



CTL.SC2x Supply Chain Design

Key Concepts



Complete Key Concepts Document

V2.0

This document contains the Key Concepts documents from each lesson within the SC2x course.

These are meant to complement, not replace, the lesson videos and slides. They are intended to be references for you to use going forward and assume you have learned the concepts and completed the practice problems.

This is an early stage draft of material, so please post any suggestions, corrections, or recommendations to the Discussion Forum under the topic thread Key Concept Documents Improvements.

Thanks,

Chris Caplice and the SC2x Teaching Community

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Week 1 Lesson 1: Introduction to Supply Chain Design

Learning Objectives

- Identify physical, financial, and information flows inherent to supply chains
- Recap SC1x: demand forecasting, inventory management, transportation
- How to approach Supply Chain Design for different products and companies
- Present a road map for the course

This lesson presented a short overview of Supply Chain Design; why it is important, how it is difficult, and how it can be approached depending on the type of products in your supply chain.

In a short review of the material from SC1x we saw why Supply Chain Design is important: because you have many choices. There are many ways to handle demand forecasting, inventory control, movement between facilities, how to work with customers and suppliers or how to organize the supply chain function. There is no single best way for all situations, not even within a single firm.

In fact, Supply Chain Design is as much an art as it is science. Science because we can quantify the impact of different choices, and find the optimal trade-offs between different choice parameters. But also an art because the assumptions we make are never going to completely match reality, and because the data we use for our models is never going to be completely accurate. There is no single right way of making these assumptions – doing this in a “good” way for a particular problem is more art than science!

Still, we learned that there are some frameworks, tools, and methods to aid the design process. Some of these have been presented in SC1x and are recapped below. Others will be presented during the course. In presenting these tools, the course will revolve around the flows in a supply chain, with each design issue discussed in a separate module:

- **Design of Physical Flows.** How should materials flow through the supply chain? We will model physical flows taking into account the costs of transportation and facilities. We will balance costs and service using Mixed Integer Programs. However, key is in not just solving the models, but in interpreting the results. Remember, the tools are *decision-support* tools, they are intended to support decisions, not make them for us!
- **Design of Financial Flows.** How to translate supply chain concepts and actions into the language of the CFO (Chief Financial Officer)? We will go through activity based costing, cash flow analysis and capital budgeting to better understand how supply chain design decisions translate to changes in the income statement and the balance sheet.
- **Design of Information Flows.** For this module, we will follow the SCOR-model’s three phases of Source, Make, and Deliver. How should you work with suppliers? How should information be coordinated between different manufacturers, internal and external? And how should you

coordinate and collaborate with customers? In this module strategies and procedures for this is discussed.

- **Designing the organization.** How should a supply chain be organized? We will investigate supply chain processes and how the measuring of the performance of the processes create different incentives. We will also discuss organizational structure.

Key Concepts:

Supply Chains - Two or more parties linked by a flow of resources that ultimately fulfill a customer request

Supply Chain Flows – physical flows, financial flows, and information flows. All are important to consider when designing a supply chain.

We went through a number of concepts presented in SC1x, which are important for the continuation of the course and thus are repeated here

Demand forecasting matrix

		Product Technology	
		Current (Have History)	New (No History)
Market	Current (Have History)	<p>Market Penetration</p> <p>Forecasting Approach: Quantitative analysis of similar situations with item using history</p> <p>Time Series, Exponential Smoothing, Regression</p>	<p>Product Development</p> <p>Forecasting Approach: Analysis of similar items: "looks-like" analysis or analogous forecasting</p> <p>Regression of "looks like" items</p>
	New (No History)	<p>Market Development</p> <p>Forecasting Approach: Customer and market analysis to understand market dynamics and drivers</p> <p>Customer Panels, Experimental</p>	<p>Diversification</p> <p>Forecasting Approach: Scenario planning & analysis to understand key uncertainties & factors</p> <p>Delphi, Expert Panel, Scenario Planning, Bass Diffusion</p>

Forecasting truisms:

- Forecast are always wrong – use ranges and track forecast error
- Aggregate forecast are more accurate – risk pooling reduces coefficient of variation
- Shorter time forecasts are more accurate – postpone customization as late as possible

Continuous review and periodic review

Inventory is generally managed using one of two key types of policies: policies using continuous review or policies using periodic review.

- *Continuous review* means that the inventory position is continuously supervised (presumably by software). As soon as the inventory position reaches a pre-determined level

s a replenishment order of Q units is placed. Consequently, the time between orders is uncertain.

