Enhancing the storage capacity by utilizing vertical space using mezzanine flooring in a small-scale industry

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Abstract. Storage is an important aspect of every business, thus every company needs to make maximum utilization of their space. However certain industries do not possess the capability to accommodate sufficient materials for production due to certain constraints. The objective of this study is to propose a suitable storage solution for a small-scale industry, while taking into consideration all these constraints. In the present study it was observed that there was abundant vertical space available which was not being utilized effectively. In order to efficiently utilize the same, various vertical storage solution models were evaluated on selected criteria. Based on the evaluation, mezzanine was found to be the most convenient and feasible solution. A design of mezzanine was proposed working within monetary and space constraints. This model produced additional space which caters to the industry’s needs, hence resolving the storage concerns of the industry.

Keywords: Small-scale industry; Storage; Material handling; Vertical storage modules; Mezzanine.

1. Introduction
In the present study, the company produces foam packaging for various hardware commodities. They provide high quality solutions capable of arranging tools of all sizes and shapes starting from hand tools to large power tools. The company utilizes two types of foam: soft and hard foam, of varying thickness depending on the product. The company was experiencing a steep increase in demand. Due to this increase in demand, the company had to store a large amount of material. Therefore, there was a requirement for additional storage space. It was observed that there was abundant vertical space available in the factory which was not being utilized effectively.

Furniture handling equipment was operated on the floor of the structure in the warehouse access aisles between the storage racks. Customer access to showroom enclosures was provided with the help of mezzanine. By physically segregating them on the mezzanine floor, the safety of the customers was ensured. An integrated building facility which occupies less cubic space of land and can be rapidly and economically erected, using reduced number of highly skilled labor was created. It provided a safer facility that allows the use of conventionally constructed stacker cranes instead of more expensive
cranes. Above all the principle objective of this invention was found to be providing an improved combination warehouse-retail sales storage facility [1].

A mezzanine floor panel having properties such as high durability, water resistance, ease of cleaning and non-skid characteristics was designed. Structural integrity of the floor was improved without significantly increasing costs, installation steps or difficulties and without causing environmental concerns. A homogenous high density, phenolic resin particle board, which produces a finished panel with various advantages, was proposed. Due to the durability of the treated surface, the panels could be held to the corrugated layer with good screws. The mezzanine floor was not susceptible to flaking or delamination either. The construction of the panel involved phenolic resins, and therefore, formaldehyde emissions were well within regulatory standards [2].

A modularly constructed storage structure with mezzanine access was designed. The storage structure provided base cabinets and upper storage cabinets by arranging a row of storage cabinets stacked on top of each other. The storage cabinets had an internal supporting structural frame work which included vertical front and back beams and horizontal side beams with the frameworks of the stacked cabinets interconnected, and the vertical back beams of the base cabinets were also secured to an underlying supporting floor. The mezzanine structure was attached to the cabinet structure with a number of spaced horizontally aligned cantilever beams of a known length which penetrate the storage structure and are individually connected directly or indirectly to front and back vertical beams of the cabinet structure. The cantilever beams have overhang ends which extend beyond the front face of the cabinet structure to support the cantilever following that of a mezzanine deck. As the mezzanine structure was entirely supported in cantilever fashion, no other vertical supports were required. It was suggested that if desired, a stairway may be attached [3].

A Vertical Carousel (VC) or a Vertical Lift Module (VLM) fall under the category of storage or retrieval systems. They consist of LED’s or any similar light emitting source incorporated into their body in proximity to access point location. An improved indicator position system used for storing and retrieving items in both VLMs and VCs was proposed. All the issues faced with prior art electronic indicator systems were overcome in a very simple and cost-effective manner. Array of lights can be configured according to the usage requirements of a storage system. Multiple operator workstations access to the same set of trays and compartments was possible, hence utilizing the same travelling light pipes associated with each of the trays. This also minimized machine movement requirements [4].

