enables the user to mathematically model an operation on a computer before physically implementing it. Statistical distributions of different parameters, such as arrival rates of trucks, profiles of orders, picking times, etc., provide the data to run the simulation. To be close to reality, time standards of basic elements are used to provide the time value as input for the simulation.

7. Comparing Present Standards Against Established Industry Standards. Finally, if the time standard has been determined for an operation, a manager can compare that standard with a predetermined time standard for a particular operation. The critical point to remember in comparing standards is that actual times may vary significantly depending upon factors which include the type of warehouse, the product handled, the physical environment, the frequency of operations, and the actual distance traveled during each operation. Nevertheless, standards do provide benchmarks to compare present productivity levels. **Figure 2.4** shows some samples of throughput standards in the warehouse compiled by the authors.

Time Standard Techniques

There are four techniques for developing time standards: through time study, from predetermined time standards, from work or activity sampling, or from historical data. **Figure 2.5** summarizes these techniques.

1. Time Study. This is the most widely used tool for developing standard times. Times are determined from actual stopwatch timing of an operation. A stopwatch time standard is estab-

Figure 2.5. Summary of Time Standard Techniques

Technique	Description	Recommended Application	Propensity for Methods Improvement	Worker Involvement	Skill Level Requirements	Accuracy
Time Study	Break down of tasks into small elements that can be readily timed	• Short, repetitive, highly variable tasks • Recommended for incentive wage programs	High	High	High	High
Predetermined Time Standards	Collection of ready-made time values without need for timing	• Short cycle, highly repetitive tasks • New operations • Good for labor estimates, alternative analysis • Third-party warehouse cost estimation	High	None	Medium	Medium to High
Work or Activity Sampling	Random observations of workers' busy and idle time	• Long cycle, highly variable tasks • Recommended for determination of idle time	Low	Low	Low	Low to Medium
Historical Data	Use of job records or productivity logs	• Long cycle, highly variable tasks • Accuracy for warehousing increases with radio frequency and WMS support	Low	None	Low	Low to Medium

Figure 3.33. Optimal Column Spacing Example (Perpendicular to Aisles)

Assumptions:

- Building columns are 12-inch square
- Reach truck works best in 8'-6" clear aisles (or 9' beam to beam)
- Back-to-back single deep pallet rack, including pallet overhang, is typically 8'-6" (or 8' beam to beam)
- The length of each center-to-center bay of racks is 17' (8'-6" + 8'-6")
- Optimal column spacing is 35' or 52' (in the direction perpendicular to the rack aisles):
    - (17'/bay x 2 bays) + 1' (for column clearance) = 35' column spacing
    - (17'/bay x 3 bays) + 1' (for column clearance) = 52' column spacing

Sample Layout:

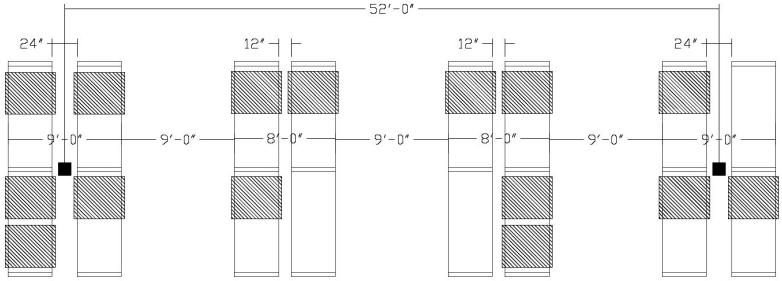


Figure 3.34. Optimal Column Spacing Example (Parallel to Aisles)

Facts:

- In the direction parallel to the rack rows, the column spacing is less critical
- The optimal column spacing is a number divisible by the centerline distance between rack sections

Example:

- 96"-long beams
- 3"-wide uprights
- The optimal column spacing in this direction must be a multiple of the total of these two distances. Since 96" + 3" equals 99", optimal column spacing includes 33'-0" (4 x 99"), 41'-3" (5 x 99"), and 49'-6" (6 x 99").

