Module – 2
Facility Location
Facility Layout
Capacity Planning

PART – I

- **Factors affecting Facility Planning at Global- Macro & Micro Level**
- **Methods for evaluating location based decisions**

PART – II

- **Basic Principles of Facility Layout**
- **Types of Layouts – Process, Product / Line, Fixed, Group / Cellular**
- **Concept of Line Balancing**
- **Concept of Assembly balancing**

PART – III

- **Measures of Capacity**
- **Capacity Planning Process (When, What, How)**
- **Capacity Expansion Strategies**
- **Service Operations & System Capacity**

(As per Syllabus of MBA (SCM), MBA(HRM) Semester – II)

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Part – I of III

Facility Location - Introduction

Facility Location is the right location for the manufacturing facility, it will have sufficient access to the customers, workers, transportation, etc. For commercial success, and competitive advantage following are the critical factors:

Overall objective of an organization is to satisfy and delight customers with its product and services. Therefore, for an organization it becomes important to have strategy formulated around its manufacturing unit. A manufacturing unit is the place where all inputs such as raw material, equipment, skilled labors, etc. come together and manufacture products for customers. One of the most critical factors determining the success of the manufacturing unit is the location.

Facility location determination is a business critical strategic decision. There are several factors, which determine the location of facility among them competition, cost and corresponding associated effects. Facility location is a scientific process utilizing various techniques.

Location Selection Factors

For a company which operates in a global environment; cost, available infrastructure, labor skill, government policies and environment are very important factors. A right location provides adequate access to customers, skilled labors, transportation, etc. A right location ensures success of the organization in current global competitive environment.

Industrialization

A geographic area becomes a focal point for various facility locations based on many factors, parameters and issues. These factors are can be divided into primary factors and secondary factors. A primary factor which leads to industrialization of a particular area for particular manufacturing of products is material, labor and presence of similar manufacturing facilities. Secondary factors are available of credit finance, communication infrastructure and insurance.

Errors in Location Selection

Facility location is critical for business continuity and success of the organization. So it is important to avoid mistakes while making selection for a location. Errors in selection can be divided into two broad categories behavioral and non-behavioral. Behavioral errors are decision made by executives of the company where personal factors are considered before success of location, for example, movement of personal establishment from hometown to new location facility. Non-behavioral errors include lack of proper investigative practice and analysis, ignoring critical factors and characteristics of the industry.

Location Strategy

The goal of an organization is customer delight for that it needs access to the customers at minimum possible cost. This is achieved by developing location strategy. Location strategy helps the company in determining product offering, market, demand forecast in different markets, best location to access customers and best manufacturing and service location.

Factors Influencing Facility Location

If the organization can configure the right location for the manufacturing facility, it will have sufficient access to the customers, workers, transportation, etc. For commercial success, and competitive advantage following are the critical factors:

Customer Proximity: Facility locations are selected closer to the customer as to reduce transportation cost and decrease time in reaching the customer.

Business Area: Presence of other similar manufacturing units around makes business area conducive for facility establishment.

Availability of Skill Labor: Education, experience and skill of available labor are another important, which determines facility location.
Free Trade Zone/Agreement: Free-trade zones promote the establishment of manufacturing facility by providing incentives in custom duties and levies. On another hand free trade agreement is among countries providing an incentive to establish business, in particular, country.
Suppliers: Continuous and quality supply of the raw materials is another critical factor in determining the location of manufacturing facility.
Environmental Policy: In current globalized world pollution, control is very important, therefore understanding of environmental policy for the facility location is another critical factor.

Levels of Facility Planning

Factory layout is the focal point of facility design. It dominates the thinking of most managers. But factory layout is only one of several detail levels. Facility planning is generally done at five levels:

- I Global (Site Location)
- II Supra (Site Planning)
- III Macro (Building Layout)
- IV Micro (Work-cell / Department Layout)
- V Sub-Micro (Workstation Design)

At the **Global level**, selecting a site location is done. This involves factors such as freight cost, labor cost, skill availability and site focus.

At the **Supra-Layout level** planning for the site is done. This includes number, size, and location of buildings. It includes infrastructure such as roads, water, gas and rail. This plan looks ahead to plant expansions and eventual site saturations.

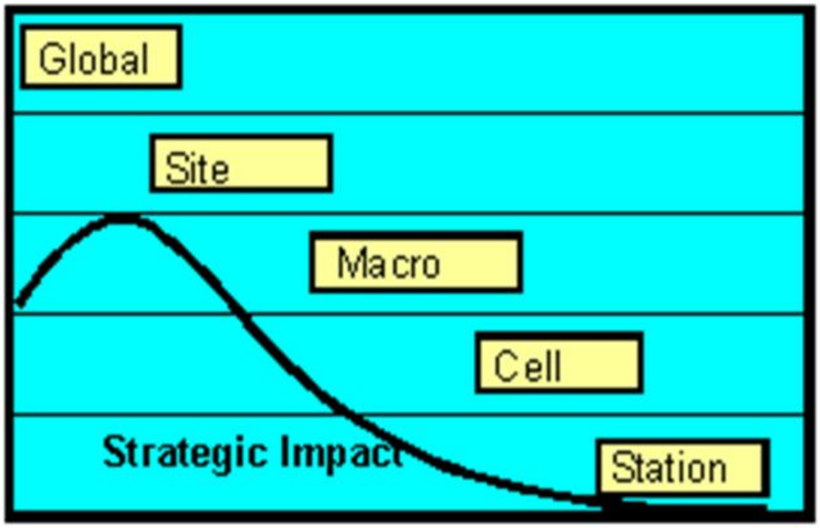
The **Macro-Layout** plans each building, structure or other sub-unit of the site. Operating departments are defined and located at this level. Frequently, this is the most important level of planning. A Macro-Layout institutionalizes the fundamental organizational structure in steel and concrete.

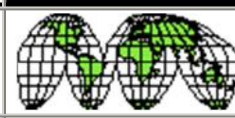
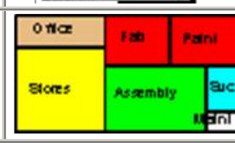
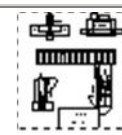
The **Micro Level** determines the location of specific equipment and furniture. The emphasis shifts from gross material flow to personal space and communication. Socio-Technical considerations dominate in this level.

The **Sub Micro Level** focuses on individual workers. Here design of workstations is done for efficiency, effectiveness and safety. Ergonomics is key feature for this level.

Ideally, the design progresses from Global to Sub-Micro in distinct, sequential phases. At the end of each phase, the design is "frozen" by consensus. This settles the more global issues first. It allows smooth progress without continually revisiting unresolved issues. It prevents detail from overwhelming the project.

In practice these phases may overlap significantly, be omitted or taken out of sequence.



Level	Activity	Space Planning Unit	Environment	Output
I Global	Site Location & Selection	Sites	World or Country	
II Supra	Site Planning	Buildings or Site Features	Site	
III Macro Layout	Building Department or Block Layout	Workcells or Departments	Building	
IV Micro Layout	Workcell of Department	Workstations or Workcell Features	Cells or Departments	
V Sub Micro Layout	Workstation Design	Tool & Fixture Locations	Workstation	

Site Planning – How to Plan for the Site for Long Term

Companies often occupy a site for decades and, occasionally, for centuries. During such time spans a firm may experience growth and significant changes in product and process. The future may be foggy but it will arrive and someone will have to cope with it.

A well thought out site plan accommodates such changes while maximizing the utilization of land, buildings and capital. Conversely, a site that develops piecemeal and from expediency hinders operations, increases cost and devours capital unnecessarily.

While it is impossible to see clearly decades into the future, it is surprising how much we can see and how well we can plan. The key is to develop plans that are flexible enough to take advantage of unforeseen opportunities and address unforeseen problems.

The site below provided many planning challenges. Among these challenges:

1) It faces a busy thoroughfare and needs a good image.
2) Residential areas to the North require consideration.
3) The land slopes significantly and a stream runs through it.

One might well criticize the original selection of this site. However, like many sites, it was a given and the designers had to work with it.

The site plan reflects an explicit Manufacturing Strategy. Some of the key points that affected site planning were:

1) Separate Strategic Business Units (SBU) for Foundry, Machine Shop, Spares and the two Assembly Operations.
2) A separate, small Corporate Headquarters.
3) Significant seasonal inventories for Implements.
4) Consideration for the image and needs of neighbors.

Master Site Plan Example

High Plains Implements

Vinyl-X Site Plan – A Case in Site Planning

The company in this case study manufactures a specialty product of vinyl plastic. The distribution system for this product was experiencing dramatic changes and the firm had established a prominent position. Their growth had averaged 17% annually for a number of years and future projections were for continued growth near this level.

The "Initial Site" shows one of their factories at the beginning of this facility planning project.

Each phase of expansion builds on the previous in a logical way that enhances material flow and, ultimately, maximizes utilization of the site.
This plan balances space between manufacturing, warehouse and administrative office areas.
Much of the space is built initially as low-cost warehouse. Some of this original warehouse space is later upgraded for manufacturing.

The plans below span a period of about twenty years and the original plans have been followed closely. A recent photograph is at bottom.

View from the Southwest after the Phase II expansion

Description	Color
Operational Building Space	Purple
Office Building	Brown
Outdoor Storage	Yellow
Car Parking & Roadway	Grey
Freight Parking & Roadway	Orange
Water	Blue
Plantings, Setbacks, Open Area	Green

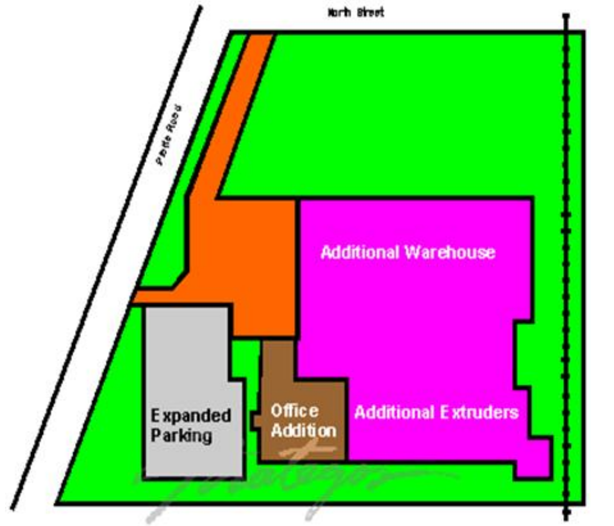
Site Plan Color Code

Satellite View of Vinyl-X Site
Final warehouse expansion is not yet in place. Expanded docks are at upper left.

Initial Site

This was the site at the beginning of the planning project. Extrusion occupied about half of the under-roof area. Resin arrives by rail on the East side and is stored in silos. Parking space was already short and many employees park on the grass.

Phase –I Expansion

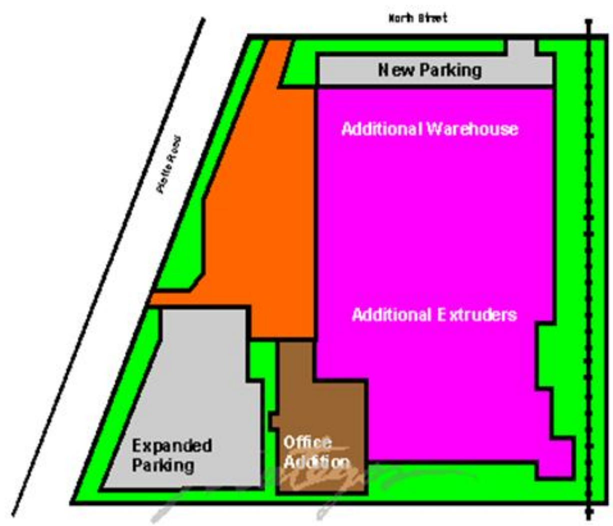


Expanding markets required additional office space and parking. Additional extrusion capacity came from upgrading existing extruders and two new extruders within the extrusion area. Significant additional warehouse space was required because of many new SKUs in addition to increased volume.

Phase –II Expansion

This expansion upgrades some warehouse space to extrusion space. Additional warehouse is added to the North side. Docks and truck maneuvering space was added in a way that provides for more warehousing later.