Effective space utilization in industrial design is of paramount importance considering the high growth rate of land value in India. An efficient system to transfer the material from lower level to higher level was designed. Static analysis was carried out on the most critical component, the crank, using relevant software [5]. Simulation analysis of an automated single-tray Vertical Lift Module (VLM) was done. The benefits of a single-tray VLM system were investigated in terms of decreasing transactions’ mean cycle time, hence resulting in better throughput of the entire system. The performance of the VLM was analyzed with respect to alternative design configurations and velocity profiles. It was concluded that the throughput performance of the VLM depends on the small heights and better velocity profile of the lift [6].

An investigation regarding the problem of the determination of the space requirements for warehouse systems operating under a dedicated storage policy, full turnover-based storage was performed. The results obtained using the optimization approach can be used for determining bounds [7]. Backtracking of material flow and transportation waste were identified as non value added activities. The CORELAP algorithm was used to increase process cycle efficiency and productivity and to reduce manufacturing lead time [8]. Study of application of inventory management system in construction industries was conducted and the benefits were discussed [9].

A preliminary study concerning a particular automated parts-to-picker, small objects picking system, called Vertical Lift Module (VLM) was done. Simulation based analysis was done to solve the problem [10]. Linear integer programming technique was used to optimize the space utilization of storage rack in garment industry and significant volume savings was achieved [11]. Vertical lift
modules can be used for storage purposes in industrial warehouse as the enclosed system with two columns of trays make it easier to retrieve the stored material. Efficiency of order picking increases due to the performance of the VLM [12].

A frequently used but comparatively expensive method of storage that is used in industrial warehouses is automated storage and retrieval system which helps in handling the material in a systematic method. It consists of a floor rack, an operator a transport conveyor and free fall movement of materials [13]. Material handling helps in increasing the production rate due to easy flow of goods and accessibility from their storage space. A few benefits of material handling can be protection of material goods and products and distribution and consumption of the same [14].

The literature review threw light on the advantages of using mezzanine flooring to improve storage efficiency. Facilities planning and material handling play important roles in enhancing the overall efficiency of a factory [15,16]. Hence, to solve the issues related to storage it was decided to design and implement mezzanine flooring.

2. Methodology
The objective of this study is to propose a suitable storage solution for a small-scale industry, while taking into consideration all the real time constraints which include availability of space, monetary constraints and work environment. The initial stages of the study included identification of the problem faced by the industry and collection of appropriate data including the layout of the industry and the relevant measurements. All the data was then carefully analyzed and studied to identify the most feasible method of tackling the issue.

It was clear that the main obstacle faced by the industry was that of lack of storage space, and that there existed a large amount of unused vertical storage space. In order to efficiently make use of the same, various vertical storage solution models were evaluated on selected criteria. The most feasible solution among these was chosen and a model was designed followed by certain volume calculations which proved that the proposed model successfully generated large amount of additional storage space in the existing environment. Figure 1 represents the methodology followed in the study.

![Figure 1. Research methodology](image-url)
3. Factory layout analysis

The company where the work was carried out was experiencing an increased demand for foam packaging and thus, required additional storage space for the accommodation of foams for large orders. The lack of storage space had inhibited the possibility of bulk orders, requiring the placement of more frequent orders and as a result, more labor hours to process. Figure 2 shows the current plant layout.

The company has a total area of 4800 square feet which was not sufficient enough to store the required quantity of raw materials for the existing demand. The company is surrounded by occupied sheds which restricts any sort of expansion.

![Diagram of Plant Layout](image)

**Figure 2. Present plant layout**

However, there was vertical space of about 15 feet, which was not being utilized. With increased storage space, the company could place bulk orders and reduce the number of times orders are being placed and hence save time which would be unnecessarily lost due to loading and unloading of the foam boards which would require extra labor hours. As the company was relatively new, large investments on storage was not feasible, thus an economical and convenient solution had to be provided. Since, there was abundant unutilized vertical space available, vertical storage solutions seemed to be the ideal solution, and various vertical storage systems were considered and evaluated.

