

# Chapter 6. Supply Chain Systems

*This is an introduction chapter quotation. It is offset three inches to the right.*

## 6.1. Introduction

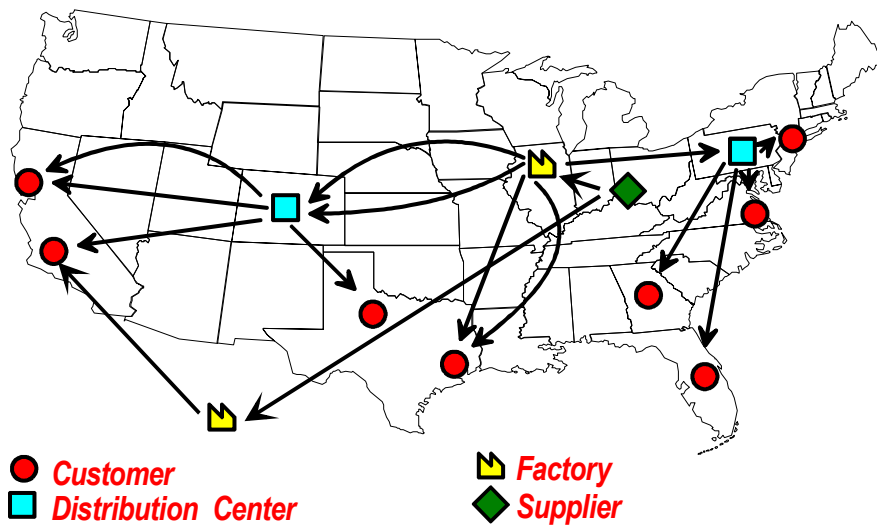
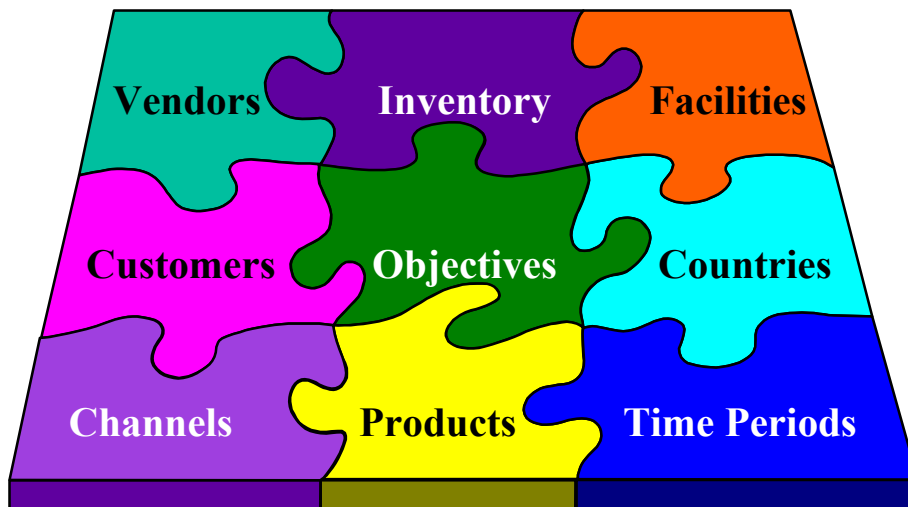


Figure 6.1. Supply Chain Schematic



**Figure 6.2. Integrated Nature of Supply Chain Decisions**

### *Customer Service*

Many Components

Many Definitions

Very Qualitative

Customer Service Stages

Pre-Transaction

- Declaring policies and procedures

Transaction

- Inventory levels and location
- Transportation channels
- Ordering and billing systems

Post-Transaction

- Maintenance and service (CALS)
- Warranties

Order Cycle Time

Time between Order Placement and Product Receipt

Wide Range (Instantaneous to 30 months)

#### Components

- Order processing
- Production
- Order Assembly and Order Picking
- Transportation

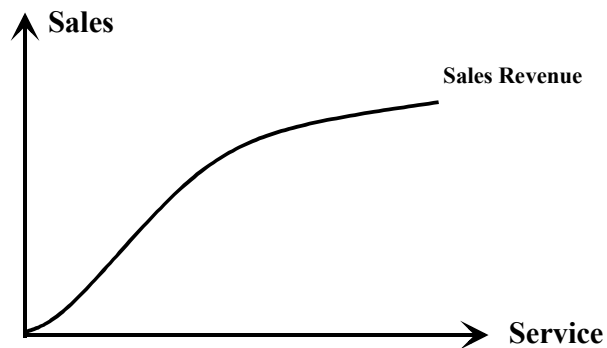


Figure 6.3. Sales versus Service Relationship Curve

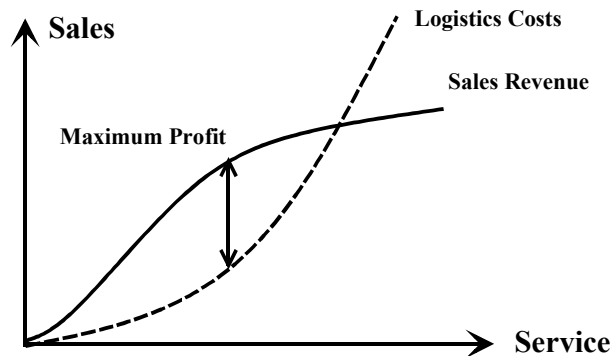


Figure 6.4. Sales versus Service Cost Relationship Curve

#### Service Constraints

- Percentage of Goods Delivered out of Stock
- Percentage of Orders Delivered within Time Limit
- Maximum Time or Distance from Supply Point
- Single Sourcing