Site Saturation

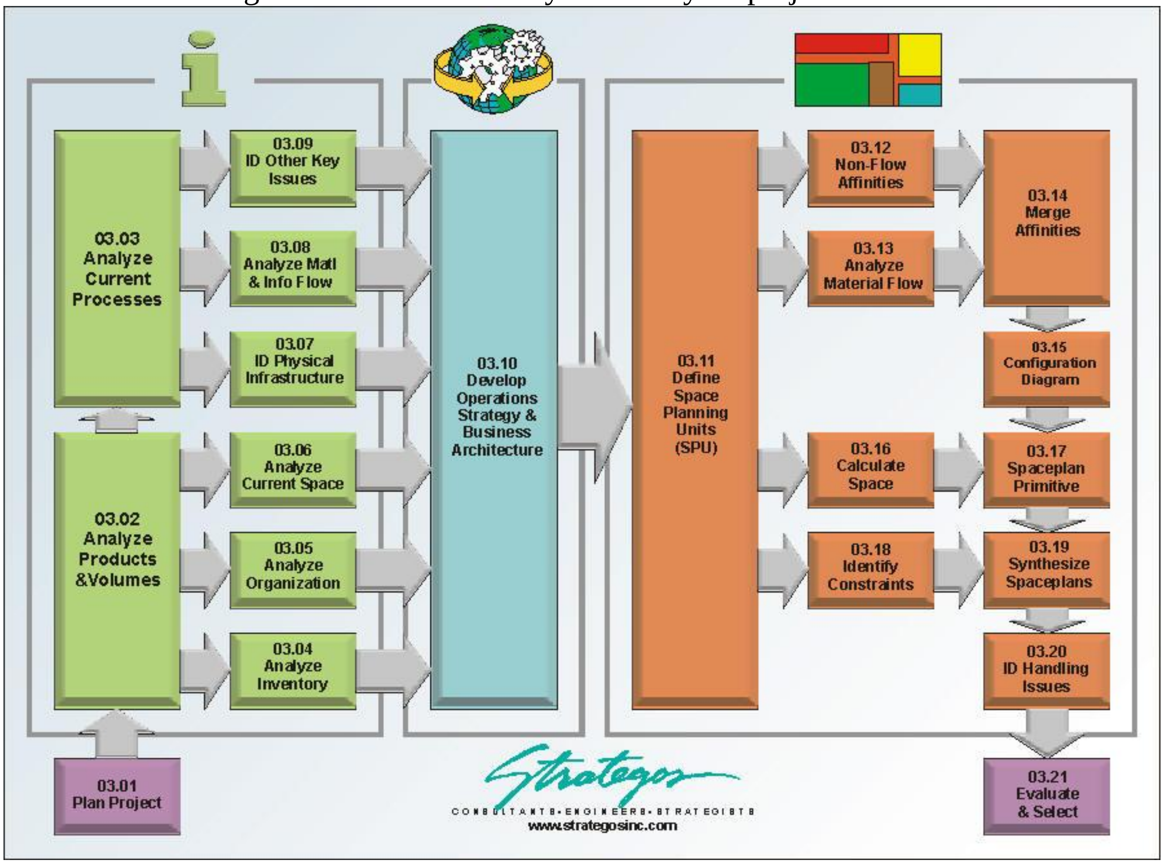


This final expansion uses all available space on the site (Site Saturation). It includes another office addition, more employee parking, more warehouse space and conversion of additional warehouse space to extrusion.

Macro Layouts – Implementing Manufacturing Strategy

The elements of factory layout are simple; the tasks required to develop them is not. These tasks and their sequence are remarkably similar for many projects. The scope, resources, methods, formality and time required varies according to size and complexity, but each task must be addressed in some way for good results.

For exemplifying the concept, the present methodology uses 25 standard tasks with modifications to suit particular projects. The figure below illustrates the tasks and their sequence. This is a "Model" for structuring the work in almost any macro-layout project.



The initial tasks (labeled "Information") plan the project and acquire basic information. These tasks also help to gain consensus and establish a factual basis for the layout. Process Mapping is an important tool here (explained after this section).

These initial tasks also begin the process of paradigm shift. The facts and information gathered and presented are often surprising. We use them to jolt the organization out of its complacency and tendency to "groupthink".

The second category ("Strategy") is only a single task. This is arguably the most important task but usually the most neglected. It determines the process and organization of the business. This is where management abandons the past and seriously re-thinks the manufacturing structure.

The third task group designs the spatial layout and associated systems. This is what most people consider as "Plant Layout". While this task group appears complex, it is actually straightforward--IF the previous task groups have been well done.

This procedure produces at least several viable layouts. Each layout has advantages and disadvantages. The final task evaluates the layout options and makes a selection.

The entire procedure can take as little as two weeks or as long as six months. The time depends on project complexity and the strategic orientation of management.

Process Mapping – How to Map (Chart) your Process

Process Mapping is also known as Process Charting or Flow Charting. It is one of the oldest, simplest and most valuable techniques for streamlining work. It is also subtle and requires experienced facilitators for best results. Some of the benefits of Process Charting (Mapping) are:

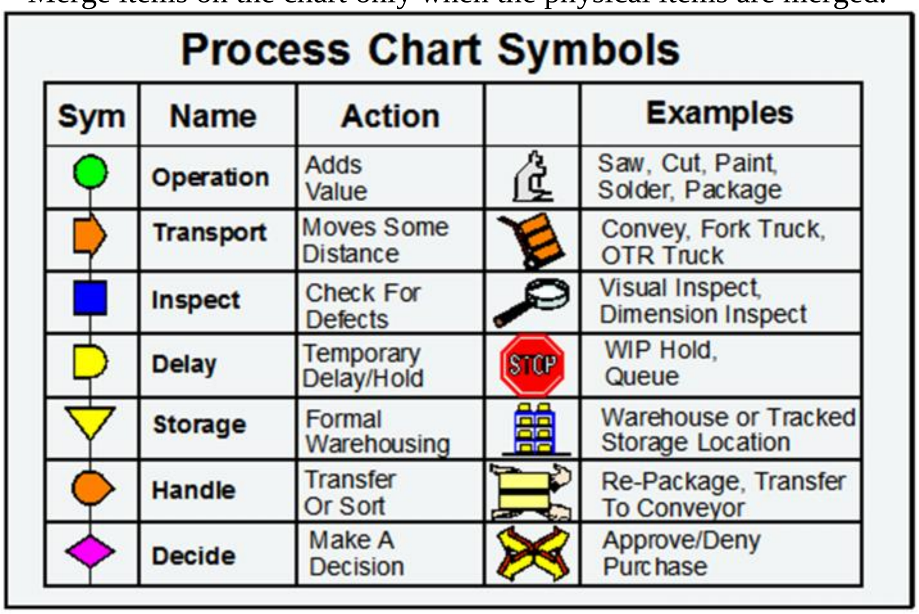
- Spotlights on waste
- Streamlines work processes
- Defines and standardizes
- Promotes deep understanding
- Builds consensus

A process map visually depicts the sequence of events to build a product or produce an outcome. It may include additional information such as cycle time, inventory, and equipment information. Several systems of conventions exist. This section explains the original system invented by Frank Gilbreth in the early 1900's is still the most useful.

The Gilbreth approach is highly visual and discriminates between waste and value-added activity. It is also simple, intuitive and easily used by untrained groups. An experienced facilitator, however, is required.

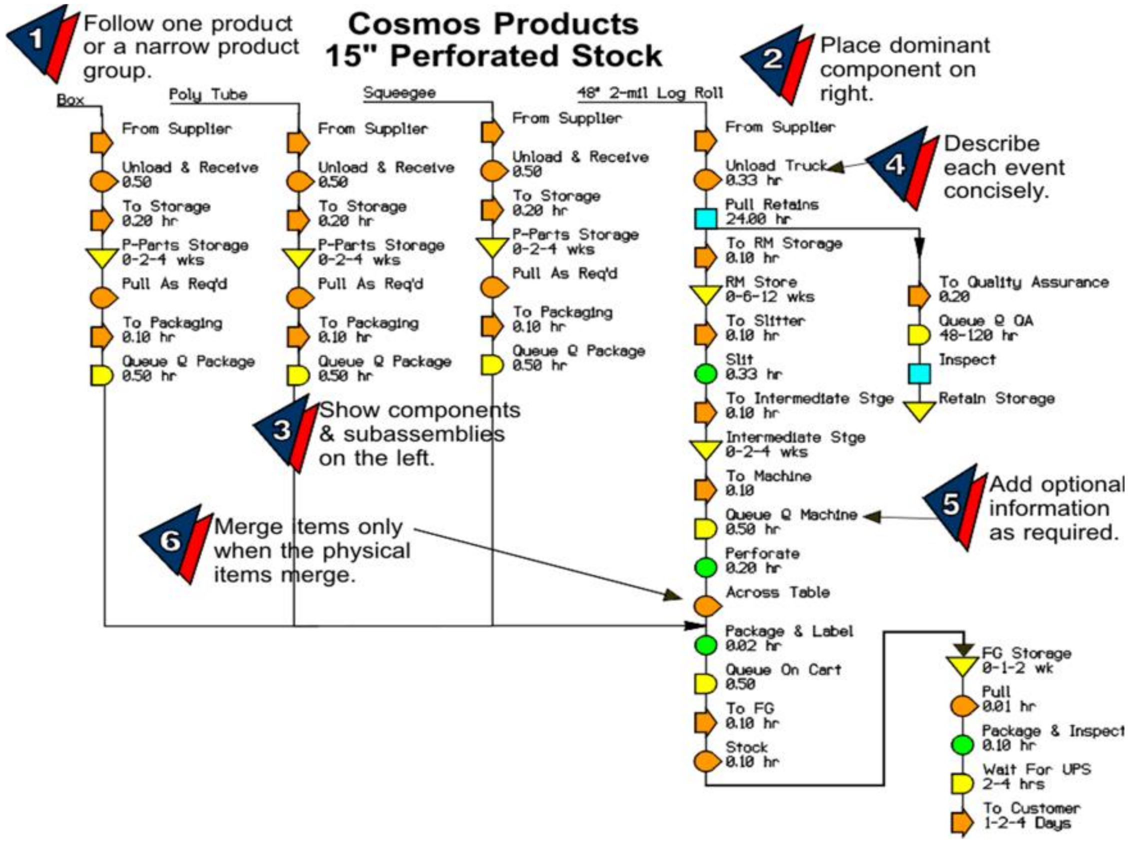
The figure below shows a Process Map example and instructions for its construction. In most situations only the circle symbol (Operation) adds value.

1. Follow one product or a narrow product group.
2. Place the dominant component on the right.
3. Show other components and subassemblies on the left.
4. Describe each event concisely.
5. Add additional information as required.
6. Merge items on the chart only when the physical items are merged.



Process Chart Symbols

Sym	Name	Action		Examples
	Operation	Adds Value		Saw, Cut, Paint, Solder, Package
	Transport	Moves Some Distance		Convey, Fork Truck, OTR Truck
	Inspect	Check For Defects		Visual Inspect, Dimension Inspect
	Delay	Temporary Delay/Hold	STOP	WIP Hold, Queue
	Storage	Formal Warehousing		Warehouse or Tracked Storage Location
	Handle	Transfer Or Sort		Re-Package, Transfer To Conveyor
	Decide	Make A Decision		Approve/Deny Purchase



General Hints

Identify The Product

Process maps and charts show the sequence of events that act on a product. Therefore, we must carefully identify the product and ask "What is being done to the product."

In manufacturing processes, the product is physical and easily identified. For service and office processes it is easy to confuse activity with the product.

Information Flows

A common criticism of Process Mapping is that it does not represent information flows. And, many Process Maps do not show information flows, but they *can* show them and often should.

To map information, consider it as packet such as a work order or a database record. Or, a component necessary to complete the event. Chart information sequence with dashed lines.