4. Evaluation of models

There are number of vertical storage models available and are commonly used in most of the industries. A study of such systems was made and the same is presented here. For the purpose of maximum utilization of the vertical space available in the industry, four different vertical storage systems were selected for consideration.
4.1. Industrial Pallet Racking System
Industrial pallet racking systems are material handling storage devices designed to store materials on forklift accessible pallets. They are ideal for warehouses with large palletized goods, high goods movement and rotation. The system is built using upright frames connected with horizontal beams to provide levels for unit load storage and can be adjusted vertically. This system has a rather large load bearing capacity and thus, is suitable for storing heavyweight products. The products to be stored are mounted on pallets and stored within these frames. These pallets are forklift accessible and provide a large amount of vertical storage while simultaneously being a cheap alternative to traditional storage systems.

Investing in industrial pallet racking systems would also include an investment in a large amount of pallets on which the products are placed, a forklift that is capable of accessing these pallets and an operator to utilize it. Substantial inventory space must also be set aside in order to store pallets when not in use. The packaging company produces lightweight packaging foams, thus the load bearing capacity of the pallet racking system is ineffectual in this situation. The industry did not have sufficient floor space for the movement or storage of forklift; neither did it have the space for pallet inventory.

Although industrial pallet racking systems are cheap, the additional space required to house the forklift and pallets and the unavailability of floor space for forklift maneuver, are crucial disadvantages. Thus, industrial pallet racking systems was eliminated from consideration.

4.2. Vertical Lift Module
Vertical lift modules are automated storage devices that consist of two parallel columns that contain multiple numbered shelves or trays into which materials can be stored. It consists of an extractor, which upon entering the shelf or tray number, travels between the columns and retrieves the required tray. Their configuration makes order picking more efficient by reducing waiting times through rapid order tracking. They are ideal for warehouses with ceiling heights up to 100 feet, frequently variable inventories that consists of heavy items that require assistance in lifting and parts that are variable in weight and size [17].

Vertical lift modules are expensive pieces of equipment and have high installation costs. Since it is anointed with software capability, operators will have to be trained on its usage which translates to high training costs, and the addition of maintenance workers supplements the initial cost. Vertical lift modules may also need frequent reconfigurations depending upon the peak throughput required at the time (throughput is the maximum number of items passing through a system). They are automated machines, therefore reconfiguration is difficult compared to traditional shelving systems and as a result, higher maintenance costs are associated with it.

They are highly expensive pieces of equipment due to it being an automated programmable machine. The addition of maintenance and training costs to the initial cost of the VLM makes it the most expensive option out of the four storage systems under consideration. The industry has a height of 15 feet, and does not require the proficiency of a VLM. Since the company makes use of only two types of foam, it negates the VLM’s advantage of increased productivity through rapid order tracking and reduced waiting times. Thus, the use of VLMs was not an economical storage solution and was eliminated from consideration.

4.3. Vertical Carousel
A vertical carousel is an automated material handling storage system that consists of a series of bins, trays or carriers that are joined together and mounted onto a continuous chain drive. It makes use of a motor that powers the bins or carriers in a vertical loop, around the track, in both forward and backward directions. They can be custom-built to the desired height of the available plant space.

Vertical carousels are ideal for warehouses with ceiling heights under 25 feet, where the stored parts have identical dimensions and items that can be hand-picked without lift assistance. Considering the height of the industry, vertical carousels are highly appropriate and since the foams being used are
lightweight, they can easily accommodate the materials for storage. Their minimal use of floor space and reducing the amount of floor space used for storage by 80% makes it an ideal solution. Vertical carousels, similar to VLMs are implemented for their throughput rate. They are also used for tracking the material in order to significantly increase the efficiency and productivity of the warehouse by making the material easier to locate [18].

They are programmable automated machines, which are highly expensive pieces of equipment. They have high training, maintenance and reconfiguration costs associated with them considering their software capability. Since the company makes use of only two types of foam, it negates the advantage of order tracking and reduced waiting times. Although vertical carousels are more appropriate to use considering the ceiling height they possess the same disadvantages of the VLM. Thus, they were not considered for implementation in the current problem.