- *Periodic review* means that the inventory position is reviewed at certain reoccurring points in time, such as every evening after a retailer closes the store. Based on the current inventory position, a replenishment order is placed to bring the inventory position up to a pre-determined level S . Consequently, the order quantity is uncertain.

Both policies are used when decisions are made for a long horizon, where the items can be stored between periods of replenishment, but demand in each replenishment period is uncertain.

Transportation options

There are several ways of organizing the transportation in a supply chain. Among them:

- One-to-one: direct point-to-point movements from origin to destination, e.g. daily full van loads to each customer
- One-to-many: multi-stop moves from a single origin to many destinations
- Many-to-many: moving from multiple origins to multiple destinations usually with a hub or terminal – this decouples line haul (from e.g. a supplier to a terminal) from local delivery operations (from e.g. a terminal to stores)

Total cost equation

The total cost equation specifies the total logistics cost for a system for an arbitrary time period:

Total cost = Purchase (Unit Value) Cost + Order (Set Up) Cost + Holding (Carrying) Cost + Shortage Cost

- Purchase: Cost per item or total landed cost for acquiring product.
- Ordering: It is a fixed cost and contains cost to place, receive and process a batch of good including processing invoicing, auditing, labor, etc. In manufacturing this is the set up cost for a run.
- Holding: Costs required to hold inventory such as storage cost (warehouse space), service costs (insurance, taxes), risk costs (lost, stolen, damaged, obsolete), and capital costs, both for units in-transit (pipeline inventory) and in warehouse (cycle stock + safety stock)
- Shortage: Costs of not having an item in stock including backorder, lost sales, lost customers, and disruption costs.

With formal notation:

- D: Demand rate (units/time)
- Q: Order quantity (units)
- L: Lead time (time)
- σ_{DL} : Standard deviation of demand during the lead time

- k: Safety stock factor
- c: Purchase cost (\$/unit)
- c_t : Ordering Costs (\$/order)
- h: Holding rate – usually expressed as a percentage (\$/\$ value/time)
- c_e : Excess holding Costs (\$/unit-time); also equal to ch
- c_s : Shortage costs (\$/unit)
- TC: Total Costs – the sum of all four cost elements

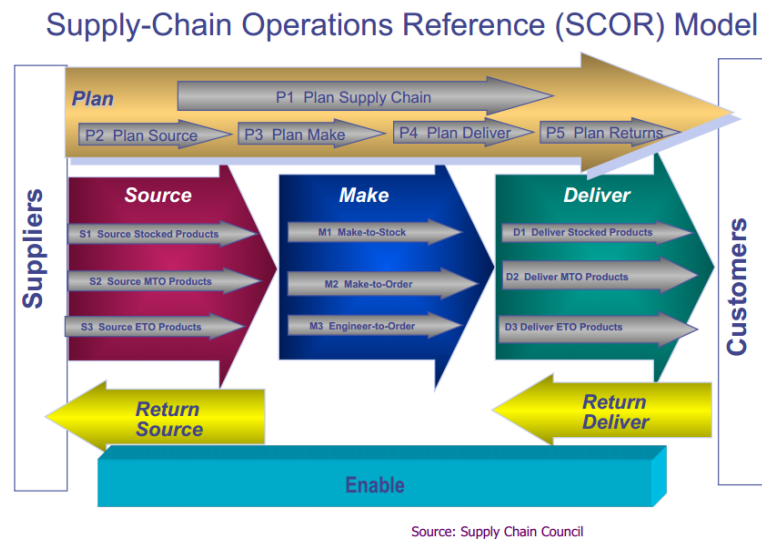
We get that

$$TC = cD + c_t \left(\frac{D}{Q} \right) + c_e \left(\frac{Q}{2} + k\sigma_{DL} + DL \right) + c_s P[\text{StockOutType}],$$

From the formula we see that transport speed as well as forecast accuracy has an impact on total cost through the inventory costs.

SCOR-model

In the third module, when investigating design of information flows, we follow the Source-Make-Deliver process of the SCOR-model.



Fisher's model: Innovative versus functional products

When designing a supply chain, the design needs to be adapted to the type of products it is intended for. In Fisher's model, products can be classified as being either more Functional or more Innovative.

- *Functional*: predictable demand, long life cycle, low margin, low error in production, low stock-out rates

- *Innovative*: unpredictable demand, short life cycle, high margin, high error in production, high stock-out rates

As a rule of thumb, functional products should have a design focusing more on efficiency, whereas innovative products should have a supply chain design focusing more on matching supply with demand.