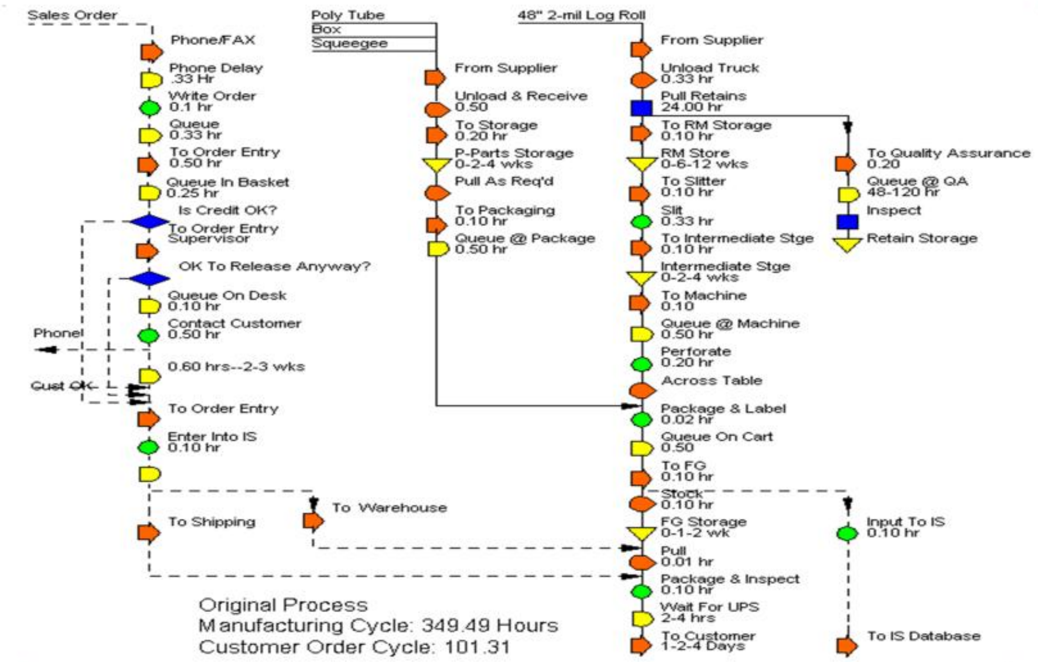
Example: Charting for Information and Intangible Products (Mapping both Materials and Information)

In this example, information processes in sales caused many order delays. These information sequences show as dashed lines on the left side of the map. The final product is a roll of automotive pin-striping tape. It starts as a large roll of vinyl sheet

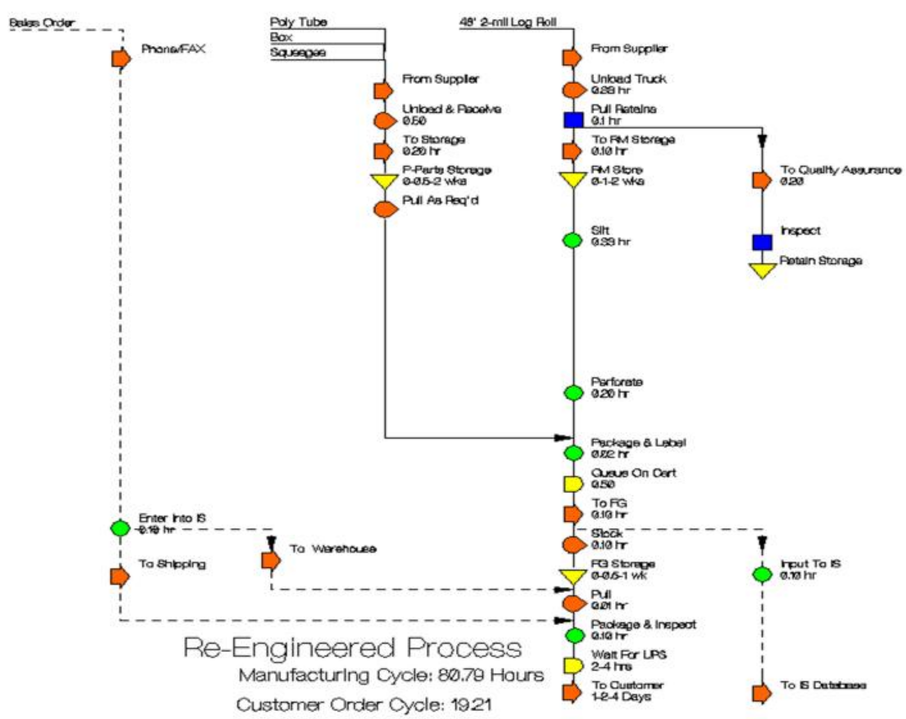
While the manufacturing cycle was longer than the customer order cycle, a finished goods stock allowed immediate delivery once the order was processed. However this long manufacturing cycle created excess inventory and many stock-outs.

Both the manufacturing and order cycle times went down by almost 80% with large savings in inventory, labor and increased customer service.

Present State



Present State



The Team

When mapping the current state, assemble a broad based team from all areas and several levels. It should include workers because they know the details of what really happens. It should include engineers and support people because they have a broad view of the process and know what is supposed to happen.

Drawing the Working Map

During a mapping session the entire team should see the entire map. And, each individual be able to focus on any detail that sparks a thought.

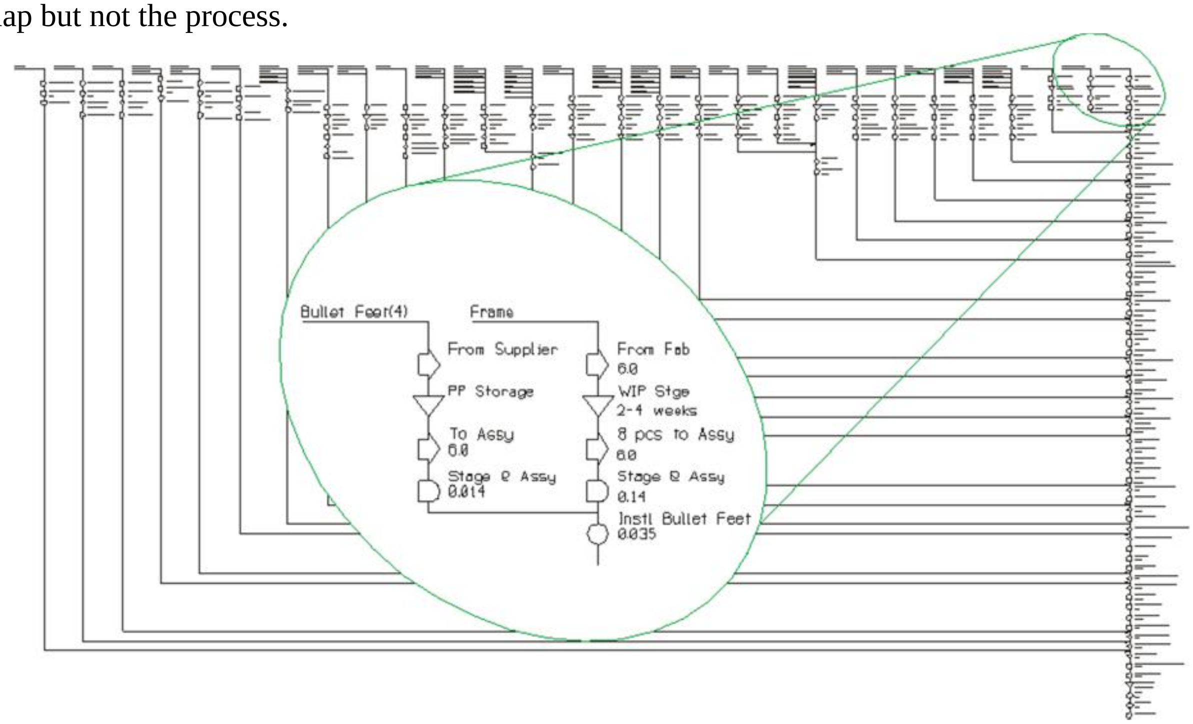
Draw the map on large paper sheets. This may cover several walls in an average conference room. Later the map can be redrawn with computer tools for distribution.

Example: Complex Assembly

The example below shows an assembly process for commercial dishwashers. Notice how the subassemblies stand out.

This particular map was very useful in laying out the assembly area. It was easy to see where subassembly areas should be located with respect to the assembly line.

Such process maps can be very large and complex but this reflects the true complexity of the process. It was tempting to take short cuts on the process map. This would have simplified the map but not the process.



Using Symbols

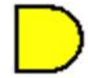
Rules of Thumb

These rules of thumb apply to a factory-level maps. You may want to modify them for more detailed maps.

Storage & Delay-

- When a product is in an official storage location with a record, use the Storage symbol.

- If the product is set aside casually to wait for a fork truck, for example, use the Delay symbol.
- Set a time, say five minutes, below which a Delay will not be shown.

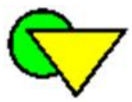


Handling & Transport

- If the product moves more than three paces, use the Transport symbol.
- If the product is sorted, rearranged or moved less than three paces, use the Handling Symbol.

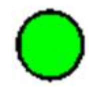
- If a transport delay is more than five minutes for a macro-level map, show it. Otherwise consider it as part of an adjacent event. Use a 30-second limit for micro-level maps.

When In Doubt...



- Combine Symbols.
- Add a question mark to signify the uncertainty.

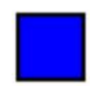
Value Added



Occasionally, it is unclear whether an event adds value. Here are three useful tests:

- Does the event physically transform the product in some way? If so, it probably adds value.
- If the customer observed the event, would he balk at paying its cost? If so, the event probably does not add value.
- If the event were eliminated, would the customer know the difference? If not, the event is probably non value added.

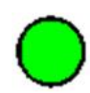
The following process events often bring controversy:



Inspection-

- Inspection refers to an examination of the product to determine if work has been done correctly. It does not refer to statistical process control activities that lie outside the chart.
- Inspection rarely adds value because it does not change the product.
- When the customer perceives inspection as value adding, requires it and pays for it, you *may* want to consider it a value adding event.

Curing/Drying-



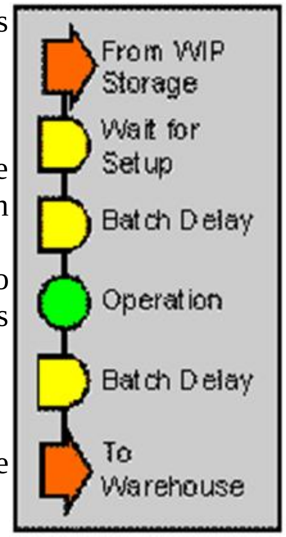
These change the physical properties of the product and should use the "Operation" symbol rather than a "Delay" symbol.

Transport-

- Transport and Handling rarely add value inside a factory.
- The customer may perceive a "value of place" and is willing to pay for it. Transport is then an added value.

Setups and Batches

Batch processes and setups frequently confuse mapping teams. When this happens, return to the question **"What is happening to the product?"**



Setups

During a setup, nothing happens to the product. It simply waits for the completion of the setup. This map detail shows a typical batch operation with setup.

The setup is a separate process and can be studied as such. It has nothing to do with product other than causing a delay and does not show on the process chart.

Batching

Processing in batches introduces a delay before and after an operation while the remainder of the batch is processed.

Batching for transport can be as problematic as batching for processing. Moves often have delays when they wait for material handlers.

Detail Levels

Process maps can depict many levels of detail. Like a Mandelbrot set, every event can expand to reveal more and more detail, as shown in the figure. Determining an appropriate level for the map is vital. With too much detail, the map becomes too large to see or print; too little and important elements are lost.

The best level depends on your purpose. Here are some guidelines:

- *Workflow & Group Technology*- The objectives here are to simplify movement between departments or develop part families. Operation events normally correspond to operations in the process specification or routings. Often, each operation is in a separate department. When charting at this level, be sure to include all moves, set downs and delays between departments as well as any moves from a departmental staging area to the process equipment.

  Workcell Design may require a finer breakdown of the events. Once the product families and cells are selected, only those events within the cell or immediately subsequent and prior need be depicted.
- *Workstation Design*- At this level, events are quite detailed. In most situations, a process map is not the best way to analyze workstations, although variations such as right-left hand charts are often useful.

Most beginners make their first charts with too little detail and often overlook non-value added events.

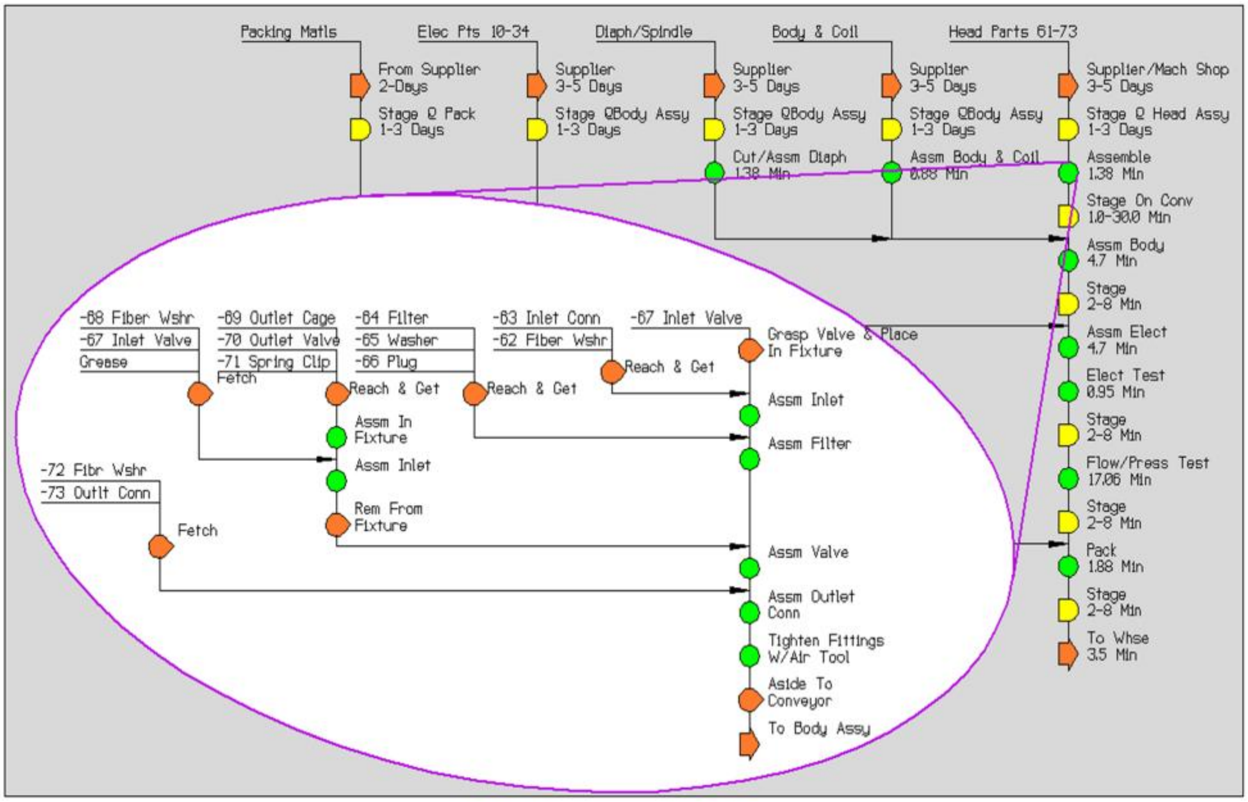
In theory, process mapping could be extended to sub-micro maps that show micro-motions. Or, It could extend to global value-chain processes. But, usually, other tools are more suitable for these situations.