4.4. Mezzanine
Mezzanines are storage systems that provide an intermediate floor in a warehouse that does not necessarily cover the floor space of a warehouse. They are particularly useful to businesses that have open warehouses with high ceilings, providing a way to utilize space by adding additional floor levels for more work and storage space. Their main advantage involves the utilization of unused space above the facility floor for storage of inventory or other uses. They are highly customizable, efficient, quick to install and profitable, maximizing the use of a building’s space while creating a distinct separation between two spaces. This optimizes space to a maximum for the least cost. A mezzanine is modular, scalable and mobile, which means it can be transformed as desired according to changes in the industry, re-sold and even be moved into other warehouses if necessary.

**Table 1.** Comparison of vertical storage systems.

| Characteristic          | Pallet Racking System | Vertical Lift Module | Vertical Carousel | Mezzanine Floor |
|-------------------------|-----------------------|----------------------|-------------------|-----------------|
| Pallets Required        | Not Required          | Not Required         | Not Required      | Not Required    |
| Floor Space Required    | High                  | Medium               | Medium            | Low             |
| Forklift Required       | Not Required          | Not Required         | Not Required      | Not Required    |
| Training of Personnel   | Not Required          | Required             | Required          | Not Required    |
| Initial Cost Low        | High                  | High                 | High              | Medium          |
| Maintenance Cost Low    | High                  | High                 | High              | Low             |
| Reconfiguration Not Required | Required             | Required             | Not Required      |                |
| Warehouse Height Customizable | Up to 100 feet       | Up to 25 feet        | Customizable      |                |
| Load Capacity 1150 kg/pallet position | 1000 kg/tray       | 648 kg/carryer       | 300-1000 kg/m²   |
| Automated Semi-automated | Automated             | Automated            | Not Automated    |
| Storage Density High only when manually achieved | High and automatically achieved | High only when manually achieved | High when Manually achieved |
The cost of the mezzanine lies comfortably between the industrial pallet racking system on the lower end and the vertical carousels and VLMs on the higher end. This makes it ideal for the company as it is not a large investment of money on storage, and at the same time utilizes vertical space efficiently with high storage density. Since the company only uses two kinds of foams, it does not require the automation that vertical carousels and VLM’s provide as they can easily be sorted, identified, removed and moved to the production area manually. Their main disadvantage is that the ground floor work area’s configuration has to be reconsidered. A clearly defined plan has to be formulated in order to be able to install the right kind of mezzanine as per requirements. Thus there is no cost or time associated with training personnel, low maintenance cost, no requirement of pallet inventory or forklifts and occupies almost no amount of floor space (except for the supports).

With additional planning concerning the floor space, the disadvantage of the mezzanine can easily be ruled out. The amount of floor space made available by the mezzanine gives opportunity for new equipment. From table 1, it can be noted that mezzanine is the most appropriate storage system for the company and is therefore, the ideal optimum real time solution for the current situation.

5. Storage Analysis
Through the evaluation of the models it was found that using a mezzanine as the storage system would be an ideal solution. Considering the factory layout as shown in figure 2, we have two halves, of which the first half is completely covered by the mezzanine whereas the second half is partially covered. The area covered by the mezzanine is as shown in figure 3. The majority of workers in the industry that handle the material to and from the storage areas are Indian men, with the women performing inspection and quality related tasks. Thus, it was decided that the height of the mezzanine should be based on the average height of the men working in this factory, which is around 5 feet and 4.93 inches. This would cater to both the male and female employees since the average height of Indian women is around 5 feet. In order to accommodate employees that may have heights above the national average and the movement of material by operators, an allowance of 3 feet was considered. Therefore, the height from the floor to the mezzanine was fixed as 8.5 feet to make it ergonomically sound. For maximum utilization of space, it was decided that the mezzanine should cover the entirety of the floor space except in the second portion of the layout for ventilation and adequate lighting. Thus in the first portion, it spans over the entire length and breadth, that is 40 feet and 60 feet respectively as seen in figure 3 and figure 4, while in the second portion it spans over the entire breadth, that is 60 feet, and lengthwise only till the opening, which was measured as 18 feet, as seen in figure 3 and figure 5. The software that was used to make the final layout is Solid Edge V20.