Remember that these are not hard and fast rules. In practice there are, of course, many products that share characteristics with both segments. Most firms are going to have a portfolio of supply chains. Further, innovative products often move into becoming more functional as their markets become more mature. This requires adaptation of the supply chain design. For instance, when the patent protection for the cholesterol lowering drug Lipitor went out, Pfizer had to reduce the price to protect the drug from generic competition. With a lower margin, the supply chain must be design with a higher focus on efficiency.

Additional References:

Arntzen, B. (2013) MIT Center for Transportation & Logistics, Hi-Viz Research Project.

Fisher, M. (1997) "What Is the Right Supply Chain for Your Product?" Harvard Business Review.

Olavsun, Lee, & DeNyse (2010) "A Portfolio Approach to Supply Chain Design," Supply Chain Management Review. Adapted from Sheffi (2010) ESD.260 Course Notes

Week 1 Lesson 2: Introduction to Network Models

Learning Objectives

- Introducing network models
- How to formulate the transportation problem and the transshipment problem
- How to create spread sheet models to solve the transportation problem and the transshipment problem
- Understand the basic assumptions of the models

Summary of Lesson

Network models are a useful class of models that can be utilized to aid many types of supply chain decisions. In this lecture, we introduced the basic notations of these models, and showed how to set up a simple spread sheet model in Excel or Libre Office to solve the model. We focused on two types of models that are relatively simple yet powerful in deriving insights to support supply chain design decisions: the Transportation Problem and the Transshipment Problem.

Both the transportation problem and the transshipment problem consider an underlying network of nodes (facilities) and arcs (transport flows between facilities). The objective is to minimize costs for a given period (day, week, year) by choosing the amount of units to be shipped/transported on different arcs during the period to fulfill demand, while meeting the capacity constraints. Both problems can be formulated as linear programs (see below) and solved using your spread sheet software of choice (e.g. Excel or Libre Office). For details on how to run the solver, please refer to the separate guide for how to setup and run the solver, which is found in the course material.

In the lesson we worked through the example of SandyCo, a sand supplier with two plants and three sales regions. To solve the problem, we went through the following steps:

1. Read and understand the problem thoroughly
2. Determine the decision variables (DVs)
3. Formulate the objective function as a linear function of DVs
4. Formulate constraints as linear functions of DVs
5. Identify upper and lower bounds on DVs

By using the solver in the spread sheet software, and including the constraints on supply and demand, we managed to find the cost-optimal solution to SandyCo's transportation problem.

We then introduced two packaging centers to SandyCo's network that all sand had to go through on its way from a plant to a sales region. We showed that to solve the problem, we needed to introduce a *conservation of flow constraint* – all that comes in to a transshipment node must come out. That is, all the sand that went into a packaging center had to be delivered to a sales region.

Lastly, we discussed some of the limitations to these network models. First, in the models presented in the lesson we limited ourselves to *variable costs for the arcs* (i.e. transport costs per unit). Clearly, the cost structure for a network is, in practice, often more complex, involving costs that are both fixed or vary over different parameters. We also considered a *single commodity* – all plants produced perfectly substitutable goods. The demand was *deterministic*, that is, we assumed that demand was perfectly known for the entire period. Finally we also assumed there was no capacity limits on the arcs, so that any amount could be transported. Clearly, all of these assumptions limit our results, so we have to be careful what inferences we make from the models. In the coming lessons we will relax some of these and also discuss how to make inference while still using a relatively simple model.

Also – we noted that transportation and transshipment problems may have several optima (the same value of the objective function is found by different value on the decision variables). Depending on the algorithm and software, different optima may be the “first choice” of the algorithm.

Key Concepts:

Network terminology

- **Node or vertices** – a point (facility, DC, plant, region)
- **Arc or edge** – link between two nodes (roads, flows, etc.)
- **Network or graph** – a collection of nodes and arcs

The transportation problem

The transportation problem considers transports from i supply nodes to j demand nodes over arcs ij . With each arc is associated a cost c_{ij} . The amount of units transported on each arc ij is denoted x_{ij} . These x_{ij} 's are our *decision variables* – we want to find the amounts for each arc that minimizes total cost.