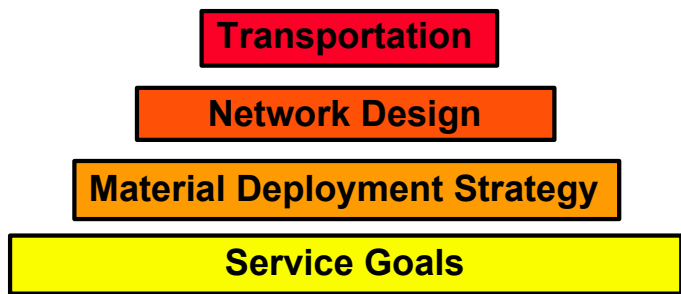


Figure 6.5. Traditional Stages in Supply Chain Design



Figure 6.6. Integrated Stage in Supply Chain Design

## 6.2. Modeling Objectives, Constraints, Data

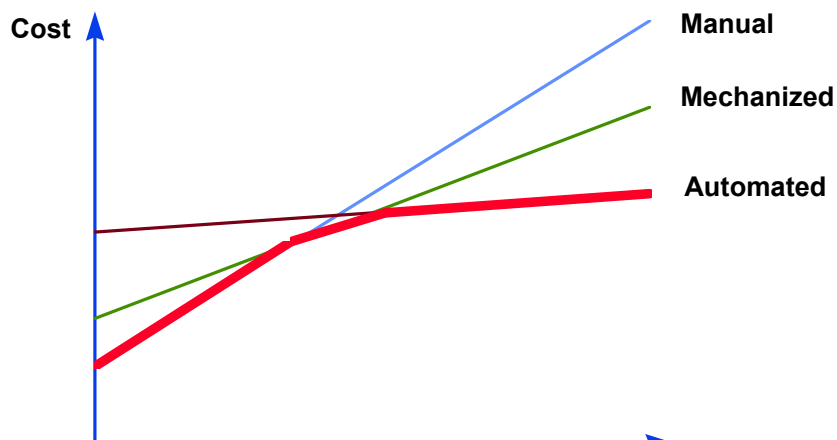


Figure 6.7. Facility Size or Technology Costs

Microsoft Excel - DEC Incinerator Location Example

	A	B	C	D	E
1	City	State	Annual Volume		
2	Boston	MA	30,000		
3	Chicago	IL	240,000		
4	New York	NY	50,000		
5	Minneapolis	MN	140,000		
6	Atlanta	GA	170,000		
7	Phoenix	AZ	230,000		
8	Baltimore	MD	120,000		
9	Denver	CO	300,000		
10	Cincinnati	OH	100,000		
11	Los Angeles	CA	40,000		
12	Memphis	TN	90,000		
13	Seattle	WA	20,000		

