Maximizing Storage Density of Steel Pipes: Optimization Modeling

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Abstract

With increased development, expansion and urbanization in recent decades, the steel pipe industry is growing rapidly and is projected to increase its market value within the coming years. As companies increase their production, pipe storage has become a pain point in accommodating the production increase. This project presents a Mixed Integer Programming (MIP) model for maximizing the storage density of steel pipes. The solution to the model maximizes the number of pallets stored, assigns them to bands of specified width within a storage yard, and consequently minimizes the space occupied. The effectiveness of the solution will be evaluated against the current state with the percentage of space utilization as the key performance metric.

Background

The consistent increase in demand of steel pipes over the past decades, in conjunction with the limited storage capacity, were the motivations for investigating the storage optimization problem for steel pipes. Collaborating and motivated by a leading manufacturer of steel pipes in the United States, this study proposed a Mixed Integer Programming (MIP) model for maximizing the storage density of steel pipes within a given storage yard. During the development of the optimization model, various factors were accounted for, such as product dimensions, supply requirements per SKU and space tolerances. A few assumptions were needed to be made in this study, which included 1) the storage yard is vacant land with no storage racks or specific configurations; 2) the pipes with identical dimensions (outer diameter and length) need to be stacked together, however there is no dedicated storage space for each combination of outer diameter and length (i.e. SKU). This implies the storage policy is shared and does not follow a dedicated policy, helping maximize space utilization at the cost of increased travel distance. In practice, when retrieval is needed, a warehouse management system would provide the exact location needed to be picked based on geographic location and scanning of barcode labels unique to each SKU. A case study at the aforementioned company allowed the use of real size storage parameters and is an ongoing study in order to compare the performance of the model with the current practice.

Mathematical Model

A mathematical model was proposed for storing a number of pipes stacked in pallets in a warehouse lot. Pipes are currently stacked in the storage yard as shown in Figure 1. The assumption was first made that the storage lot is rectangular, and divide it into several equally sized strips (or bands), label them with numbers (1 to S), and try to store the pipe racks starting from one corner and filling the strips individually until allocation is complete (Figure 2). The width of each strip is calculated based on the width of the pipe pallets and accounting for the necessary lateral clearances on both side of the rack, which are meant for forklift maneuvering and accessibility.

The objective function of the mathematical model favors pipe allocation to smaller strip labels of strips, resulting in storing to be concentrated in one side of the lot and filling the strips as much as possible. The unused spaced (unallocated adjacent strips) on the opposite side will have a rectangular shape with a maximal area, which is ideal for future utilization in comparison to the utilization of random racks storage or using FIFO.

The variables and parameters of the model are defined as follows:

$x_{i,j,k}$ number of pipe batches of length type i (=1, 2, …, L) and diameter type j (=1, 2, …, D) stored in strip k (=1, 2, …, S)

$z_{i,j,k}$ $\begin{cases} 1 & \text{if the pipe of length type } i \text{ and diameter type } j \text{ is stored on strip } k \\ 0 & \text{otherwise} \end{cases}$

L number of different lengths of pipes

D number of different outer diameters of pipes

S total number of strips, equal to the quotient $\left\lfloor \dfrac{\text{Length of the lot}}{\text{Width of the pallet + (5+5) feet side clearance}} \right\rfloor$

l_i lengths (in feet) of pipes of length type i type

W width of the storage lot

q_{ij} quantity of pipes of type i, j in one batch

s_{ij} number of pipes of type i, j needed to be stored

$$\begin{aligned}\text{Minimize}\quad & z_{1,1,1} + z_{1,2,1} + \ldots + z_{1,D,1} + z_{2,1,1} + z_{2,2,1} + \ldots + z_{2,D,1} + \ldots + z_{L,D,1} + \\ & 2z_{1,1,2} + 2z_{1,2,2} + \ldots + 2z_{1,D,2} + 2z_{2,1,2} + 2z_{2,2,2} + \ldots + 2z_{2,D,2} + \ldots + 2z_{L,D,2} + \ldots + \\ & Sz_{1,1,S} + Sz_{1,2,S} + \ldots + Sz_{1,D,S} + Sz_{2,1,S} + Sz_{2,2,S} + \ldots + Sz_{2,D,S} + \ldots + Sz_{L,D,S}\end{aligned}$$