Let z be the objective function (i.e., the function expressing the total cost we want to minimize). We introduce the following additional notation:

S: Set of supply nodes

D: set of demand nodes

S_i : supply capacity in node i

D_j : demand in node j

The transportation problem is then formulated in the following way:

$$\text{Min } z = \sum_i \sum_j c_{ij} x_{ij}$$

s.t.

$$\sum_j x_{ij} \leq S_i \quad \forall i \in S$$

These are the supply constraints – the total number of shipped units from a supply node i to **all** demand nodes j must be less than (or equal to) the supply capacity of node i .

$$\sum_i x_{ij} \geq D_j \quad \forall j \in D$$

These are the demand constraints – the number of shipped units to a demand node j from **all** supply nodes i must be at least the demand at node j .

$$x_{ij} \geq 0 \quad \forall ij$$

These are the non-negativity constraints – we do not allow negative volumes on any arc

The transshipment problem

The transshipment problem is similar to the transportation problem. The difference is that we now introduce a set of nodes that are neither supply nodes nor demand nodes, but transshipment nodes, meaning that over a period, anything that goes in to the transshipment node needs to come out.

We formulate the problem in the following way

$$\text{Min } z = \sum_i \sum_j c_{ij} x_{ij}$$

s.t.

$$\sum_j x_{ij} \leq S_i \quad \forall i \in S$$

$$\sum_i x_{ij} \geq D_j \quad \forall j \in D$$

$$\sum_i x_{ij} - \sum_i x_{ji} = 0 \quad \forall j \notin D, \notin S$$

$$x_{ij} \geq 0 \quad \forall ij$$

Note that we have the same formulation as for the transportation problem **but** with one difference: a third constraint has been added (highlighted). This constraint is the constraint forcing the transshipment node to be “empty” – the *conservation of flow* constraint. Consider transshipment node j . The first sum in the constraint is then the total number of units shipped to node j from all other nodes i . The second sum is the total number of units shipped from node j to all other nodes i . The constraint says that this difference must be zero.

Additional References:

Watson, Michael, Sara Lewis, Peter Cacioppi, and Jay Jayaraman, Supply Chain Network Design, 1st Edition, FT Press, 2013

Chopra, Sunil and Peter Meindl, Supply Chain Management, Strategy, Planning, and Operation, 5th edition, Pearson Prentice Hall, 2012

Week 2 Lesson 1: Facility Location Models

Learning Objectives

- How to formulate the continuous single facility problem
- How to formulate and solve network facility location problems (discrete candidate selection)
- How to use network flow models to evaluate the number of facilities in a network
- How to incorporate Level-Of-Service (LOS) constraints in the network models

Summary of Lesson

In the previous lesson we introduced network flow models and showed how to solve them. In all those models, however, we assumed that every facility in the network was used. In this lesson, we relaxed that assumption. First, we investigated where to locate a facility, given that we needed a *single* facility. We then proceeded to investigate how many (and which) facilities to use, given a set of candidates. Lastly, we investigated how to incorporate explicit Level Of Service (LOS) constraints in our models, to investigate certain cost and service trade-offs in more detail.

For the *single facility case* we looked at two fundamentally different ways of approaching the decision. The first was by considering all points in the Euclidian space as potential candidates, and search for an optimal location for a facility anywhere in this space. For this we used both the center-of-gravity-method and the Weber method. While the former has an intuitive appeal, we saw that the Weber method is more appropriate as it minimizes the actual transportation costs. The fundamental problem of relying on either of these methods, though, is that the optimal solution may end up in places that are not feasible for a wide number of reasons: lack of infrastructure (we could end up in a lake!), high construction costs, difficulty of getting permits etc. So while these methods are useful to get a ball park figure of where to locate the facility, they provide only a region to target. We therefore investigated another approach where, instead of considering the full Euclidian space, we investigated only a finite set of candidate locations. We showed that this problem can be approached using a Mixed Integer Linear Program (MILP), for which we can use a spread sheet solver to find the solution.

We then saw that the MILP used to solve the single facility problem could be easily extended to investigate the case of *multiple facilities*. The model could then be used to answer both how many facilities to use, and which facilities to use.

Finally, we went through how to incorporate explicit LOS constraints in our models. Two types of service performance were considered: the average weighted distance to customers, and the amount of demand within a certain distance from a DC. We saw how we could specify bounds for these performance measures and include them in the MILP, to ensure that the optimal solution met the LOS requirements.

Key Concepts:

Continuous single facility problem

With a continuous single facility model, the aim is to find one optimal point in the Euclidian space. In the lesson, we went through two methods of doing this.