The maps below show two levels of detail. The upper map shows individual elements within a workcell such as Head Subassembly and Body-Coil Subassembly. It also shows the moves and delays between these elements within the cell.

The lower map explodes the Head Subassembly operation into smaller elements. Even this map could conceivably be exploded into micro-motions, but there is not much point in doing so.

At an even higher level than shown below, all assembly operations would compress into the single element, "Assemble Pump." Such a map would work well in sorting out product families.

The first map, below, would be appropriate for workcell design while the second map would help workstation design.



Setting Boundaries

Process maps are most useful at a micro or macro level. Micro level charts show small steps such as "Assemble Cover" and "Adjust Tension." Their boundaries are usually the physical boundaries of a work-cell or department.

Macro-level maps show the process on a larger scale and often have boundaries corresponding to the boundaries of the factory. Macro-level maps consolidate small process events into a single larger event such as "Assemble Product."

A road map of Missouri also shows parts of Iowa, Kansas, Illinois and Arkansas. Apply this idea to your process map also. Start a bit upstream from the perceived area of interest and move downstream a bit beyond your area of interest.

For example, if you are concerned with the entire factory, start at the supplier's dock or inbound truck. Include the customer or the outbound truck.

If the project is a work-cell design, start with the upstream work-center or area. In this way, you capture moves in and out. You may discover that factors outside your perceived area of interest have major effects.

Drawing the Micro Layout – Preparing Detailed Plant Layout Drawings

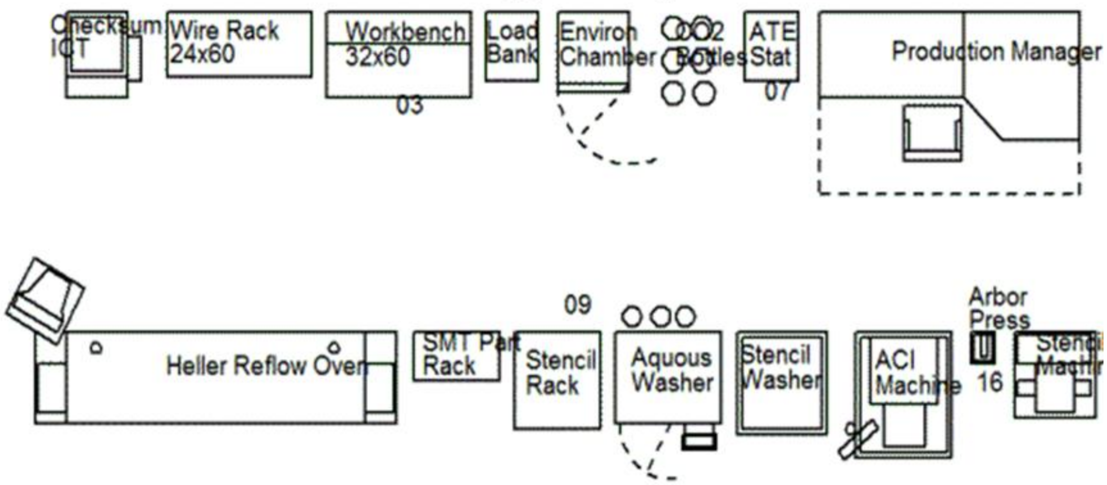
The Approach

The micro or detail layout is approached by taking one Space Planning Unit (cell, activity area, department) at a time and considering it as in independent project. If the macro-layout was done well, few difficulties will arise.

Product-focused work-cells require the most analysis and effort.

Functional SPUs such as a maintenance department, may require only a list of equipment and furniture. It then becomes a matter of placing the various pieces within the allotted space while accommodating traffic and other considerations. In other situations, a process chart for that part of the process internal to the SPU will be helpful.

Typical Templates



Hints for Drafting

Setup Layers

The following minimum set of layers is recommended. Beyond this minimum set, layer management depends largely on individual experience, convenience and the situation.

TITLE BLOCK LAYER--contains the title block and borders. This layer is off during the drawing activities but should be on for printing.

BUILDING LAYER-- This layer contains column centerlines, columns, permanent walls and other features that are unlikely to change.

GRID LAYER-- This layer consists of markers or points on (usually) 1' centers. It is most useful when making prints for installation. In most instances, the installers work by scaling the drawing using the grid points rather than explicit dimensions.

MACRO-LAYER-- This layer shows the macro-layout. It can be turned on or off during the detail layout work.

MICRO-LAYER(S)--this layer is where most objects are placed. There may be several such layers.

Establish Reference Lines

The usual reference line are column centerlines and the inside surface of permanent walls. They are usually on the original architect's drawings when such drawings are available. If the building was designed on a CAD system, the CAD drawings are usually reliable. For older buildings each dimension should be verified with field measurements. Check & double check these dimensions.

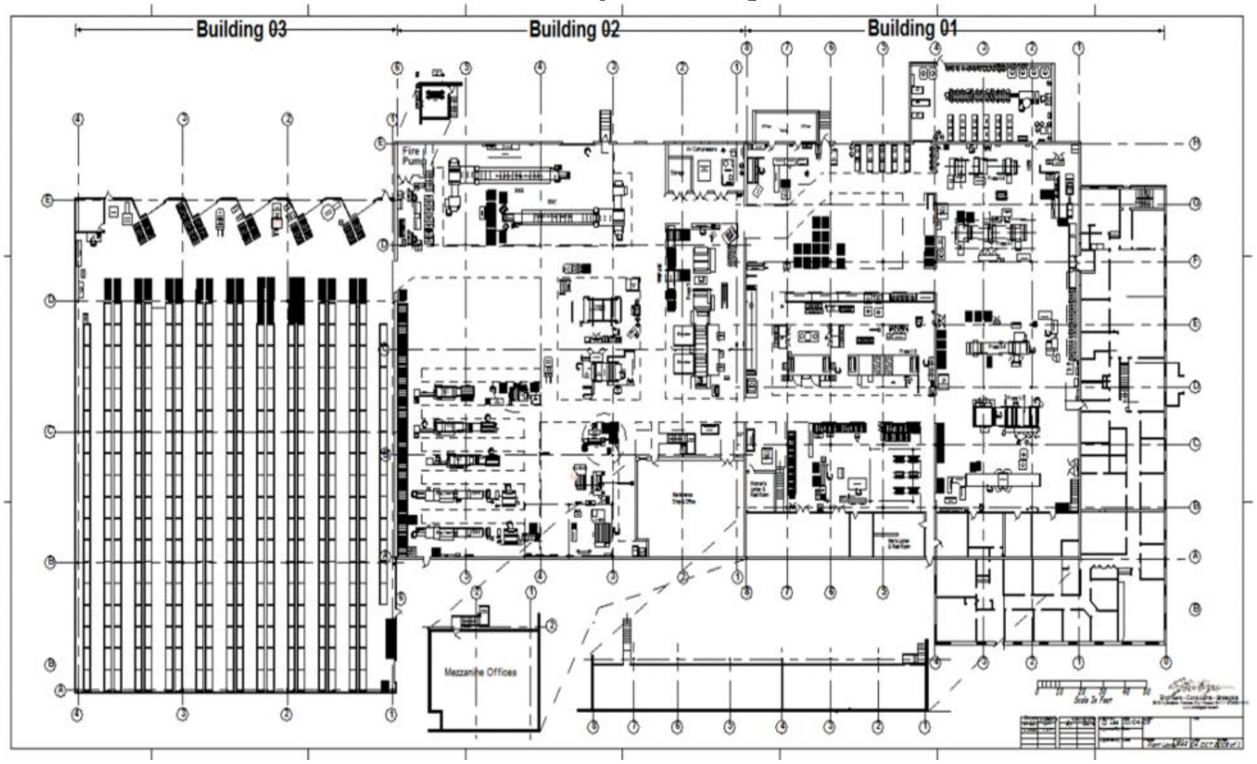
Draw Equipment Templates

Draw templates for all items of furniture or equipment that require floor space. The outside dimensions of templates should be accurate within +/- 1". Interior features of equipment usually needs only pictographic representation that suggests the appearance of the actual machine. Store the templates as blocks or groups within the CAD system. Labels should identify the type of equipment.

Dimensioning

Most layout drawings have few dimensions. Rather, they are drawn to scale and printed to a scale that can be measured easily when equipment and furniture is placed.

Micro-Layout Example



Workstation Design – Applied Ergonomics & Motion Economy

At the level of workstation design, Ergonomics and Motion Economy dominate the design. Motion Economy maximizes individual productivity by making tasks faster and easier. Ergonomics optimizes the integration of people with equipment. It also ensures that workers can perform the task with minimal risk of injury.

The figure below shows the tasks required to properly design a workstation along with their sequence.

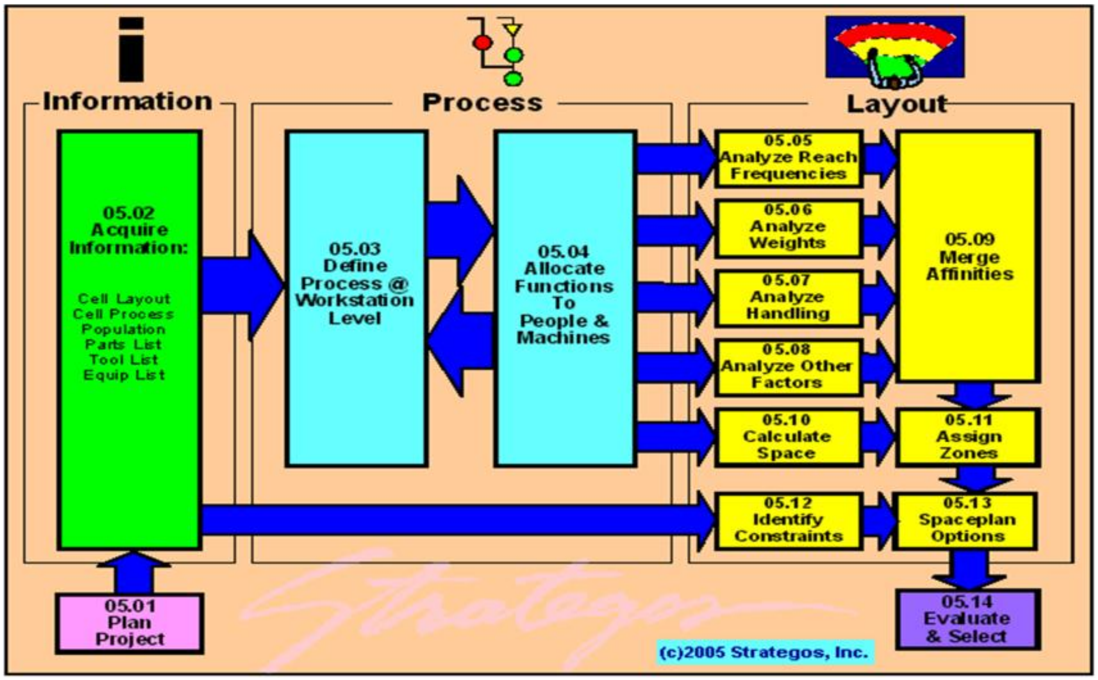
Task 05.02 is information acquisition. The designer needs information on products, processes, equipment, tools, components and other items.