Figure 6.8. DEC Incinerator Example Data

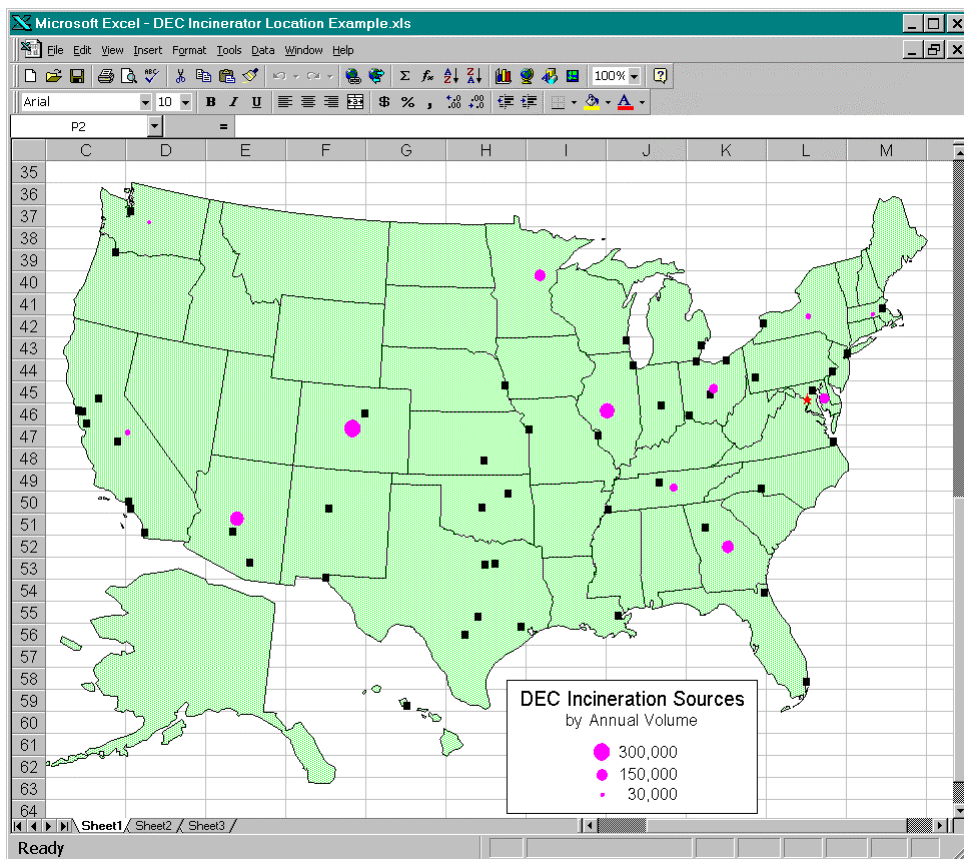


Figure 6.9. Geocoding the DEC Incinerator Example with Excel

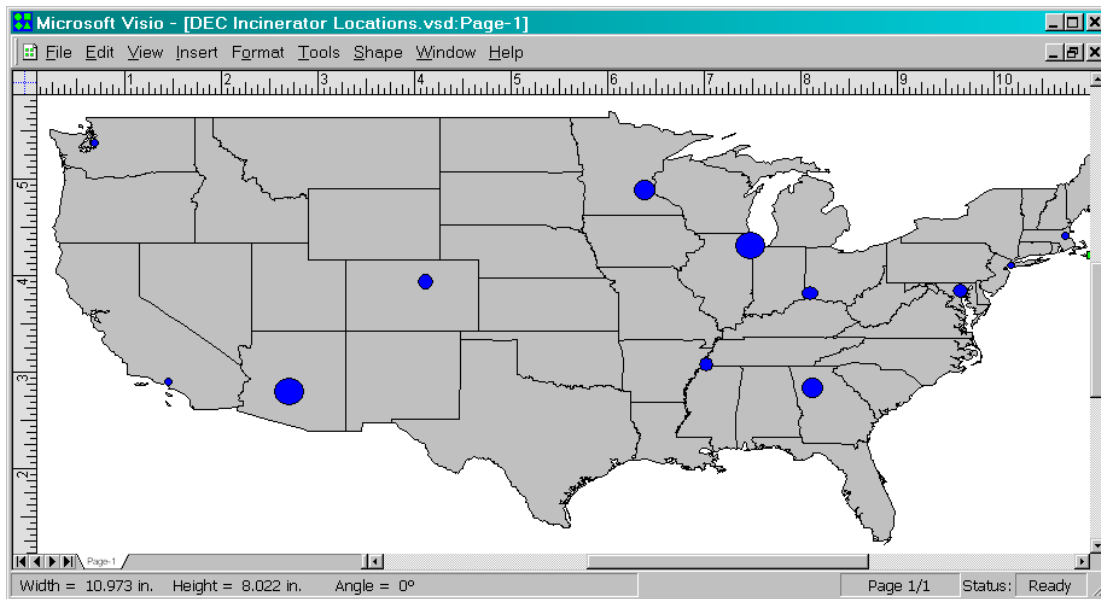


Figure 6.10. Geocoding the DEC Incinerator Example with Visio

## 6.3. *Logistics Objects and their Characteristics in the Supply Chain*

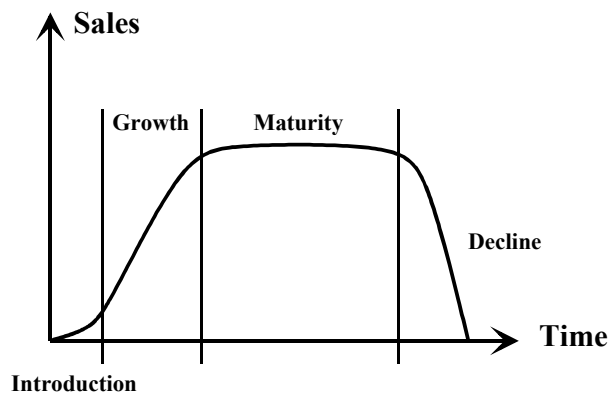
### Products

#### *Product Types*

1. Convenience and Commodities
  - Multiple sales points
  - Food items, office supplies
2. Comparison Shopping
  - Fewer sales points
  - Cars, fork lift trucks
3. Specialty Products
  - Very limited distribution

- Art, specialized machines

### *Product Life Cycle*



**Figure 6.11. Product Life Cycle Graph**

#### Introduction

- Limited Availability
- Few sales points and channels
- Centralize distribution

#### Growth

- Expanding channels and sales points
- Flow quantity more important than cost

#### Maturity

- Stable sales volume
- Many sales points and channels
- Optimization opportunity

#### Decline

- Declining sales volume
- Decreasing sales points and channels
- Centralized distribution