Center of gravity. With a center of gravity model, we let the optimal point's coordinates be given by weighted x and y coordinates, where the weight given to each node k is given by the demand in that node. For instance, if we want to find the optimal location for a DC that will support 3 stores, the optimal location will be given by the weighted coordinates of the stores, where each store's coordinates are weighted by the demand at the store. Formally, we have

$$x = \sum_{k \in K} w_k x_k$$
$$y = \sum_{k \in K} w_k y_k$$

Weber method. With the Weber method, instead of taking the weighted coordinates of the nodes, we try to minimize the weighted Euclidian *distances* between nodes k and location (x,y) . The weights are still given by the demand at the different nodes. We thus have the optimal location given by the following

$$\text{Min } z = \sum_{k \in K} w_k d_k(x, y) = \sum_{k \in K} w_k \sqrt{(x - x_k)^2 + (y - y_k)^2},$$

Where z is optimized by changing the decision-variables x and y .

Network facility location

When we have a number of candidate locations to choose between, we can create a network flow model to find which of the candidate locations provide the lowest cost. To do this, we formulate a Mixed Integer Linear Program (MILP). Our problem is MILP because it has a linear objective function and linear constraints, but with some variables being integers instead of continuous. The integer values are the Y_i 's that describe whether facility i is used ($Y_i = 1$) or not ($Y_i = 0$). Associated with each facility is a fixed cost for the time period, f_i . As with the transportation problem, the number of units shipped between two nodes are given by the x_{ij} 's.

We introduce the following additional notation:

M_{ij} : An arbitrary large number, specific to each arc (but the value could be the same between arcs)

P_{\min} : Minimum number of facilities

P_{\max} : Maximum number of facilities.

With z being the objective function, the problem is formulated as follows

$$\text{Min } z = \sum_i \sum_j c_{ij} x_{ij} + \sum_i f_i Y_i$$

s.t.

$$\sum_j x_{ij} \leq S_i \quad \forall i \in S$$

$$\sum_i x_{ij} \geq D_j \quad \forall j \in D$$

$$x_{ij} - M_{ij} Y_i \leq 0 \quad \forall ij$$

$$\sum_i Y_i \geq P_{MIN}$$

$$\sum_i Y_i \leq P_{MAX}$$

$$x_{ij} \geq 0 \quad \forall ij$$

$$Y_i = \{0,1\} \quad \forall i$$

These are the supply and demand constraints

These are the *linking constraints* – to ensure that we do not allocate shipments to a location that is not used, the units shipped on an arc must be less than (or equal to) a large number times the Y associated with the node where the transport originates

These are constraints on the number of facilities to use – the sum of the Y -variables will be the total number of facilities in use

These are the non-negativity constraints (for x 's) and the binary constraints (for the Y 's)

Note that for a single facility location problem, we let $P_{MIN}=P_{MAX}=1$.

Multiple location selection model

For this we use the same MILP as for the network facility location problem above. If we have a given number of locations we want to choose, we let $P_{MIN}=P_{MAX}=k$, where k is the number of locations. If we instead want to find the optimal number of locations, we remove the constraint on the sum of Y , so that this sum can be infinitely large (or less than some large number). Note that we want to keep a minimum constraint on the sum of Y , otherwise the model will choose all $Y_i=0$.

Enforcing LOS

To create enforcing LOS, we use the same basic setup as before, with the highlighted addition:

$$\text{Min } z = \sum_i \sum_j c_{ij} x_{ij} + \sum_i f_i Y_i$$

s.t.

$$\sum_j x_{ij} \leq S_i \quad \forall i \in S$$

$$\sum_i x_{ij} \geq D_j \quad \forall j \in D$$

$$x_{ij} - M_{ij} Y_i \leq 0 \quad \forall ij$$

$$\sum_i Y_i \geq P_{MIN}$$

$$\sum_i Y_i \leq P_{MAX}$$

$$\sum_{ij} \left(\frac{d_{ij} x_{ij}}{\sum_j D_j} \right) \leq \text{MaxAvgDist}$$
$$\sum_{ij} \left(\frac{a_{ij} x_{ij}}{\sum_j D_j} \right) \geq \text{MinPctIn50}$$

$$x_{ij} \geq 0 \quad \forall ij$$

$$Y_i = \{0,1\} \quad \forall i$$

Note that two constraints were added (highlighted).

- *A constraint on the average weighted distance.* This constraint takes the (demand)-weighted average distance and ensures that it is less than or equal to some critical level MaxAvgDist, the maximum allowed average weighted distance. Consequently, the model will make sure that the average customer is not “too far away”.
- *A constraint on the amount of demand within a certain distance.* The previous constraint considers only the average, which means that we do not know how much of our demand that has an LOS below a certain threshold. For instance, even if we know that the average distance is less than 50 miles, we may be interested in ensuring that at least 75% of our demand is less than 50 miles from a DC. This constraint ensures that. For this we need to specify a distance (say 50 miles). The binary variable a_{ij} then denotes whether or not a certain link is longer ($a_{ij}=1$) than 50 miles or not ($a_{ij}=0$). That is, the constraint ensures that not “too many” customers are far away.