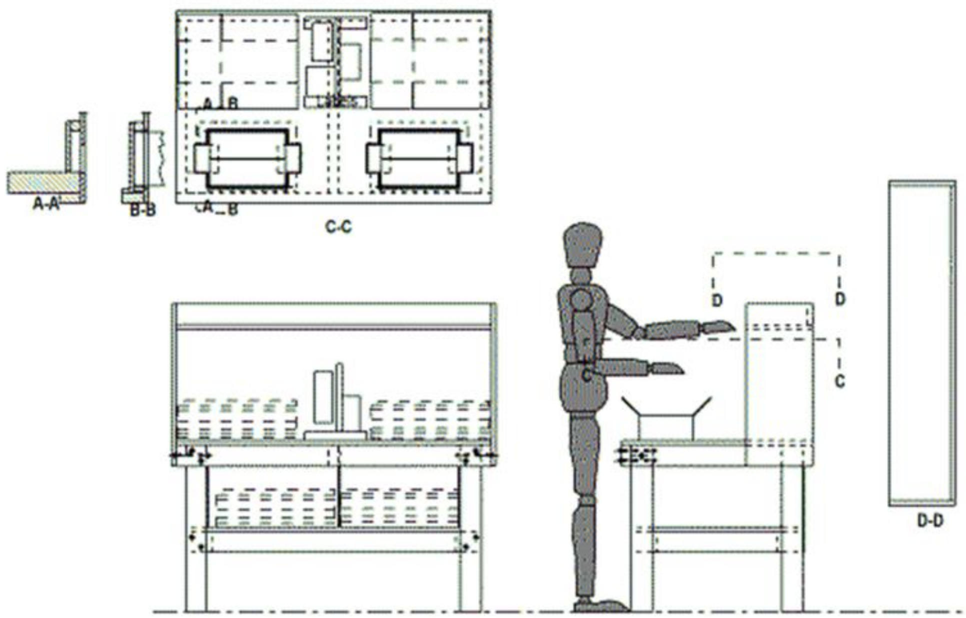
The next task group defines the process and allocate functions to machines or people. This is where automation and mechanization decisions are made.

The final task group places elements into a spatial arrangement. It parallels tasks at other levels of plant layout.

An experienced designer performs many of these steps informally or mentally. The process is not as complex or lengthy as the charts indicate. However, failure to perform a step results in design by accident, a risky proposition.

Design Procedure





Methods for evaluating Location based Decisions

Location Factor Rating

The decision where to locate is based on many different types of information and inputs. There is no single model or technique that will select the "best" site from a group. However, techniques are available that help to organize site information and that can be used as a starting point for comparing different locations.

In the **location factor rating** system, factors that are important in the location decision are identified. Each factor is weighted from 0 to 1.00 to prioritize the factor and reflect its importance. A subjective score is assigned (usually between 0 and 100) to each factor based on its attractiveness compared with other locations, and the weighted scores are summed. Decisions typically will not be made based solely on these ratings, but they provide a good way to organize and rank factors.

EXAMPLE 1	Location Factor Rating

The Dynaco Manufacturing Company is going to build a new plant to manufacture ring bearings (used in automobiles and trucks). The site selection team is evaluating three sites, and they have scored the important factors for each as follows. They want to use these ratings to compare the locations.

		Scores (0 to 100)		
Location Factor	*Weight*	*Site 1*	*Site 2*	*Site 3*
Labor pool and climate	0.30	80	65	90
Proximity to suppliers	0.20	100	91	75
Wage rates	0.15	60	95	72
Community environment	0.15	75	80	80
Proximity to customers	0.10	65	90	95
Shipping modes	0.05	85	92	65
Air service	0.05	50	65	90

SOLUTION:

The weighted scores for each site are computed by multiplying the factor weights by the score for that factor. For example, the weighted score for "labor pool and climate" for site 1 is

$$(0.30)(80) = 24 \text{ points}$$

The weighted scores for each factor for each site and the total scores are summarized as follows:

	Weighted Scores		
Location Factor	*Site 1*	*Site 2*	*Site 3*
Labor pool and climate	24.00	19.50	27.00
Proximity to suppliers	20.00	18.20	15.00
Wage rates	9.00	14.25	10.80
Community environment	11.25	12.00	12.00
Proximity to customers	6.50	9.00	9.50
Shipping modes	4.25	4.60	3.25
Air service	2.50	3.25	4.50
Total score	77.50	80.80	82.05

Site 3 has the highest factor rating compared with the other locations; however, this evaluation would have to be used with other information, particularly a cost analysis, before making a decision.

Center-of-Gravity Technique

In general, transportation costs are a function of distance, weight, and time. The **center-of-gravity,** or *weight center*, technique is a quantitative method for locating a facility such as a warehouse at the center of movement in a geographic area based on weight and distance. This method identifies a set of coordinates designating a central location on a map relative to all other locations.
The starting point for this method is a grid map set up on a Cartesian plane, as shown in Figure below.

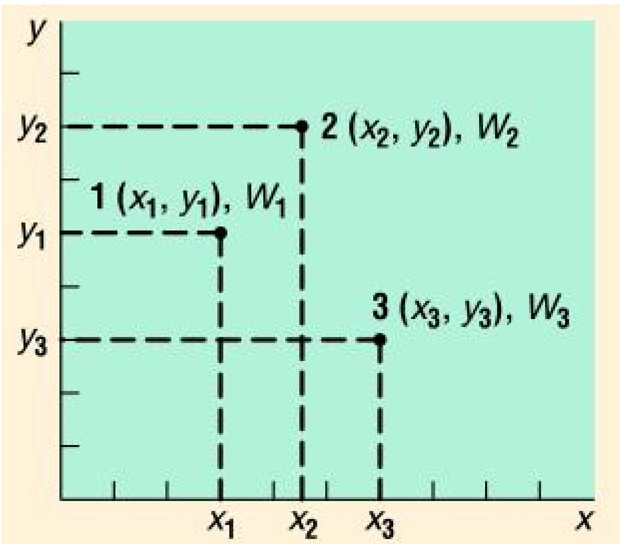


Figure: Grid Map Coordinates

There are three locations, 1, 2, and 3, each at a set of coordinates (x_i, y_i) identifying its location in the grid. The value W_i is the annual weight shipped from that location. The objective is to determine a central location for a new facility.
The coordinates for the location of the new facility are computed using the following formulas:

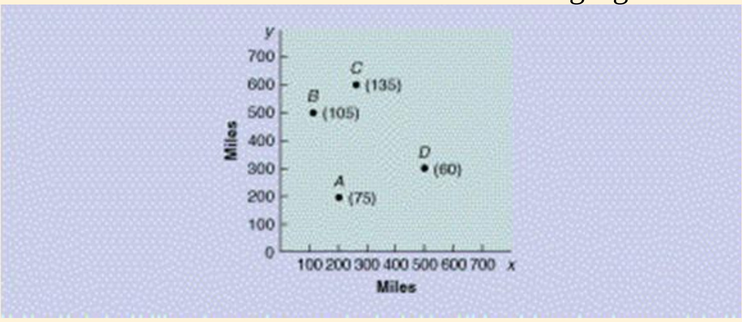
$$x = \frac{\sum_{i=1}^{n} x_i W_i}{\sum_{i=1}^{n} W_i}, \quad y = \frac{\sum_{i=1}^{n} y_i W_i}{\sum_{i=1}^{n} W_i}$$

where

x, y= coordinates of the new facility at center of gravity
x_i, y_i= coordinates of existing facility i
W_i= annual weight shipped from facility i

EXAMPLE 2	The Center-of-Gravity Technique

The Burger Doodle restaurant chain purchases ingredients from four different food suppliers. The company wants to construct a new central distribution center to process and package the ingredients before shipping them to their various restaurants. The suppliers transport ingredient items in 40-foot truck trailers, each with a capacity of 38,000 pounds. The locations of the four suppliers, A, B, C, and D, and the annual number of trailer loads that will be transported to the distribution center are shown in the following figure:



Using the center-of-gravity method, determine a possible location for the distribution center.

SOLUTION:

A	B	C	D
$x_A = 200$	$x_B = 100$	$x_C = 250$	$x_D = 500$
$y_A = 200$	$y_B = 500$	$y_C = 600$	$y_D = 300$
$W_A = 75$	$W_B = 105$	$W_C = 135$	$W_D = 60$

$$x = \frac{\sum_{i=A}^{D} x_i W_i}{\sum_{i=A}^{D} W_i}$$

$$= \frac{(200)(75) + (100)(105) + (250)(135) + (500)(60)}{75 + 105 + 135 + 60}$$

$$= 238$$

$$y = \frac{\sum_{i=A}^{D} y_i W_i}{\sum_{i=A}^{D} W_i}$$

$$= \frac{(200)(75) + (500)(105) + (600)(135) + (300)(60)}{75 + 105 + 135 + 60}$$

$$= 444$$

Thus, the suggested coordinates for the new distribution center location are $x = 238$ and $y = 444$. However, it should be kept in mind that these coordinates are based on straight-line distances, and in a real situation actual roads might follow more circuitous routes.

Load-Distance Technique

A variation of the center-of-gravity method for determining the coordinates of a facility location is the **load-distance technique.** In this method, a single set of location coordinates is not identified. Instead, various locations are evaluated using a load-distance value that is a measure of weight and distance. For a single potential location, a load-distance value is computed as follows:

$$LD = \sum_{i=1}^{n} l_i d_i$$

where

LD = the load-distance value

l_i = the load expressed as a weight, number of trips, or units being shipped from the proposed site to location i

d_i = the distance between the proposed site and location i

The distance d_i in this formula can be the travel distance, if that value is known, or can be determined from a map. It can also be computed using the following formula for the straight-line distance between two points, which is also the hypotenuse of a right triangle:

$$d_i = \sqrt{(x_i - x)^2 + (y_i - y)^2}$$

where

(x, y) = coordinates of proposed site

(x_i, y_i) = coordinates of existing facility

The load-distance technique is applied by computing a load-distance value for each potential facility location. The implication is that the location with the lowest value would result in the minimum transportation cost and thus would be preferable.

EXAMPLE 3	The Load-Distance Technique

Burger Doodle wants to evaluate three different sites it has identified for its new distribution center relative to the four suppliers identified in Example 9.2. The coordinates of the three sites under consideration are as follows:

Site 1: $x_1 = 360, y_1 = 180$

Site 2: $x_2 = 420, y_2 = 450$

Site 3: $x_3 = 250, y_3 = 400$

SOLUTION:

First, the distances between the proposed sites (1, 2, and 3) and each existing facility (A, B, C, and D), are computed using the straight-line formula for d_i:

Site 1: $d_A = \sqrt{(x_A - x_1)^2 + (y_A - y_1)^2}$

$= \sqrt{(200 - 360)^2 + (200 - 180)^2}$

$= 161.2$

$d_B = \sqrt{(x_B - x_1)^2 + (y_B - y_1)^2}$

$= \sqrt{(100 - 360)^2 + (500 - 180)^2}$

$= 412.3$

$d_C = \sqrt{(x_C - x_1)^2 + (y_C - y_1)^2}$

$= \sqrt{(250 - 360)^2 + (600 - 180)^2}$

$= 434.2$

$d_D = \sqrt{(x_D - x_1)^2 + (y_D - y_1)^2}$

$= \sqrt{(500 - 360)^2 + (300 - 180)^2}$

$= 184.4$

Site 2: $d_A = 333,\ d_B = 323.9,\ d_C = 226.7,\ d_D = 170$

Site 3: $d_A = 206.2,\ d_B = 180.3,\ d_C = 200,\ d_D = 269.3$

Next, the formula for load distance is computed for each proposed site:

$$\text{LD(site 1)} = \sum_{i=1}^{n} l_i d_i$$

$= (75)(161.2) + (105)(412.3) + (135)(434.2) + (60)(184.4)$

$= 125,063$

$\text{LD(site 2)} = (75)(333) + (105)(323.9) + (135)(226.7) + (60)(170)$

$= 99,789$

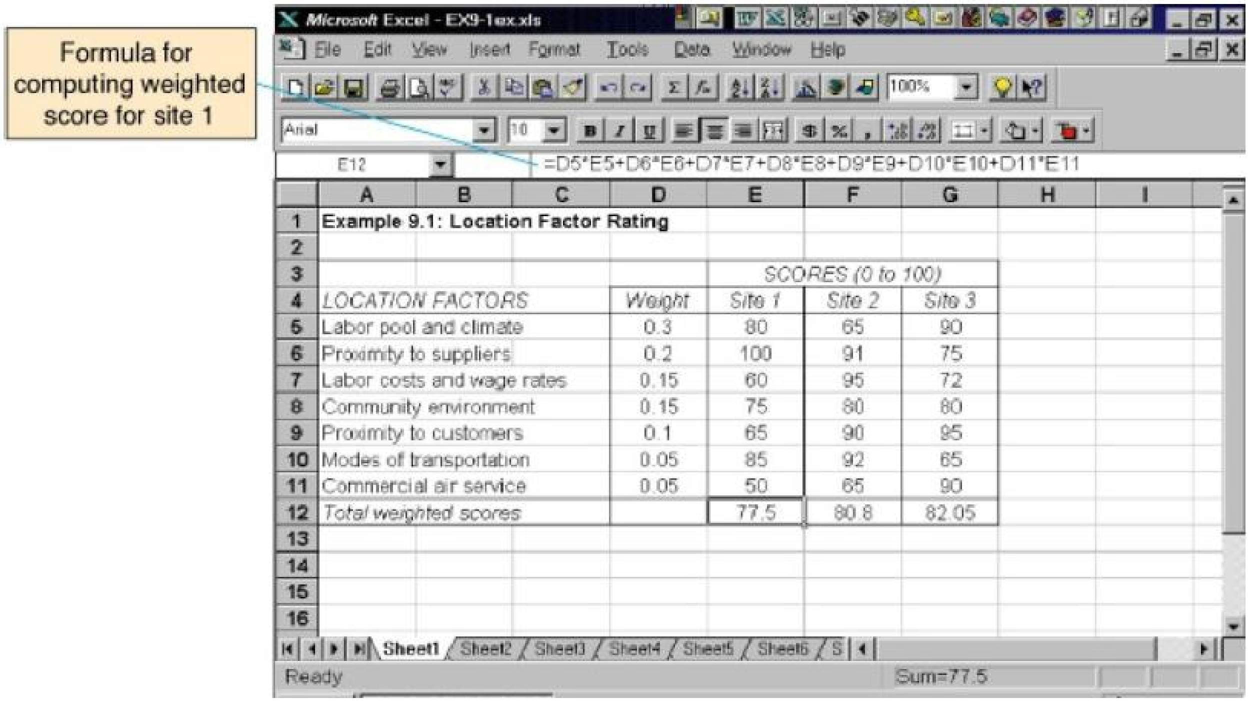
$\text{LD(site 3)} = (75)(206.2) + (105)(180.3) + (135)(200) + (60)(269.3)$

$= 77,555$

Since site 3 has the lowest load-distance value, it would be assumed that this location would also minimize transportation costs. Notice that site 3 is very close to the location determined using the center-of-gravity method in Example 9.2.