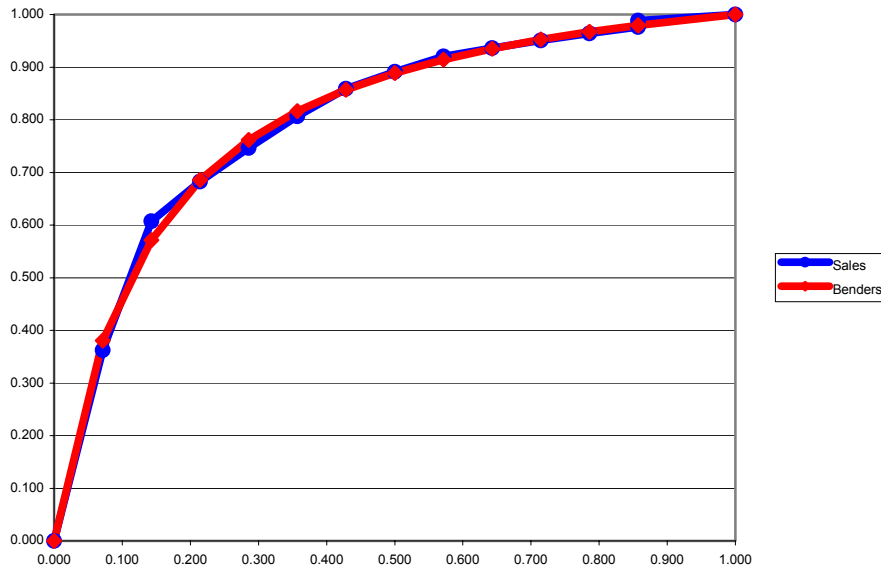
### *Pareto's Principle and Curve*

In many logistics and other systems a majority of the operations or of the economic impact is generated by relatively small fraction of the products. This differentiation and concentration phenomenon has become known as Pareto's Principle. Vilfredo Pareto (1848-1923) observed at the end of the nineteenth century that about 80 percent of the wealth in Italy was concentrated into about 20 percent of the population. The Pareto principle states that a small subset of actors (the "vital few") affecting a common outcome tend to occur much more frequently than the remainder (the "useful many"). The concentration does not always have to 80-20, but the 80-20 term has become associated with this concentration characteristic. The concentration can be graphically illustrated by the Pareto or 80-20 curve. The curve plots the cumulative effect, such as sales or transactions, versus the cumulative actors, such as customers. In Figure 6.12 the Pareto curve is shown corresponding to the sales data in Table 6.1. Pareto bar charts provide an equivalent tool for visualizing the Pareto principle. A Pareto chart can be used to decide which subset of problems should be solved first, or which products deserve the most attention. In warehousing and logistics, products typically are classified as fast, medium, and slow movers based on the Pareto curve.

**Table 6.1. Example Product Sales Data**

Product	Cumulative Products	Sales	Cumulative Sales
1	0.071	5056	0.362
2	0.143	3424	0.607
3	0.214	1052	0.683
4	0.286	893	0.746
5	0.357	843	0.807
6	0.429	727	0.859
7	0.500	451	0.891
8	0.571	412	0.921
9	0.643	214	0.936
10	0.714	205	0.951
11	0.786	188	0.964
12	0.857	172	0.976
13	0.929	170	0.989
14	1.000	159	1.000
14		13966	





**Figure 6.12. Benders Pareto Curve for Example Product Sales**

Observe that the curve in the above figure passes through the points (0.20, 0.65) and (0.35, 0.80), but not through the point (0.20, 0.80). Also observe that many different curves may all pass through the point (0.20, 0.80).

The Pareto curve can be described mathematically by several different formulas, such as the power, exponential, and Bender's formulation, given by formulas (6.1), (6.2), and (6.3), respectively. We will focus from now on the formulation originally proposed by Bender (1981), but the other formulations have analogue derivations.

$$Y = X^A \quad (6.1)$$

$$Y = 1 - e^{-AX} \quad (6.2)$$

$$Y = \frac{(1+A)X}{A+X} \quad (6.3)$$

For each of the above formulations, the  $A$  parameter needs to be computed in such way that the curve matches the observed data points as closely as possible. We can rearrange the Bender's curve formulation to derive the following explicit formula for the parameter  $A$ .

$$A = \frac{X(1-Y)}{Y-X} \quad (6.4)$$

The value of  $A$  can then be based on one or more data points  $(X_i, Y_i)$ . A better curve fit can be found by minimizing the sum of squared errors ( $SSE$ ) between the actual data values ( $Y_i$ ) and then data values derived from the curve ( $\hat{Y}_i$ ). The data values on the curve are computed with the following formula.

$$\hat{Y}_i = \frac{(1+A)X_i}{(A+X_i)} \quad (6.5)$$

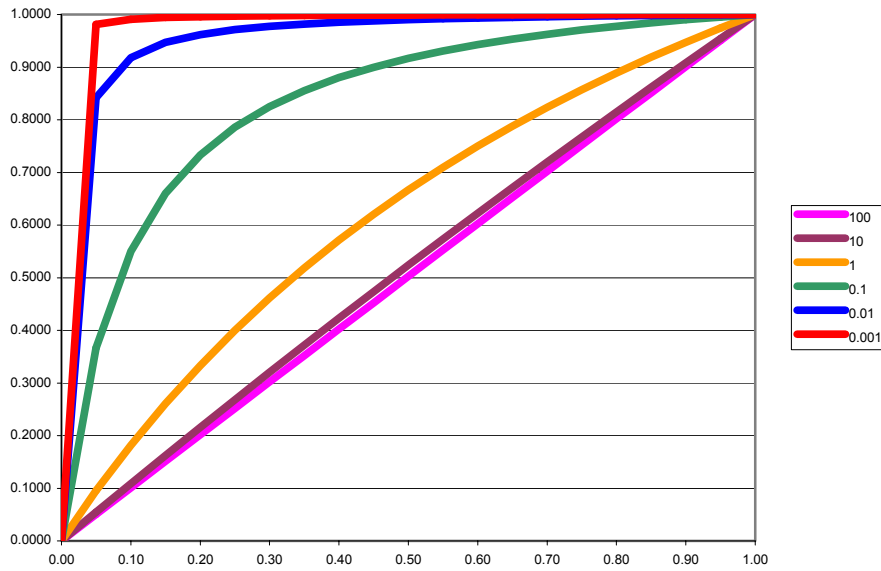
Setting the first derivative of  $SSE$  with respect to the parameter  $A$  equal to zero yields the least-squares estimator for the parameter  $A$ .

$$SSE = \sum_{i=1}^N (Y_i - \hat{Y}_i)^2 \quad (6.6)$$

$$\frac{\partial SSE}{\partial A} = 0 \quad (6.7)$$

$$\sum_i \frac{Y_i(X_i - X_i^2)}{(A + X_i)^2} - \sum_i \frac{(1+A)(X_i^2 - X_i^3)}{(A + X_i)^3} = 0 \quad (6.8)$$

The smaller the value of the  $A$  parameter, the more skewed the curve becomes. If all products had equal sales, then the curve would be the diagonal line connecting the points (0.0, 0.0) and (1.0, 1.0) and the  $A$  parameter would be infinitely large. A skewed curve, which follows the Pareto principle, is pulled toward the top left area of the graph. The estimation of the  $A$  parameter based on a single point with formula (6.4) for an 80-20 and 90-10 curve is 0.0667 and 0.0125, respectively. Benders Pareto curves for different values of the  $A$  parameter are shown in the next figure.