It is also important to note that when we introduce service constraints, we may need to introduce binding constraints on the demand. If not, the model may try to enforce the service constraint by delivering more than demanded to certain demand nodes. This will however be artificial (and unsold) demand. To ensure this is not the case, let the demand constraint be given by equality, instead of the computationally more efficient inequality.

Week 2 Lesson 2: Supply Chain Network Design

Learning Objectives

- How to combine previous models to a Supply Chain Network Design Model
- How to fill the model with data
- How to construct relevant baselines for the analysis
- How to run scenarios and interpret the results

Summary of Lesson

In this lesson, we combined the different techniques learned in the two previous lessons into one model. We took the network optimization we learned two lessons ago, and combined it with the facility location models we just learned the previous lesson and tied those together into what's known as a supply chain network design model.

Throughout the lesson we went through the case of NERD4. Using this case as an example, we showed how to collect data for the model, how to construct relevant baselines for our analyses, how to run scenario analyses and interpret the results. Remember, it is easy to run a scenario – it can be more difficult to interpret the results and make correct inferences from the model.

Key Concepts:

Data collection: Transportation Data

The first step in building the model is to collect data. For transports, we want to know the costs and capacities associated with both inbound and outbound transportation.

With the Supply Chain Network Design Model, transportation costs are assumed linear in transport volumes. Clearly, this is not always the case: there may be minimum charges, fixed costs, or many other types of fixed and variable cost components. However, in order to build the model, a linear approximation must be found. This could be done in several different ways:

- Take average transport cost from historical data
- Use list prices
- Use regression analysis to find the costs
- Use benchmark rates from other sources

Whichever way you use to uncover these costs, you need to be aware of how your linear approximation affects the reliability of the model. For a brush-up on linear regression, please refer to the Key Concepts document from SC1x.

Data collection: Facility Data

The Supply Chain Network Design Model allows facility costs to be both fixed and variable in volume. There will always be people arguing that “all costs are fixed” or “all costs are variable”, but what you need to consider is how fixed and variable cost components *affect the solution your model searches for*. Fixed costs will make it expensive to have many facilities, so the model will try to reduce the number of facilities. Variable costs will make it costly to have long distances, and the model will therefore try to increase the number of facilities (or at least reduce average distances).

If facilities are owned and/or operated by a third-party, finding the fixed and variable costs is normally straight-forward – they are given in the contract.

If a facility is operated in-house, other techniques have to be used. Among them:

- Activity-based costing to find variable costs
- Regression analysis over volume (note that the intercept is the fixed cost component)

For facilities we also need to understand the capacity. The capacity is the maximum throughput over a specified unit of time (e.g. a week). Note that this can be very difficult to measure in practice, since shifts can be added, while capacity also depends on planning and scheduling.

Network Design Baselines

You should be careful in which baseline you use for comparing your results. Three baselines are important to consider:

- *Baseline 1 – Actual costs*: what cost does the model give us if we use the actual, current flows? We want to know how well the model matches reality. You use this baseline to calibrate the model.
- *Baseline 2 – Adhere to policy*: there may be a policy in place that you are simply not adhering to in your operations. With this baseline you want to know how other solutions compare to what you ought to be doing according to the policy in place.
- *Baseline 3 – Optimal DC assignment*: if you were to use the optimal assignment for the DC – what would the solution look like? With this baseline you can isolate the effect of number of DCs since you optimize allocation.

It is important to keep in mind that you compare design changes to the right baseline. For instance, if you use the model to figure out how much you could reduce costs by reducing the number of DCs, you need to be aware the model will tell you this while, at the same time, optimizing the allocation given the number of DCs. Hence you should compare your solution - the “optimal number of DCs under optimal allocation” - to Baseline 3, where you have the “current number of DCs under optimal allocation”. Why? Because otherwise you compare solutions that have optimal allocations to solutions that do not have optimal allocations – you do not isolate the effect of changing the number of DCs.

Run Scenarios

One of the key benefits of the Supply Chain Network Design Model is that it is easy and fast to run different scenarios. Scenarios can investigate uncertain parameters (sensitivity analysis) or explore how different constraints affect the optimal solution.