Figure 1: Stacking of pipes in the storage yard

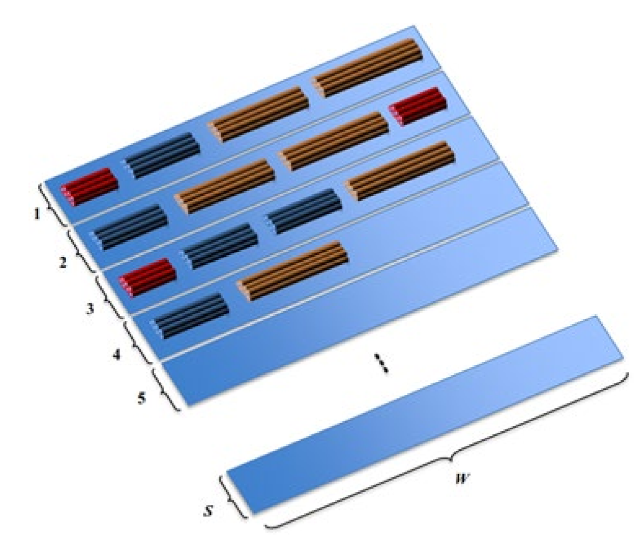

Figure 2: Schematic illustration of the way the pipes are stored in the storage yard. The lot is divided into S strips with equal widths, which incorporates the necessary aisle clearance for forklifts.

The intent of the objective function, shown above, is to minimize the sum of strip numbers selected for storing the pipe racks, which leads to less utilization of the storage lot. There were a total of four constraint groups. The first constraint group represents width constraint, meaning the overall length of stored pipes in each strip can't exceed the width of the strips (or the lot). The second represents storage constraint, in which the total number of stored pipes of a certain diameter and length is greater than or equal to its produced amount. The third constraints group forces that if a certain pipe for type i,j is chosen to be stored at a specific strip k (happens when $z_{i,j,k}$ = 1), then the corresponding variable $x_{i,j,k}$ should be at least equal to 1 and at most the maximum number of pipe racks of type i,j. Finally, the last constraint defines the type of decision variables (general integers and binary integers).

Model Solution & Analysis

The stated Mixed Integer Programming (MIP) model belongs to the NP-hard class of problems, which means the solution space grows exponentially with the increase of the number of variables. The accuracy can be verified using a small-size problem described as follows:

We assume there is an 11 yard by 24 yard lot, and there are numerous lumbers to be stored on the lot in consecutive rows and in a single layer (they are not stored at height). The widths of lumbers are equal to 1 yard and an additional yard of aisle clearance is needed between rows (two half-yard clearances for each for of lumber on both sides). As a result, each strip would have a width of 2 yards and the length of the lot (24 yards), which will be divided into S= 12 strips of 2 yard width. The width of the lot is W= 11 yards . The lumbers come at four different lengths of 1, 2, 3 and 4 yards, and the supply of each lumber type is 7, 11, 9, and 8, respectively.

For simplicity sake, the i and j indices in the model are combined into one index, as we do not have different types of a certain lumber size. The decision variables will then be $x_{1,k}$, $x_{2,k}$, $x_{3,k}$, and $x_{4,k}$, representing respectively the number of lumbers of lengths 1, 2, 3, 4 yards allocated to strip k, and their respective binary variables $z_{1,k}$, $z_{2,k}$, $z_{3,k}$, and $z_{4,k}$ indicate whether or not a lumber of length i is allocated to strip k. Also, $q_1 = q_2 = q_3 = q_4 = 1$, which means the lumbers are not put on top each other, and the supply parameters are $s_1 = 6$, $s_2 = 11$, $s_3 = 10$, and $s_4 = 8$.