**Figure 6.13. Benders Pareto Curves for Different A Parameter Values**

How closely the curve fits the original data is typically quantified by the  $R^2$  statistic, also called the coefficient of determination. This coefficient ranges between zero and one and the closer the coefficient is to one, the better the curve fit. The  $R^2$  statistic is computed with the following formulas.

$$R^2 = 1 - \frac{SSE}{SST}$$

$$SSE = \sum_{i=1}^N (Y_i - \hat{Y}_i)^2 \quad (6.9)$$

$$SST = \left( \sum_{i=1}^N Y_i^2 \right) - \frac{\left( \sum_{i=1}^N Y_i \right)^2}{N}$$

If the  $A$  parameter has a large value, the logistics strategy would be to treat the products identically. A very skewed Pareto curve with corresponding small value of the  $A$  parameter indicates that the products should be treated differently, e.g. by differentiated distribution. If the curve is strongly skewed, then we can establish product classes, typically called A, B, and C, or fast, medium, and slow movers. From this ABC classification, the curve derives its alternative name of ABC curve.

The exponential curve can be determined using the built-in GROWTH function of the Excel spreadsheet. Since the GROWTH function calculates the least squares fit through a set of points using the equation

$$CY = B^x$$

you must first compute the complement  $CY_i = (1 - Y_i)$ , fit the curve through the transformed data points  $(X_i, CY_i)$ , and then finally take the complement  $\hat{Y}_i = (1 - C\hat{Y}_i)$  again.

There exists considerable variation in the way the boundaries between the three classes are computed. In general, class A corresponds to the region where the curve has a strongly vertical slope. Class B corresponds to the region with the bend or knee of the curve. Class C corresponds to the region of the curve where the curve has a more horizontal slope. The classes are often constructed so that 80% of the cumulative effect is created by the products in class A, the next 15 % of the cumulative effect is created by the products in class B, and the last 5 % of the cumulative effect is caused by the products in class C. The more skewed the curve, and the smaller the  $A$  parameter, the easier it is to determine the dividing lines between the classes. For very large values of the  $A$  parameter, when the curve displays a single homogeneous population, the dividing lines between the classes are very hard to determine and very arbitrarily.

The Pareto curve is an example of how raw sales data can be transformed into information, which is necessary for logistics knowledge and decisions. The information is the shape of the Pareto curve and the value of the  $A$  parameter. The logistics knowledge is based on the curve and will treat products identically or differently and divide the products into classes based on their location along the curve.

### *Benders Pareto Curve Example*

The detailed steps to compute the Benders formulation of the Pareto curve using the Microsoft Excel spreadsheet are given next. Figure 6.14 shows the spreadsheet with the initial data. The data are not sorted and listed by part number. The objective is to construct the Pareto curve of the cumulative product sales in dollars in function of the cumulative number of products.

	A	B	C	D
1	Product	Units Sold	Unit Value	Sales
2	101	31000	\$0.10	\$3,100
3	202	880000	\$0.15	\$132,000
4	303	13000	\$0.90	\$11,700
5	404	210000	\$0.03	\$6,300
6	505	120000	\$0.02	\$2,400
7	606	25000	\$0.55	\$13,750
8	707	70000	\$0.35	\$24,500
9	808	40000	\$0.75	\$30,000
10	909	90000	\$0.10	\$9,000
11	1010	5000	\$0.08	\$400
12	1111	6500	\$0.07	\$455

**Figure 6.14. Excel Spreadsheet with Sales Data**

The next spreadsheet shows the same sales data after they have been sorted by decreasing dollar sales, i.e. by column D with heading Sales. The next four columns show the cumulative fraction of products ( $X$ ), the cumulative fraction of sales ( $Y$ ), the cumulative fraction of sales based on the Benders Pareto curve ( $BY$ ), and the square of the deviation between the actual sales and the sales curve or squared error ( $SE$ ). The following formulas are used to compute each  $SE$  and  $BY$  and then  $SSE$ .

$$BY_i = \frac{(1 + A)X_i}{(A + X_i)}$$

$$SE_i = (Y_i - BY_i)^2$$

$$SSE = \sum_{i=1}^{11} SE_i$$

The next two columns show the cumulative fraction of sales based on the exponential Pareto curve ( $EY$ ) and the squared error for the exponential curve fit. The following is formula used to compute  $EY$ .