While this is a great benefit, it is important not to get “analysis paralysis” – just because it is possible to run many scenarios does not mean it is the way to go. It is important to understand which scenarios that are relevant and, most importantly, how to interpret the results. For instance, which baseline should be used for comparing the results of the scenario?

Week 3 Lesson 1: Advanced Topics in Supply Chain Network Design

Learning Objectives

- How to perform robust optimization using supply network models
- How to construct multi-commodity flow models
- How to build in flexibility
- How to expand the model into several time periods
- How to incorporate inventory costs into the network models

Summary of Lesson

In this lesson we provided overviews of some advanced topics in Supply Chain Network Design. We first introduced and provided an example of robust optimization using simulation along with optimization. This is a relatively simple and quick way to get a handle on the impact of the variability of demand (or other factors) on facility selection. We then introduced multi-commodity flow problems, which significantly increases both the complexity and size of the models. While more complicated, multi-commodity flow models are still very similar to the transshipment and facility location models explored previously. The concept of Flexibility was introduced following the approach developed by Jordan and Graves (1995). We found that forming chains between plants increases the overall flexibility at a much lower cost than if we provided full flexibility. The final expansion of the model we explored was covering multiple time periods. This is meant for more tactical planning periods – but again, the models were very similar to the simpler single commodity transshipment models with the addition of inventory balance equations. The final section discussed how pipeline inventory, safety stock, and cycle stock can be included in strategic network design models.

Key Concepts:

Robustness in supply chain network models – demand uncertainty

Supply Chain Network Design (SCND) models are deterministic. They assume that each input value is known with certainty and exhibits no variability. We know this is not the case in reality. So, while there are many more sophisticated mathematical techniques that address this shortcoming, we can use simple Monte-Carlo simulation to try to understand how robust our solutions are.

Essentially, the method involves re-solving the model with new input information each time. The new input data is randomly selected using estimates of the distribution of the variables. In the videos, we showed how to do this for a facility location problem by simulating different demand values for the customer locations. The easiest way to simulated random variables in spreadsheets is to use the RAND() function. It returns a number between 0 and 1.00 following a uniform distribution.

- To simulate a uniform distribution with mean of X, plus or minus Y%, we would set the value to:
 $=X*(1+(RAND()-0.50)*(2*Y))$
 So that if we wanted 250 +/- 20%, we'd use $=250*(1+(RAND()-0.50)*0.40)$ returning values from ~200 to 300.
- To simulate a Normal Distribution with a mean of X and a standard deviation of Y, we would use:
 $=NORM.INV(RAND(), X,Y)$
 So for mean of 300 with standard deviation of 45 we'd use $=NORM.INV(RAND(),300,45)$ returning values $\sim N(300,45)$.

After each new simulation of input values, the model is run and the results are stored. The analysis of the resulting runs can help determine which facilities, for example, are more likely to stay open under a variety of demand outcomes. This is not an exhaustive method – simply one approach to gauge the robustness of the design.

Multi-commodity flows

Multi-commodity flow models introduce multiple products. Each product will have its own demand, supply and other characteristics. If each product is independent and there are no interactions, then we can simply model each commodity individually. Whenever there is a shared resource (common capacity constraint, for example), then a multi-commodity flow model is needed.

The formulation is shown below. The primary addition to the original formulation is the additional subscript of k for the different commodities for the costs, decision variables, demand, and supply. We added, in this formulation, two types of supply capacity constraints: one that is location-commodity specific and one that is location specific for all commodities there. These are quite common in practice.

$$\text{Min } z = \sum_i \sum_j \sum_k c_{ijk} x_{ijk}$$

s.t.

$$\sum_j x_{ijk} \leq S_{ik} \quad \forall i \in S, k \in K$$

$$\sum_j \sum_k x_{ijk} \leq S_i \quad \forall i \in S$$

$$\sum_i x_{ijk} \geq D_{jk} \quad \forall j \in D, k \in K$$

$$\sum_i x_{ijk} - \sum_i x_{jik} = 0 \quad \forall j \notin D, \forall i \in S, k \in K$$

$$\sum_i \sum_k x_{ijk} \leq CAP_j \quad \forall j \notin D, \forall i \in S$$

$$x_{ijk} \geq 0 \quad \forall ijk$$

Solving the MCF models are the same as the single commodity models – they are simply larger and more difficult to interpret. The multiple layers of constraints make the calculation of individual costs difficult – this will be discussed in Week 4 when we introduce activity based costing and managerial accounting.