The model was coded and solved in the Lindo™ software. A graphical illustration of the obtained solution is depicted in Figure 3, which shows that the model preferred to stack the lumbers mostly in strips with lower numbers and left the last three strips unused, opposed to a suboptimal allocation which utilizes the lot improperly.

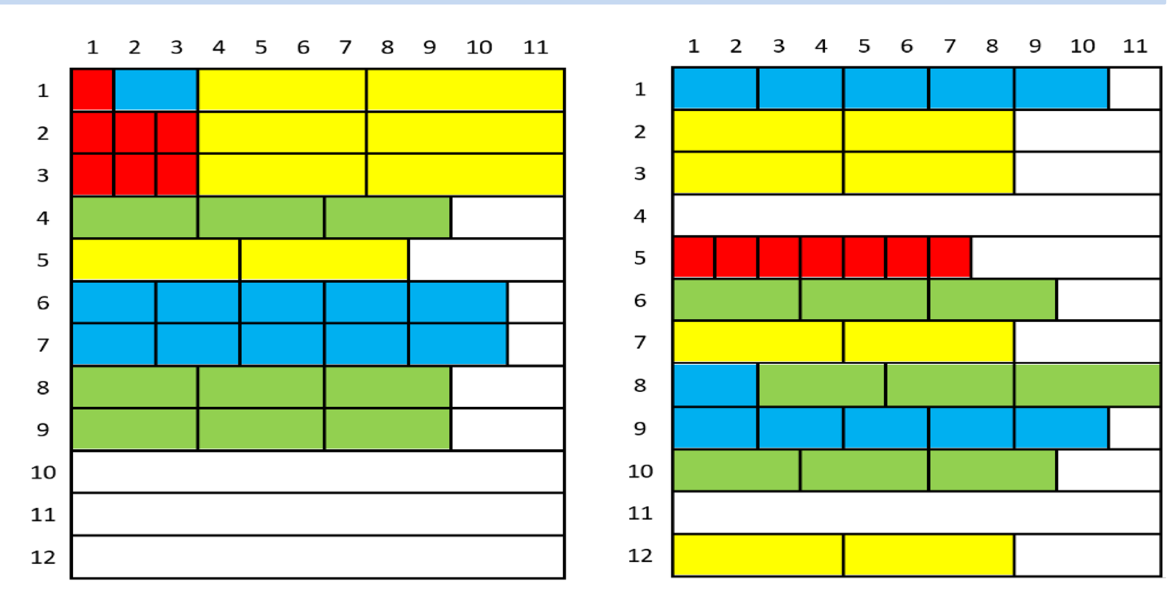

Figure 3: (a) Lindo output solution of the MIP model; (b) A suboptimal solution that utilizes the lot improperly. The red, blue, green and yellow colors represent lumbers of length 1, 2, 3 and 4 yards, respectively.

Conclusion

The increase in warehousing costs has drawn attention to storage optimization as a possible solution to alleviate some of the challenges tied with meeting increasing demand. This project proposed and MIP model to optimize space utilization of a storage yard for storing steel pipes. The two key characteristics of steel pipes are their length and outer diameter. The pipes are normally stacked on top of each other under certain height and width requirements. The model assumes that the yard can be divided into an equal number of strips (or bands) with no cross aisles. The objective function seeks to minimize the total area occupied for storing the pipes.

For future optimization, pick time could be considered to account for travel time and operational cost. The Travelling Salesman Problem (TSP) could be used as a basis for optimizing the route that a single resource would take on a multi-pick mission, reducing travel time through a non-greedy algorithmic approach. Other considerations for performing this type of analysis include the number of resources in the yard, movement rates and more. Furthermore, the optimal layout would need to consider the benefit of adding cross-aisle lanes through which resources can travel. Although this strategy would reduce available space for storage, it increases the ability to minimize travel time.