$$EY_i = 1 - e^{-AX_i}$$

	A	B	C	D	E	F	G	H	I	J
1								Benders		Exponent.
2	Product	Units Sold	Unit Value	Sales	X	Y	BY	SSE	EY	SSE
3					0.000000	0.000000	0.000000		0.000000	
4	202	880000	\$0.15	\$132,000	0.090909	0.565056	0.538019	0.000731	0.433493	0.017309
5	808	40000	\$0.75	\$30,000	0.181818	0.693478	0.721292	0.000774	0.679070	0.000208
6	707	70000	\$0.35	\$24,500	0.272727	0.798356	0.813684	0.000235	0.818191	0.000393
7	606	25000	\$0.55	\$13,750	0.363636	0.857216	0.869363	0.000148	0.897004	0.001583
8	303	13000	\$0.90	\$11,700	0.454545	0.907301	0.906585	0.000001	0.941652	0.001180
9	909	90000	\$0.10	\$9,000	0.545455	0.945827	0.933223	0.000159	0.966945	0.000446
10	404	210000	\$0.03	\$6,300	0.636364	0.972796	0.953228	0.000383	0.981274	0.000072
11	101	31000	\$0.10	\$3,100	0.727273	0.986066	0.968804	0.000298	0.989392	0.000011
12	505	120000	\$0.02	\$2,400	0.818182	0.996340	0.981276	0.000227	0.993990	0.000006
13	1111	6500	\$0.07	\$455	0.909091	0.998288	0.991486	0.000046	0.996596	0.000003
14	1010	5000	\$0.08	\$400	1.000000	1.000000	1.000000	0.000000	1.000000	0.000004
15										
16				Sum			A	SSE	A	SSE
17				\$233,605			0.093933	0.003001	6.250926	0.021214

**Figure 6.15. Excel Spreadsheet to Determine the Optimal Benders Parameter**

The sum of squared errors or SSE for the Benders curve is shown in cell H17. This sum depends on the value of the parameter  $A$ , which is shown in cell G17. The optimal value of the parameter  $A$  is found by minimizing the sum of squared errors with the help of the Excel Solver. The corresponding dialog window for the solver is shown in Figure 6.16. The options for the Excel solver are shown in Figure 6.17. The optimal value of the parameter  $A$  for the exponential curve was found with the Excel GROWTH function.

**Solver Parameters**

Set Target Cell:

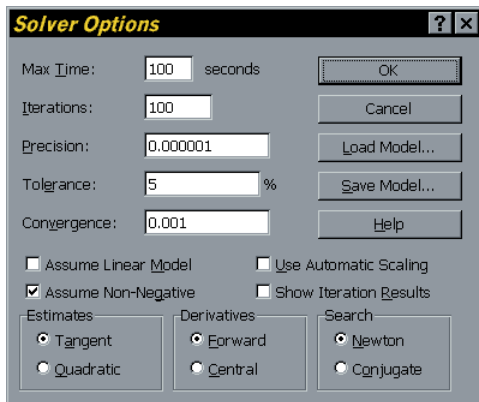
Equal To: ☐ Max ☒ Min ☐ Value of:

By Changing Cells:

Subject to the Constraints:

Buttons: Solve, Close, Guess, Options, Add, Change, Delete, Reset All, Help

**Figure 6.16. Solver Dialog Window for Determining the Optimal Benders Pareto Parameter**



**Figure 6.17. Solver Options Dialog Window for Determining the Optimal Benders Pareto Parameter**

For the Benders curve, the total sum of squared errors is 0.003 for a parameter value of 0.0939. The sum of squared errors is very small which indicates a very good curve fit. In this particular example 27 % of the products make up 80 % of dollar sales. This curve is less skewed than the standard 80-20 curve, i.e., it takes more than 20 % of the products to account for 80 % of the dollar sales. For the exponential curve, the total sum of squared errors is 0.021 for a parameter value of 6.251. The sum of squared errors is still very small which indicates a good curve fit. The actual cumulative sales and the computed cumulative sales curves are shown in the next Excel chart. This chart can then be copied and pasted into other documents as illustrated in Figure 6.12.

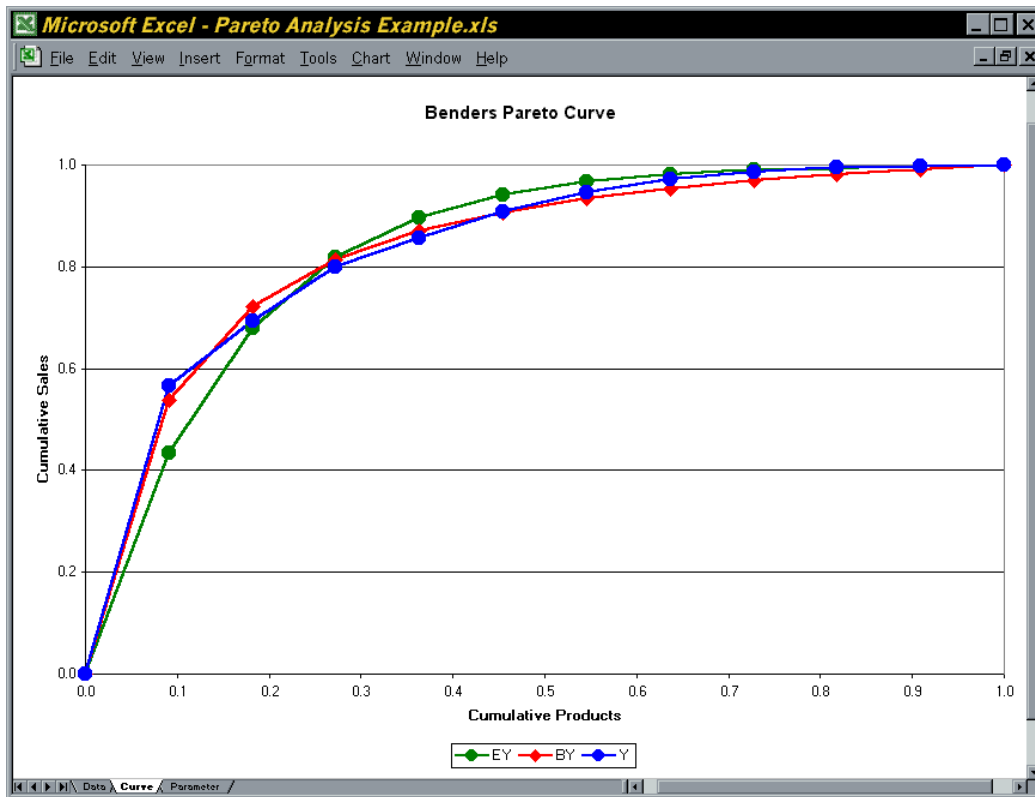


Figure 6.18. Actual versus Computed Cumulative Sales Curves based on the Benders Pareto Curve

