To this end, various levels of using parking slots of the terminal will be established, valued in block rotation a year (\(\rho\)) (number of times slots are filled and empty a year).

Since the cost associated with vehicles rehandling is a stochastic variable, the total cost of the yard is expressed in terms of expected total cost:

\[
E[C_T(\beta)] = (E[R_{\text{block}}]\rho C_R + S_{b+v,i}C_F + n\rho C_V)k + \Delta C_\beta \rho P
\]

(21)

Where:

- \(\rho\): Rotation of slots per year (number of times each slot is in use annually)
- \(n\): Block capacity (number of vehicles)
- \(C_R\): Labor cost associated with rehandling moves (€/rehandle).
- \(C_F\): Area cost (€/m²) corresponding to the fixed part of the concession fee.
- \(C_V\): Variable cost corresponding to the concession fee and based on the number of vehicles handled by the terminal a year (€/vehicle).
- \(\Delta C_\beta\): Capacity reduction of the layout \(i\) in respect of those considered to have maximum capacity \((\beta_{\text{min}})\). For instance, taking the results obtained in Table 2 it has \(\Delta C_{\beta=1.5} = 0\) and \(\Delta C_{\beta=37.5} = 8400\) vehicles.
- \(P\): Opportunity cost per vehicle as it goes through the terminal (€/vehicle) (price charged by the terminal).

Finally, the objective to be achieved is to determine the optimal block layout that minimizes the operational cost of the terminal \((E[C_T(\beta)])\).

As an example (Figure 4) we proceed to determine the optimal shape parameter \((\beta^*)\). Here we take into account the following parameters obtained from the terminals of vehicles operating in the Port of Barcelona: \(C_F = 7€/m^2\), \(C_V = 1€/vehicle\), \(C_R = 5€/movement\), \(P=10€\) and for the next demand (rotation): \(\rho = 20\) and 80 uses per year.
In Figure 4 it can be observed that when increasing the rotation ($\rho$), the labor costs increase, in respect of rehandling, also increases the variable part of the concession fee when raising productivity and ultimately the opportunity cost. In the considered cases, for practical purposes, the following parameters can be accepted as optimal values: $\beta=4.2$, $\beta=6.0$ y $\beta=9.4$. Also, since $\rho$, reduction of labor cost with $\beta$ is lower as $\beta$ increases (increases proportionally to the square of number of vehicles per row), while the increase of opportunity cost is linear with $\beta$.

Moreover, since the cost components that have more sensitivity in the total count are the labor cost and the opportunity cost associated with each layout, we proceed to analyze the adequacy of each layout for different combinations of the following unit costs, $C_R$ and $P$. For this analysis the following parameters will be assumed: $C_R=5€/m^2$, $C_V=1€/vehicle$ and $\rho = 20 and 80$, taking into account the explicit characteristics in Table 2 (see Figure 5).
The results shown in Figure 5 lead to the following considerations:

- When the unit cost of opportunity ($P$) is low, independent of the demand of the terminal, the optimal block layout is to have two vehicles per row ($\beta = 37.5$). In this case, operating costs of rehandling are null and opportunity costs associated with the capacity difference is negligible due to its low unit cost.

- As the unit cost of opportunity ($P$) increases, layouts with more than two vehicles per row become more favorable. This trend is observed in Figure 5(a), when the rehandling cost increases ($C_R$), the parameter decreases until it reaches its minimum value ($\beta = 1.5$). Therefore, when both unit costs are raised, it is advisable to design blocks that maximize the use of the storage area (to maximize the capacity of the terminal). In the present case, there has been 34% of capacity increase (with $\beta = 1.5$ in regard to $\beta = 37.5$).

- Finally, when terminal demand increases, and therefore there is greater rotation of slots of the storage area, the use of blocks of storage is still recommended to ensure the maximum terminal capacity ($\beta=1.5$). The highest revenues of the terminal by being able to move more vehicles outweigh handling costs (which increase with $\rho$).

The results of this section suggest that it is not necessary to heavily invest in the increase of the storage area in order to increase the terminal capacity, whether when storing in extension or vertically. Depending on the potential demand, average staying time of vehicles and operational costs, it is possible to design and configure the storage area characterized by the parameter $\beta$, so that the productivity of the terminal increases.

In certain situations it will be optimal to choose block layouts involving an additional cost for rehandles ($\beta <37.5$), but the increase cost mentioned is compensated by revenues derived from the increase of the storage productivity.

However, in many cases to save the compliance of quality and safety requirements set by vehicle manufacturers to minimize the risk of vehicle damage, there are currently two types of solutions: expansion of the terminal storage area (when that option exists and the cost of land is low) or building vertical storage (when no option to expand and/or the land cost is expensive). The latter has been used at various terminals in Europe, for example, Port of Barcelona (Spain) or Southampton (UK), among others.
Nevertheless, a third option is also plausible, that is through reconfiguration of the storage area. It is, ultimately, choosing a block layout that fits the operating characteristics of the terminal and that is most compatible for the trade-off between rehandling cost and productivity of the yard.

6 CONCLUSIONS

This paper addressed the problem faced by terminal operators in organizing the storage yard of port terminals where import vehicles will be stored temporarily. An analytical model was developed to quantify the expected rehandles that result from storing more than two import vehicles per line. Moreover, storage density was considered as a criterion to evaluate storage layouts.

It has been demonstrated that there exists a trade-off between the rehandles and the storage density, that is, when the number of vehicles per row increases, the expected number of rehandles moves increases and storage density per vehicle decreases. In order to find this trade-off, the cost analysis was provided. Total cost function includes labor costs, port fees (fixed and variable) and opportunity costs regarding the layout which maximizes terminal capacity.

This paper has explored the way to increase the capacity of port terminals which handles a large amount of import vehicles by reorganizing storage yard. This option involves an increase of operational cost and some risk situations regarding quality and security of vehicles. However, large investments will not be required.

The results have shown that when labor and opportunity costs are high, the trend is to use a block layout which shape parameter \( \beta \) value is close to unity.

The model developed here was based on expected values, so total cost is an expected value too. A particularly interesting line of further research could be the inclusion of risk cost analysis, especially regarding labor cost associated to rehandling moves.
REFERENCES