5.1. Design of mezzanine
The primary area of the factory with mezzanine flooring is shown in figure 4. The mezzanine structure is composed of I-section beams and square box columns. These I-section beams are designed to support the mezzanine because of their ability to resist bending moments. The connection of beams or other supporting members are simplified by the design of this section as it has a neat and flat surface in two mutually perpendicular directions. This design provides easy access to operate the nuts and bolts for easy installation and modification. Hence, if any further expansion or modification needs to be done, it can be conveniently incorporated without causing major disturbance to the existing structure.

There is an opening provided with the dimensions 10 feet x 6 feet to access the goods stored on the mezzanine as shown in figure 4. The opening can be accessed by using portable stairs. The secondary area with the mezzanine flooring is as shown in figure 5. The structure of the secondary mezzanine flooring is similar to the primary mezzanine flooring and can be accessed using portable stairs. The secondary mezzanine flooring does not cover the entirety of the secondary area in order to not hinder the existing ventilation and due to the presence of the cabin shown in figure 2.
Figure 3. Area covered by Mezzanine

Figure 4. The primary area of the factory with mezzanine flooring
Figure 5. Secondary area with mezzanine flooring

Figure 6. Primary and secondary areas with mezzanine flooring
Figure 6 shows the combined primary and secondary areas after erection of mezzanine flooring. The mezzanine floor caters to the enhanced storage requirements of the organization. Further calculations reveal that this solution has provided substantial space to store material to accommodate future requirements of the organization.

5.2. Calculations
Height from floor to mezzanine = 8.5 feet
Height from mezzanine to roof = 6.5 feet
Dimensions of mezzanine = 60 feet x 18 feet and 60 feet x 40 feet
Referring to figure 2 and figure 3, we get the dimensions of the length and breadth. The height from floor to roof is 15 feet.

Initial storage volume = length x breadth x height
\[ = \left( (60 - 6.5 - 7.75 - 4.15) \times 15.34 \right) \times 15 \]
\[ = 9572.16 \text{ cubic feet} \]

Referring to figure 4 and figure 5, we get the dimensions of mezzanine. We subtract the volume of the opening to get the volume of the mezzanine. The height from mezzanine to roof is 6.5 feet.

Final storage volume = initial volume + volume achieved by mezzanine
\[ = 9572.16 + \left[ (60 \times 40) + (60 \times 18) - (6 \times 10) \right] \times 6.5 \]
\[ = 31802.16 \text{ cubic feet} \]

When we subtract the initial storage volume from the final storage volume, we obtain the additional storage volume.

Additional Storage Volume = Final Storage Volume – Initial Storage Volume
\[ = 31802.16 - 9572.16 \]
\[ = 22230 \text{ cubic feet} \]

\[ \% \text{ Additional Storage Volume} = \left( \frac{\text{Final Storage Volume} - \text{Initial Storage Volume}}{\text{Initial Storage Volume}} \right) \times 100 \]
\[ = \left( \frac{31802.16 - 9572.16}{9572.16} \right) \times 100 \]
\[ = \left( \frac{22230}{9572.16} \right) \times 100 \]
\[ = 232.13\% \]

The additional storage volume obtained was 22230 cubic feet hence, the available storage volume increased by 232%.

6. Conclusion
This study has substantiated that the implementation of the mezzanine flooring in the designated areas has considerably increased the amount of space available in the facility for the storage of foams. This additional storage area has freed up a good amount of floor space, as mezzanines do not occupy much
of the same. The only floor space being used by the designed mezzanine is for its supporting columns, which is significantly low. The newly available floor space can be used for storage or can be allotted for positioning new equipment. The mezzanine used is cost effective, has a high load capacity, does not require training of personnel or forklifts or pallet inventory and can be easily accessed by the workers through the opening or by the use of portable stairs. It can be reconfigured manually to allow for maximum storage density without any hassle. In a scenario where there are monetary constraints, unutilized vertical storage space and a need of additional floor space, designing a mezzanine has efficiently catered to all the needs and is an absolutely feasible solution.

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