Computerized Location Analysis with Excel, POM for Windows, and Excel OM

Location factor ratings can be done with Microsoft Excel. Figure shows the Excel spreadsheet for Example 1.

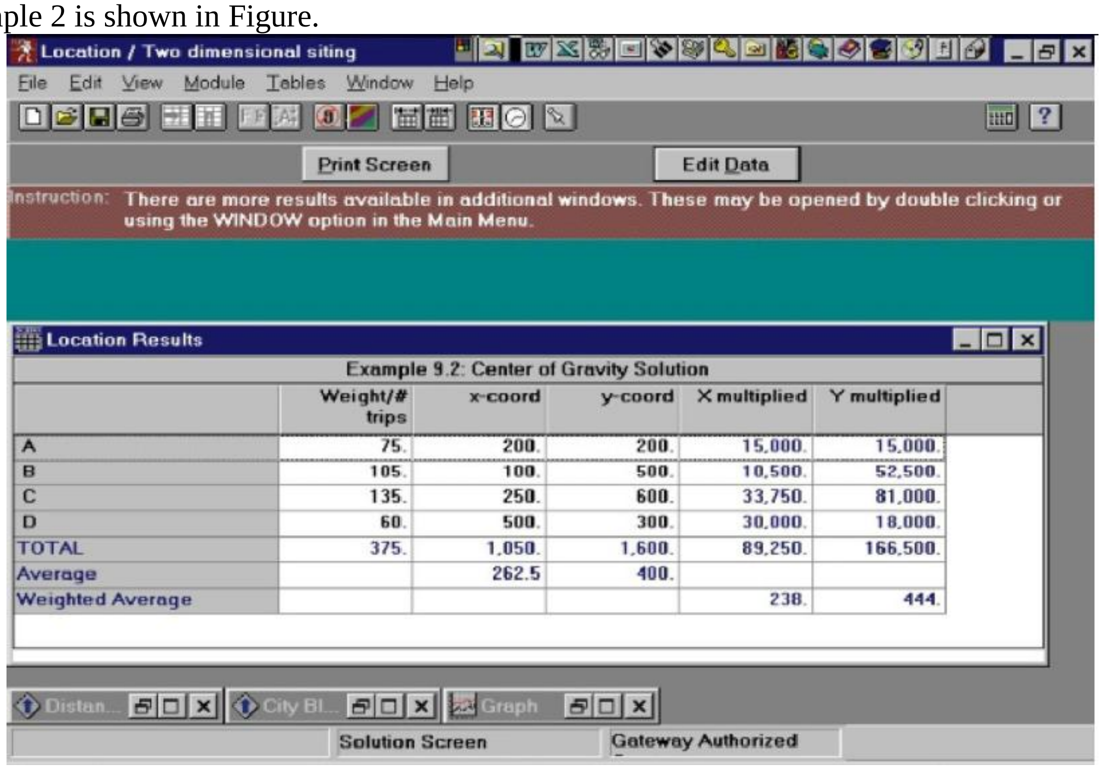


Example 9.1: Location Factor Rating

LOCATION FACTORS	Weight	SCORES (0 to 100) Site 1	Site 2	Site 3
Labor pool and climate	0.3	80	65	90
Proximity to suppliers	0.2	100	91	75
Labor costs and wage rates	0.15	60	95	72
Community environment	0.15	75	80	80
Proximity to customers	0.1	65	90	95
Modes of transportation	0.05	85	92	65
Commercial air service	0.05	50	65	90
Total weighted scores		77.5	80.8	82.05

Notice that the active cell is E12 with the formula (shown on the formula bar at the top of the spreadsheet) for computing the weighted score for site 1.

POM for Windows also has a module for computing location factor ratings as well as the center-of-gravity technique. The solution screen for the application of the center-of-gravity technique in Example 2 is shown in Figure.



Example 9.2: Center of Gravity Solution

	Weight/# trips	x-coord	y-coord	X multiplied	Y multiplied
A	75.	200.	200.	15,000.	15,000.
B	105.	100.	500.	10,500.	52,500.
C	135.	250.	600.	33,750.	81,000.
D	60.	500.	300.	30,000.	18,000.
TOTAL	375.	1,050.	1,600.	89,250.	166,500.
Average		262.5	400.		
Weighted Average				238.	444.

Excel OM also has modules for location factor ratings and the center-of-gravity technique. Figure 1 Figure 2 show the solution screens for Examples 1 and 2, respectively.

Factor weighting

Enter the data in the shaded area

Data

	Weight	Site 1	Site 2	Site 3
Labor pool and climate	0.3	80	65	90
Proximity to suppliers	0.2	100	91	75
Wage rates	0.15	60	95	72
Community environment	0.15	75	80	80
Proximity to customers	0.1	65	90	95
Shipping modes	0.05	85	92	65
Air service	0.05	50	65	90

Results

Total	1			
Weighted sum		77.5	80.8	82.05
Weighted average		77.5	80.8	82.05

Figure 1

Center of gravity

Enter the weights and coordinates in the data area.

Data

	Weight	X coord	Y coord
Site A	75	200	200
Site B	105	100	500
Site C	135	250	600
Site D	60	500	300

Results

Sum	375	1050	1600
Average		262.5	400
Weighted Average		238	444

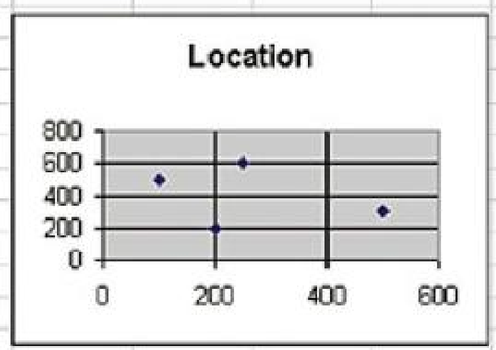


Figure 2

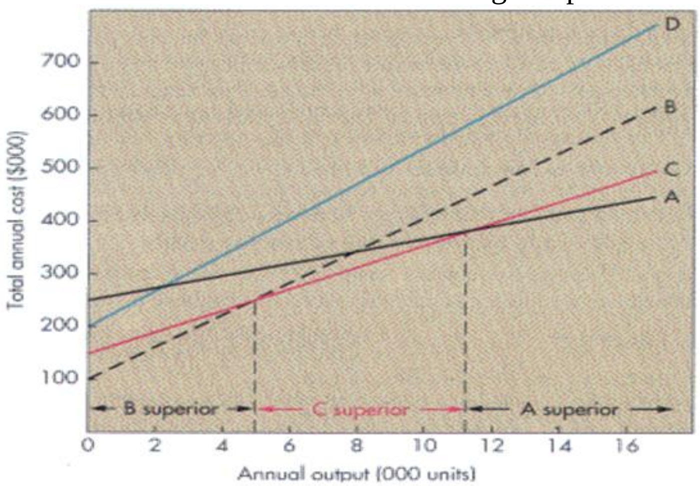
Locational Cost-Profit-Volume Analysis

Graphical Assumption:

1. Fixed costs are constant for the range of probable output.
2. Variable costs are linear for the range of probable output.
3. The required level of output can be closely estimated.
4. Only one product is involved.

Graphical Procedure:

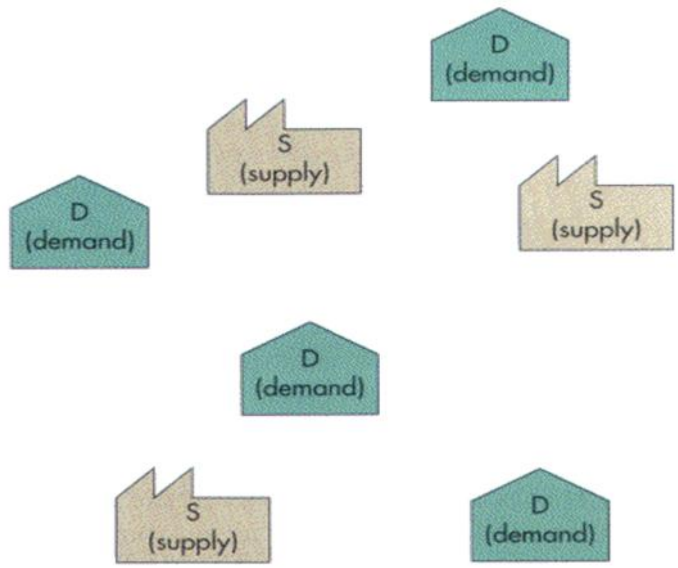
1. Determine the fixed and variable costs associated with each location alternative.
2. Plot the total-cost lines for all location alternatives on the same graph.
   $\text{Total cost} = FC + VC \times Q$
   where
   FC= fixed cost
   VC= variable cost per unit
   Q= quantity or volume of output
3. Determine which location will have the lowest total cost for the expected level of output. Alternatively, determine which location will have the highest profit.



For a profit analysis, compute
$\text{total profit} = QR - (FC + VC \times Q) = Q(R - VC) - FC$,
where
R= revenue per unit.
When a problem involves shipment of goods from multiple sending points to multiple receiving points, and a new location (sending or receiving point) is to be added to the system, the company should undertake a separate analysis of transportation. In such instances, the transportation model of linear programming is very helpful.

Transportation Model

The transportation problem involves finding the lowest-cost plan for *distributing* stocks of goods or supplies from multiple *origins* to multiple *destinations* that demand the goods.
The following figure shows the nature of a transportation problem in real life.



The information needed consists of the following:

1. A list of origins and one's capacity or supply quantity per period.
2. A list of the destinations and each one's demand per period.
3. The unit cost of shipping items from each origin to each destination.

The information is arranged into the following transportation table.

Cost to ship one unit from factory 1 to warehouse A.

Factory	Warehouse A	Warehouse B	Warehouse C	Warehouse D	Supply
1	4	7	7	1	100
2	12	3	8	8	200
3	8	10	16	5	150
Demand	80	90	120	160	450 / 450

Factory 1 can supply 100 units per period

Total supply capacity per period

Warehouse B can use 90 units per period

Total demand per period

Assumptions are:

1. The items shipped are homogeneous.
2. Shipping cost per unit is the same regardless of the number of units shipped.
3. There is only one route or mode of transportation being used between each origin and each destination.

Major steps in solving the transportation using the table are:

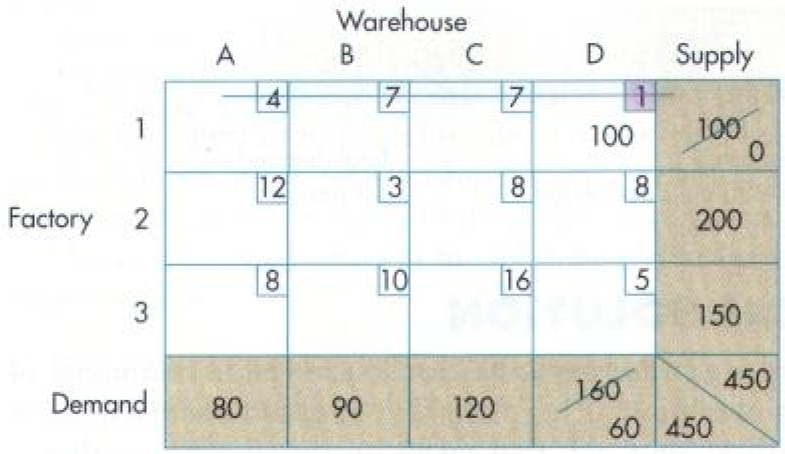
1. Obtaining an initial solution.
2. Testing the solution for optimality.
3. Improving sub-optimal solutions.