## Suppliers and Vendors

### Strategies for Raw Material Procurement

The strategies for sourcing and transformation decisions in supply chain configuration and their respective advantages and disadvantages were summarized by Cohen and Lee (1989).

#### *Centralization*

The centralization sourcing strategy purchases the total requirement of this raw material from a single vendor. The advantages are the lower purchasing prices and lower purchasing overhead. This strategy has advantages of scale. However, the supply system is not robust. The material management at various plants from a central location is complex.

#### *Regionalization*

The regionalization strategy sources the raw materials and subcomponents required by a plant from vendors in the same region. This allows improved communication between the plant and the vendors



and quick response and just in item supply policies, which result in lower inventory costs. This strategy also has the advantage of reduced inbound transportation costs.

### *Consolidation*

The consolidation strategy reduces the number of vendors on a worldwide basis. The smaller number of vendors allows for economies of scale, such as lower purchasing prices due to quantity discounts. The transportation costs for inbound materials may be higher.

### *Dispersion*

The dispersion or diversification strategy sources materials from a variety of vendors that are geographically dispersed. This strategy has diseconomies of scale and scope. The main advantage of the strategy is a more robust supply system that does not depend on the performance of a single vendor. This strategy also provides the opportunity to take advantage of currency exchange rate fluctuations. It may also have lower inbound transportation costs.

## **Transformation Facilities**

### **Strategies for manufacturing network configuration**

#### *Regionalization*

In a regionalization strategy, each manufacturing plant will serve all the customers in a particular geographical area with the full product assortment offered by the company. In essence, the global manufacturing network is divided into a number of local manufacturing networks with independent distribution to their assigned customers. This strategy enables a close link and cooperation between the manufacturing and the customers it serves. Each plant must be flexible and capable of producing all the products in demand in its area in the limited quantities corresponding to its area. This strategy suffers both diseconomies of scale and scope. This strategy has the advantages of enhanced customer service, the easy of decentralized decision-making. The distribution and transportation of finished goods is limited to a small geographical area. This strategy is also robust viewed from a global perspective since a catastrophic occurrence in one geographical area does not impact other areas. This strategy is however not robust at all viewed from the local perspective, since if production at the single plant serving the area is interrupted all products in the local market are no longer available.

### *Consolidation*

In a consolidation strategy, all the production of all products for the entire world takes place at one or two places. Each manufacturing plant serves either the whole world or a very large section of the world. This strategy allows the plant economies of scale, such as product design, production design, and large production batches. The finished goods have to be distributed of large geographical areas. This strategy is not robust, since a catastrophic occurrence at the single plant would shut down production in the whole world. To avoid this situation, management often specifies as a strategic constraint that at least two plants in the world must produce or must be able to produce the products.

### *Product Focus*

In a product focus strategy, each plant specializes in the production of a single class of finished products. Each plant serves the whole world for that group of finished products. This strategy allows the plant economies of scale, such as product design, production design, and avoids diseconomies of scope, such small production batches. The finished goods have to be distributed of large geographical areas. This strategy is not robust, since a catastrophic occurrence at the single plant would shut down production in the whole world for a limited number of finished goods.

### *Process Focus*

In process focus strategy, each plant specializes in a particular manufacturing process, which typically corresponds to a stage in the overall manufacturing process, such as component production, assembly of subcomponents, or finished product assembly. This strategy also allows for economies of scale and economies of scope. The plant may use a higher level of automation or it may be located in a location with inexpensive manual labor. The disadvantage of this strategy is that it requires tight control integration among the different stages to ensure good production performance of the overall supply chain. This strategy also may require more transportation of work-in-process goods.

### *Dispersion*

In a dispersion strategy, plants are located at various locations geographically dispersed over the world. Each plant may have the capability to product a limited number of products or execute a limited number of processing steps. The overall goal is to have overlapping coverage by several plants of the demand for various products in the world. This strategy tends to have both diseconomies of scale and of scope. However, it is considered to be very robust since for every product-customer combination there are at least two plants capable of servicing this demand and these plants are geographically not far from the

customers. However, this strategy requires extensive coordination between the various plants to provide acceptable service to the customers while maintaining acceptable capacity utilization at the various facilities.

## **Strategies for distribution network configuration**

### *Consolidation*

The consolidation strategy uses a single large distribution center to service most of the customers in the world with a large variety of products. The strategy has the advantage of the economies of scale. One specific effect is reduction of safety inventory since the demand uncertainty of many customers is pooled together to create a more stable aggregate demand. Another advantage is the reduced fixed facility costs. The disadvantages are related to higher distribution cost of the finished goods and reduced robustness of the distribution system.

### *Customer Focus*

The customer focus strategy use a number of geographically dispersed distribution centers close to customer markets so that the transportation time to the customer is kept below a certain bound. This leads to faster response times and a higher level of service to the customer. However, demand pooling is much more limited and hence the total safety inventory in the system tends to be larger. Cycle inventories may also be larger than in the case of a consolidated warehouse, since the local demand may warrant less frequent replenishment. This strategy has diseconomies of scale and scope and higher fixed and operating costs are typical.