Sample Layout:

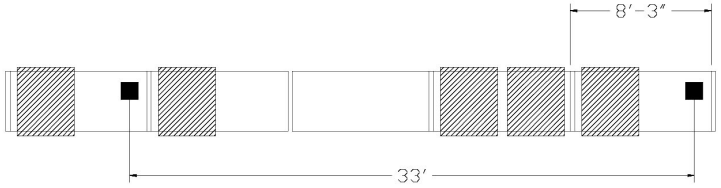
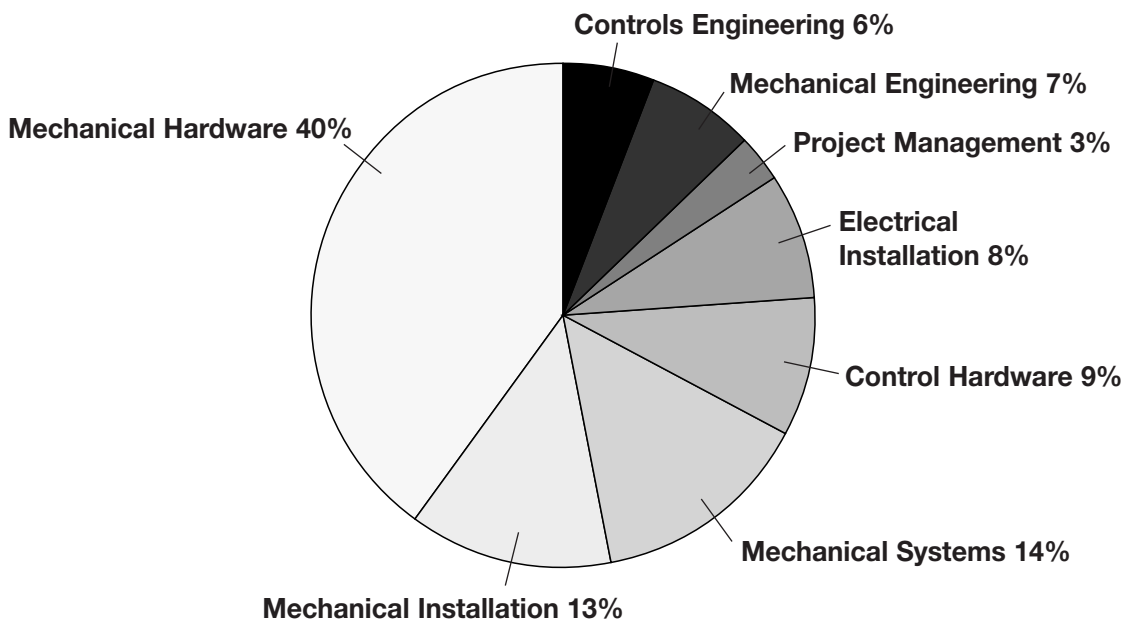


Figure 4.4. Conveyor Systems Project Cost Breakdown



Step 3. Identify Storage Equipment Costs. Costs of storage equipment can be obtained from manufacturers and industrial equipment suppliers. Quantity discounts are usually available on large installations. Used storage equipment in good condition can be considered in the bidding process, but only if it meets specifications. Getting seismic code approval for used rack can be difficult. **Figure 4.5** shows some typical cost estimates of new storage modules.

For pallet rack systems, the cost of materials differs between structural steel and roll-formed beams and uprights. In the past, roll-formed steel rack systems were less expensive than structural steel rack systems. The difference in prices has narrowed to as little as 10%. Structural steel racks are more likely to withstand impact and damage compared to roll-formed racks. When a roll-formed upright is struck, its load-carrying capacity is reduced. The load should be removed immediately and the damaged upright replaced. Additional pallet rack options will increase costs. Some of these options include safety bars, upright protectors, and decking.

Costs increase when shelving and flow racks are used to support mezzanines or used as part of a specialized system as in pick-to-light applications.

Step 4. Determine and Identify Other Special Costs. These are miscellaneous costs incurred in the start-up of a new or improved warehouse. They include the following:

Planning and Design Costs. These are estimated expenses incurred by the study and implementation team to assess, design, justify, and implement the new design. These include