Obtaining An Initial Solution --- The Intuitive Lowest-Cost Approach

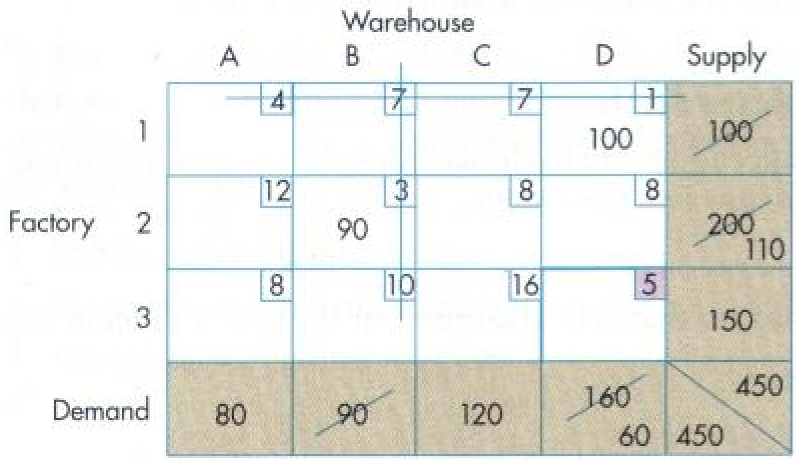
The procedure involves these steps:

1. Identify the cell with the lowest cost.

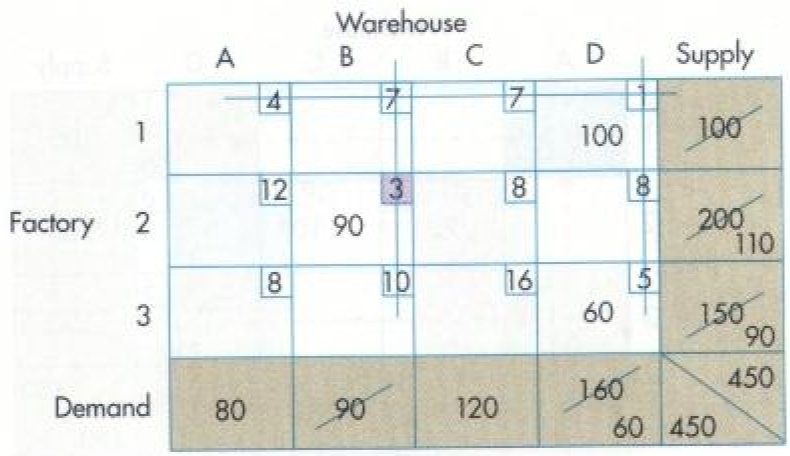
2. Allocate as many units as possible to that cell, and cross out the row or column (or both) that is exhausted by this.
3. Find the cells with the next lowest cost from among the feasible cells.
4. Repeat steps (2) and (3) until all units have been allocated.



Factory \ Warehouse	A	B	C	D	Supply
1	[4]	[7]	[7]	[1] 100	~~100~~ 0
2	[12]	[3]	[8]	[8]	200
3	[8]	[10]	[16]	[5]	150
Demand	80	90	120	~~160~~ 60	450 / 450



Factory \ Warehouse	A	B	C	D	Supply
1	[4]	[7]	[7]	[1] 100	~~100~~
2	[12]	[3] 90	[8]	[8]	~~200~~ 110
3	[8]	[10]	[16]	[5]	150
Demand	80	~~90~~	120	~~160~~ 60	450 / 450



Factory \ Warehouse	A	B	C	D	Supply
1	[4]	[7]	[7]	[1] 100	~~100~~
2	[12]	[3] 90	[8]	[8]	~~200~~ 110
3	[8]	[10]	[16]	[5] 60	~~150~~ 90
Demand	80	~~90~~	120	~~160~~ 60	450 / 450

Warehouse

Factory	A	B	C	D	Supply
1	[4]	[7]	[7]	[1] 100	~~100~~
2	[12]	[3] 90	[8]	[8]	~~200~~ 110
3	[8] 80	[10]	[16]	[5] 60	~~150~~ 10 ~~90~~
Demand	~~80~~	~~90~~	120	~~160~~ 60	450 / 450

Warehouse

Factory	A	B	C	D	Supply
1	[4]	[7]	[7]	[1] 100	100
2	[12]	[3] 90	[8] 110	[8]	200
3	[8] 80	[10]	[16] 10	[5] 60	150
Demand	80	90	120	160	450 / 450

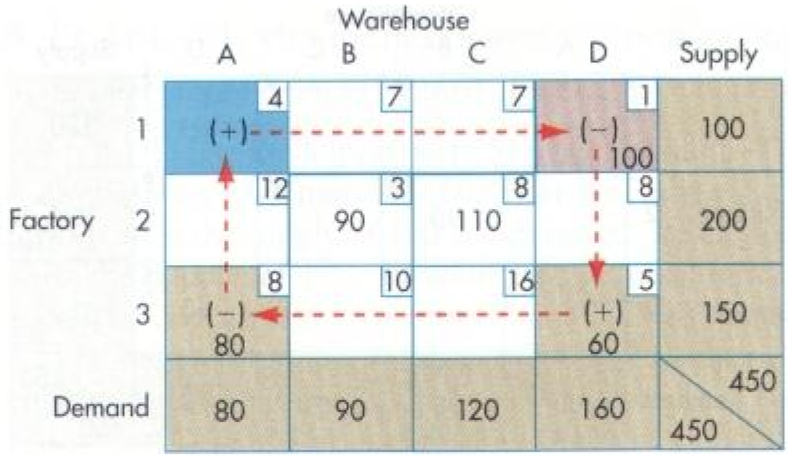
Testing For Optimality --- Stepping Stone

In the stepping-stone method, cell evaluation proceeds by borrowing one unit from a full cell and using it to assess the impact of shifting units into the empty cell. Helpful rules for obtaining evaluation paths are

1. Start by placing a + sign in the (empty) cell you wish to evaluate.
2. Move horizontally (or vertically) to a completed cell (a cell that has units assigned to it). It is OK to pass through an empty cell or a completed cell without stopping. Choose a cell that will permit your next move to another completed cell. Assign a minus (-) sign to the cell.
3. Change direction and move to another completed cell. Again, choose one that will permit your next move. Assign a plus sign (+) to the cell.
4. Continue this process of moving to a completed cell and alternating + and – signs until you can complete a closed path back to the original cell. Make only horizontal and vertical moves.
5. You may find it helpful to keep track of cells that have been evaluated by placing the cell evaluation value in the appropriate cell with a circle around it.

For instance, if a shift of one unit causes an increase of $5, total costs would be increased by $5 times the number of units shifted into the cell. Obviously, such a move would be unwise, since the objective is to decrease costs.

Evaluation path for cell 1-A.

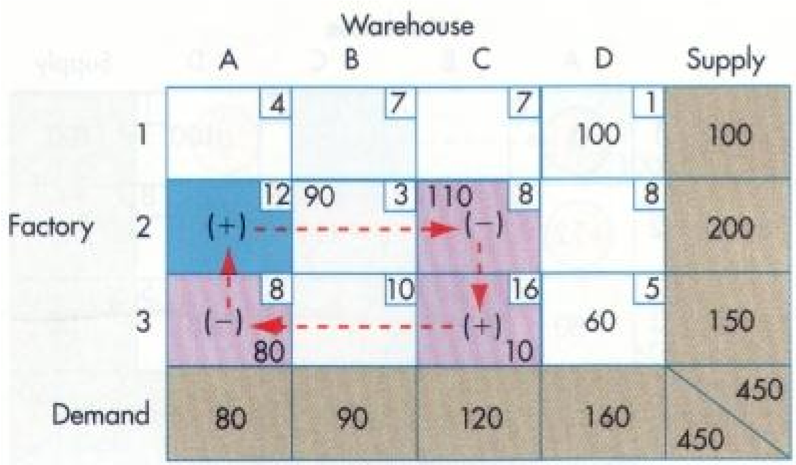


The name *stepping-stone* derives from early descriptions of the method that likened the procedures to crossing a shallow pond by stepping from stone to stone.

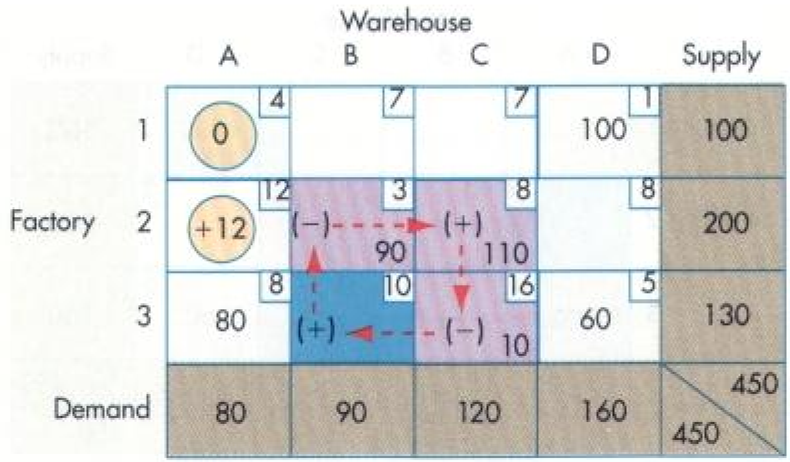
It is important to mention that constructing paths using the stepping-stone method requires a minimum number of occupied cells. The number of occupied cells must equal the sum of the number of rows and columns minus 1 (full rank), or *R*+*C*-1, where *R*= number of rows and *C*= number of columns.

If there are too few occupied cells, the matrix is said to be *degenerate*.

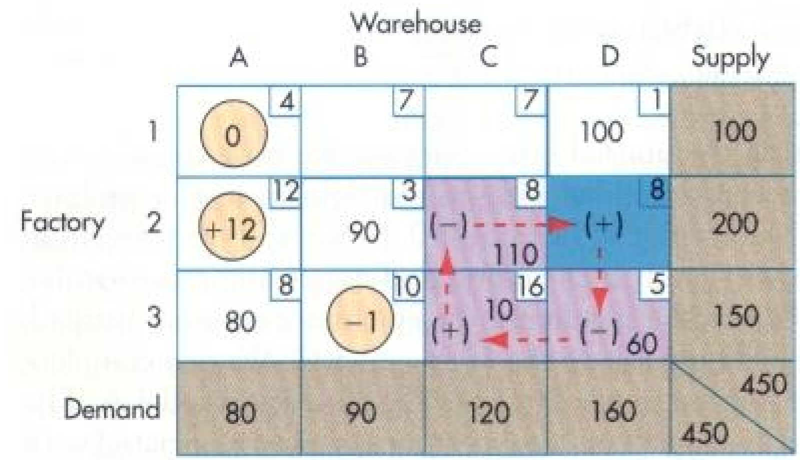
Evaluation path for cell 2-A.



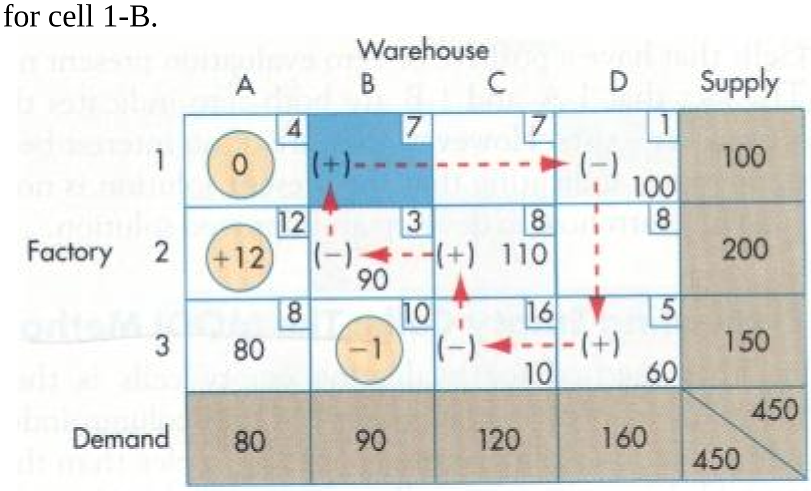
Evaluation path for cell 3-B.



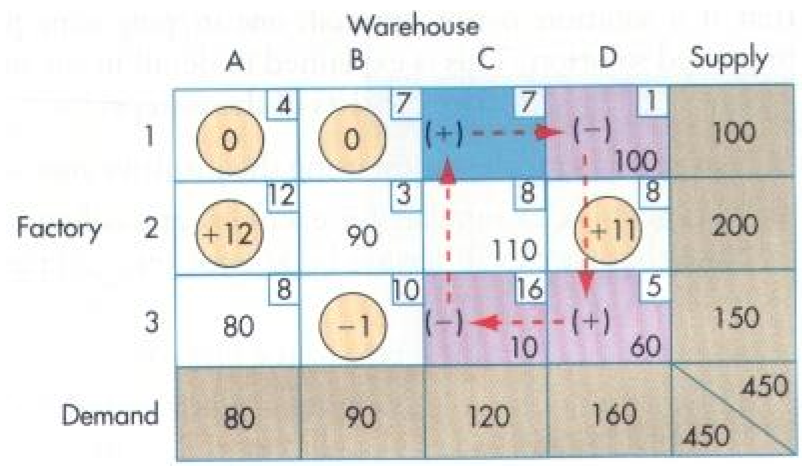
Evaluation path for cell 2-D.