### *Co-Location*

The co-location strategy places a distribution center next to every manufacturing facility so that the distribution center can perform some of the final value-added operations on the product. The distribution center functions as the finished goods storage location for that manufacturing plant.

## **6.4. Computer Implementation**

### **Decision Support System Components**

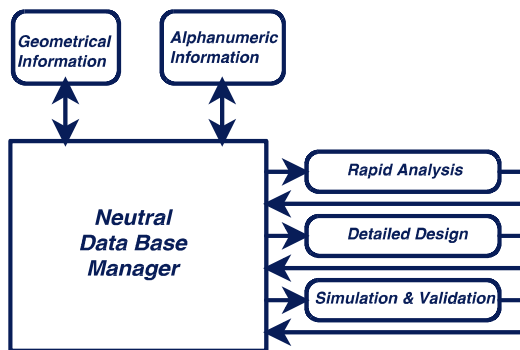
System Data and Data Base

## Design Models

## Solution Algorithms

## Reports, Displays and Interactive Executive

While the solution of large mixed integer programming models has been one of the limiting factors on the implementation of optimization based techniques for the design of strategic logistics systems, the lack of easy interpretation and representation of the results has also contributed to the lack of acceptance by industry. Because our model is generic, i.e. has standard components, we were able to develop a graphical representation of the problems. At the same time we were able to develop a relational database corresponding to the coefficients and parameters in our model. The relational database can be stored as a set of flat files or in a true relational data base manager.



**Figure 6.19. CIMPEL Component Structure and Flowchart**

We selected the Microsoft Windows environment for our implementation because of its widespread acceptance and familiarity in industry. A sample screen of the CIMPEL program is shown in Figure 6.20. The user can select in the standard fashion the algorithms to be executed. After a solution has been obtained, the user can change through simple dialog boxes parameter values, force facilities open or closed, etc. For small or relatively simple cases the mixed integer programming solver can be called directly from within the CIMPEL program through a dynamic link library. For larger cases, the MPS file is generated, the solver is run in batch mode, and the solution file is read back into CIMPEL to display the results.

In our experience, the use of such a graphical front end is an absolute requirement for the adaptation of optimization-based techniques in the design of industrial logistics systems.

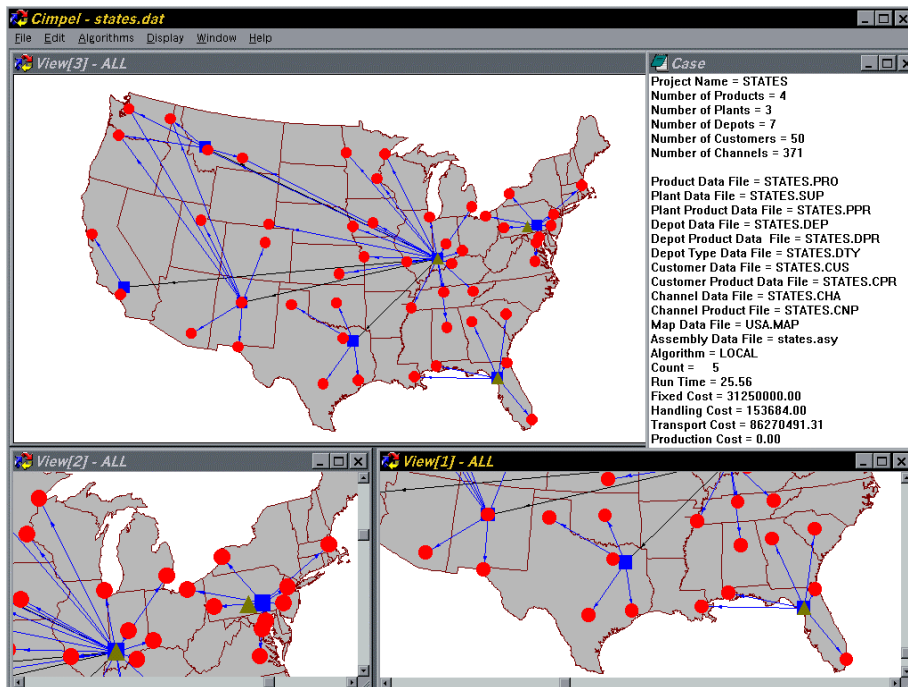


Figure 6.20. Cimpel Screen Illustration

**Edit Customer Cus**

Name: Customer

Label: Cus

Longitude or X Coordinate: -80 0 0

Latitude or Y Coordinate: 35 0 0

Country: USA

Number of Sources: Multi

Max Distance to Source: 12427.51

Max Time to Source: 999999.99

Display Symbol: CIRCLE

Display Size: 20

Display Color: RED

Products

OK Cancel Help

Figure 21. Catenas Edit Customer Dialog Window

**Edit Channel From Supplier HOU To Customer CHI**

Input Output

Transport Mode: Truckload

Distance: 1131.13415649957

Mean Transit Time: 0.00646362375142613

Transit Time Distribution: Deterministic

Transit Time Parameter 1: 0

Transit Time Parameter 2: 0

Shipping Frequency: 1

INCO Terms: FOB

Display Color: FOREST

Products Periods Resources

OK Cancel Apply Help

Figure 22. Catenas Edit Channel Input Dialog Window



Figure 6.23. Design Tools for the 21st Century

## Exercises

## References

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