Evaluation path for cell 1-B.



Evaluation path for cell 1-C.



Evaluation result:

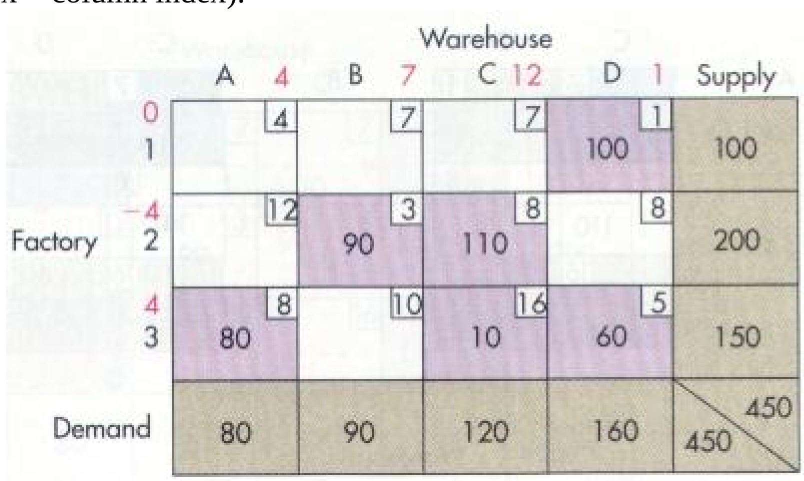
Cell	1A	2A	3B	2D	1B	1C
Cost	0	+12	**-1**	+11	0	**-5**

The fact that 1-A and 1-B are both zeros indicates that at least one other equivalent alternative exists. However, they are of no interest, because other cells have negative cell evaluations, indicating that the present solution is not an optimum.

Testing For Optimality --- MODI

Another method is the **modified distribution method** (MODI) The MODI procedure consists of these steps:

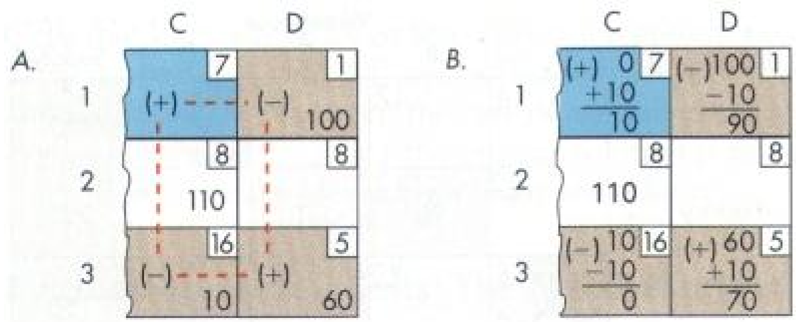
1. Obtain index numbers for rows and columns using only *completed* cells. Note that there will always be at least one completed cell in each row and in each column.
   a. Begin by assigning a zero to the first row.
   b. Determine the column indices for completed cells in row 1 using the relationship: cell cost = column index + row index.
   c. Each new column value will permit the calculation of at least one new row value, and vice versa.
   d. Continue the computation until all rows and columns have index numbers.
2. Obtain cell evaluations for *empty* cells using the relationship: cell evaluation = cell cost – (row index + column index).



Cell	Evaluation
1-A	4 − (0 + 4) = 0
1-B	7 − (0 + 7) = 0
1-C	7 − (0 + 12) = −5
2-A	12 − (−4 + 4) = 12
2-D	8 − (−4 + 1) = 11
3-B	10 − (4 + 7) = −1

Obtaining An Improved Solution

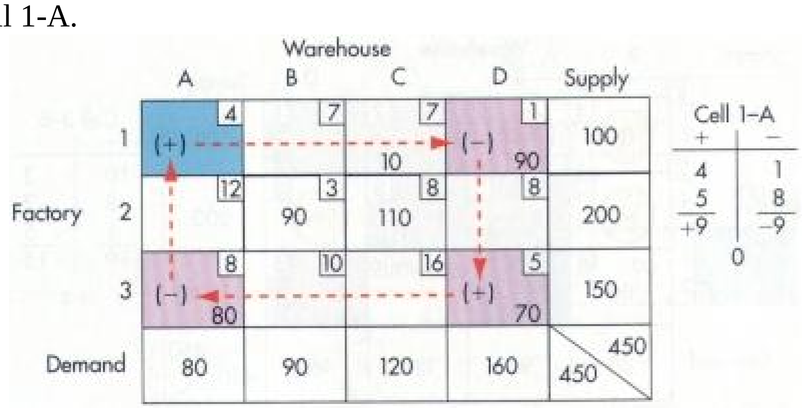
Evaluation path for cell 1-C and re-allocation of 10 units around the path.



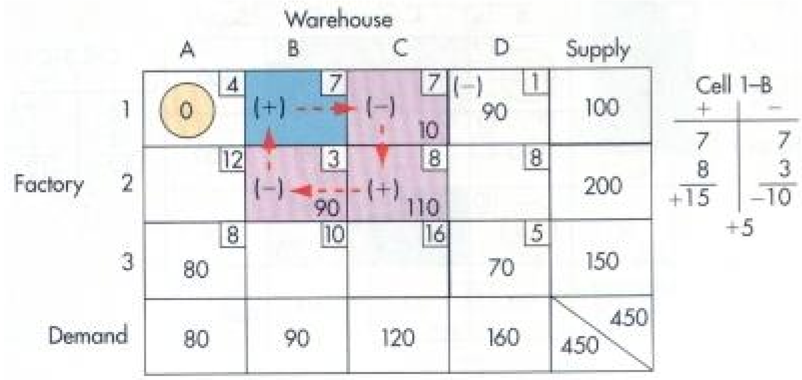
Revised solution.

Factory \ Warehouse	A	B	C	D	Supply
1	[4]	[7]	[7] 10	[1] 90	100
2	[12]	[3] 90	[8] 110	[8]	200
3	[8] 80	[10]	[16]	[5] 70	150
Demand	80	90	120	160	450 / 450

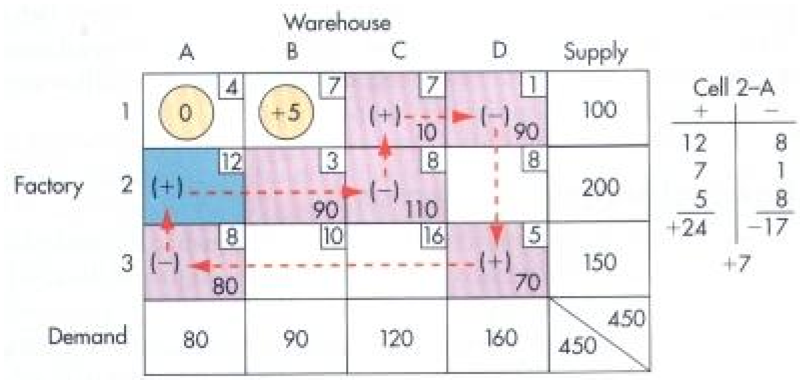
Evaluation of cell 1-A.



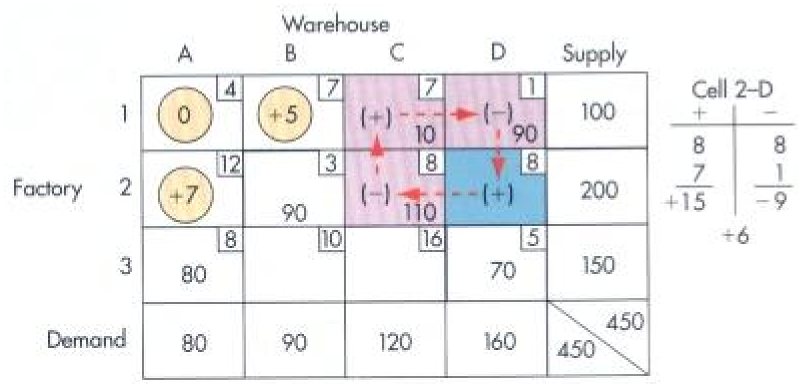
Evaluation of cell 1-B.



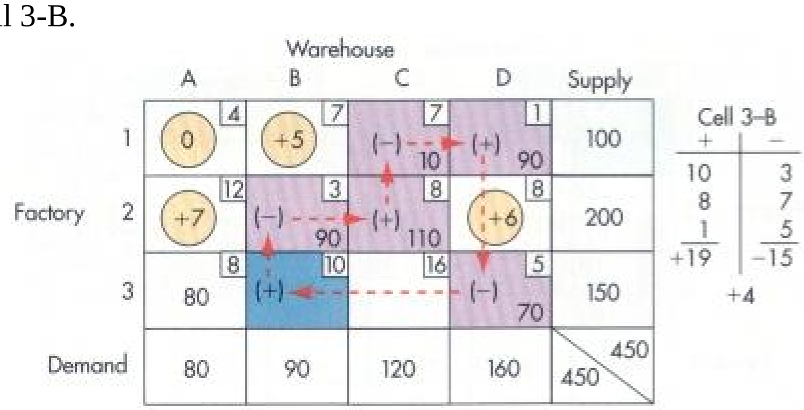
Evaluation of cell 2-A.



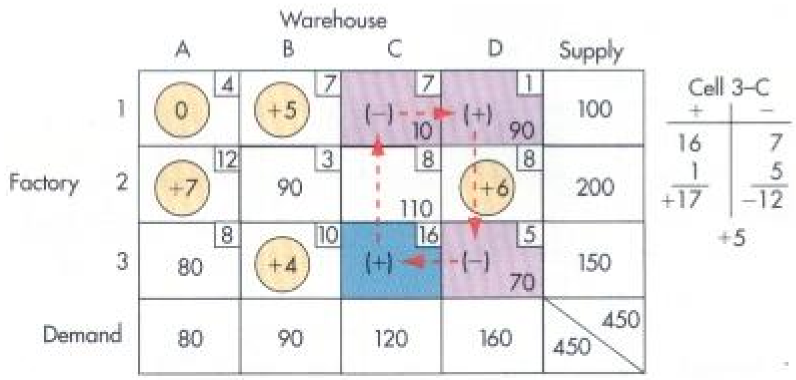
Evaluation of cell 2-D.



Evaluation of cell 3-B.



Evaluation of cell 3-C.



Special Problem --- Unequal Supply and Demand

When supply exceeds demand, this problem can be remedied by adding a dummy destination with a demand equal to difference between supply and demand. Unit shipping costs of the dummy cells are $0s.

From: \ To:	A	B	Supply
1	[5]	[9]	100
2	[4]	[2]	100
Demand	80	90	170 \ 200

From: \ To:	A	B	Dummy	Supply
1	[5]	[9]	[0]	100
2	[4]	[2]	[0]	100
Demand	80	90	30	200 \ 200

The resulting numbers in the final solution indicate which resource(s) will hold the extra units or will have excess capacity.

From: \ To:	A	B	Dummy	Supply
1	[5] 70	[9]	[0] 30	100
2	[4] 10	[2] 90	[0]	100
Demand	80	90	30	200 \ 200

A similar situation exists, when demand exceeds supply.

Note: When using the intuitive approach, if a dummy row or column exists, make assignments to dummy cell(s) last.

Special Problem --- Degeneracy

Degeneracy exists, when there are too few completed cells to allow all necessary paths to be constructed. Because degeneracy could occur in an initial solution or in subsequent solutions, it is necessary to test for degeneracy after each iteration using *R*+*C*-1.

	A	B	C	Supply
1	[3] 40	[2]	[5]	40
2	[8]	[1] 50	[4] 10	60
3	[7]	[7]	[6] 20	20
Demand	40	50	30	120 / 120

Degeneracy can be remedied by placing a very small quantity, represented by the small δ, into one of the empty cells and then treating it as a completed cell. The quantity is so small that it is negligible; it will be ignored in the final solution.

	A	B	C	Supply
1	[3] 40	[2]	[5]	40
2	[8]	[1] 50	[4] 10	60
3	[7] ε	[7]	[6] 20	20
Demand	40	50	30	120 / 120

Some experimentation may be needed to find the best spot for δ, because not every cell will enable construction of evaluation paths for the remaining cells. Moreover, avoid placing δ in a minus position of a cell path that runs out to be negative because reallocation requires shifting the smallest quantity in a minus position. Since the smallest quantity is δ, which is essentially zero, no allocation is possible.