Chain approach to flexibility

As noted earlier, SCND models do not consider variability of demand. A MILP solution, while optimal, can often be quite fragile. This means, that if any of the input values change, the total costs could change dramatically. We might want to find a SCND that is more flexible in its ability to handle changes in demand – in particular sudden surges or peaks in demand for certain products or commodities.

Full flexibility can be achieved by forcing each plant to manufacture every product. This provides complete demand flexibility as capacity can be diverted from any plant to handle surges of a certain product. This is very expensive, however. The opposite extreme is to create dedicated plants that only manufacture a single product. Dedicated plants are able to leverage economies of scale and tend to increase the level of expertise, however, they also increase risk exposure and limit flexibility to respond to surges. A clever design called chaining allows manufacturing networks to achieve most of the flexibility allowed in fully flexible designs, but at a fraction of the cost.

Time-expanded networks

Up to this point, each model assumed a single bucket of time. We have expanded this now to consider multiple time periods. This is more common with tactical time frame (weeks to months) models.

To model multiple time periods we need to introduce the idea of the inventory level at a location, j , at time t , I_{jt} . This is the quantity available at location j at the *end* of time t . This allows us to charge an inventory holding charge (h) for each time period.

We also need to include an inventory balance constraint – similar to the conservation of flow constraints in transshipment models. This is the 3rd constraint in the formulation below, which states, the sum of all flow into node j during time t , minus the sum of all flow out of node j during time t , plus the inventory available at node j at the end of time $t-1$, minus the inventory available at node j at the end of time t is zero.

$$\text{Min } z = \sum_i \sum_j \sum_t c_{ijt} x_{ijt} + \sum_j \sum_t h I_{jt}$$

s.t.

$$\sum_j x_{ijt} \leq S_{it} \quad \forall i \in S, t \in T$$

$$\sum_i x_{ijt} \geq D_{jt} \quad \forall j \in D, t \in T$$

$$\sum_i x_{ijt} - \sum_i x_{jit} + I_{j,t-1} - I_{j,t} = 0 \quad \forall j \notin S, t \in T$$

$$I_{jt} = I_{initial} \quad \forall j, t = 0$$

$$x_{ijt} \geq 0 \quad \forall ijt$$

Inventory considerations in supply chain network models

Thus far, inventory has not been considered in the design of the supply chains! Surprisingly, it is very common to ignore inventory considerations when designing a supply chain. This is due to a couple different reasons. First, inventory policies are based on probabilistic models that do not combine well

with deterministic MILP optimization models. Second, most of the key determinants of inventory levels (demand variability, lead time, service level, order size, etc.) are only known tactically not strategically. Finally, inventory balance equations, which would be needed to model inventory costs, cannot be used to track and optimize strategic inventory decisions that are made at yearlong increments.

Instead, we suggested an approach that leverages the non-linear empirical relationship between inventory and throughput. It has been found that average inventory for a specified time period is equal to: αT^β where T is the throughput in items or value, and α and β are estimated coefficients. The β parameter is typically between 0.5 and 0.8. This provides some empirical adjustment to the square root rule for safety stock that was discussed in SC1x. One can simply add this quantity to different runs as a post-hoc analysis or incorporate it into the model with binary variables.

Additional references:

Jordan and Graves (1995), "Principles on the Benefits of Manufacturing Process Flexibility," *Management Science*, 41, (4), p 577-594.

Watson, Michael, Sara Lewis, Peter Cacioppi, and Jay Jayaraman, Supply Chain Network Design, 1st Edition, FT Press, 2013.

Shapiro, Jeremy. Modeling the Supply Chain, 2nd Edition, Duxbury Applied Series, 2007.

Week 3 Lesson 2: Practical Considerations in SCND

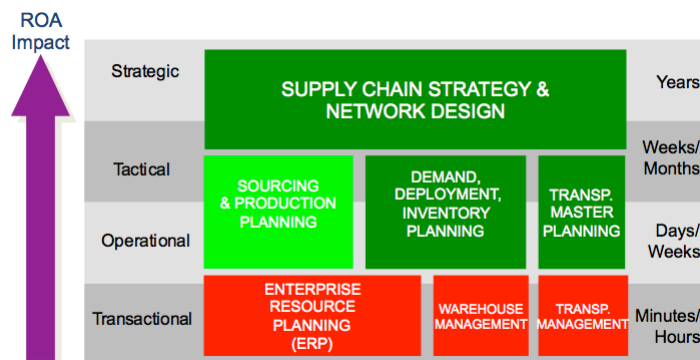
Learning Objectives

- Gain an appreciation and understanding of practical considerations when conducting SCND engagements
- Understand how the SCND problem fits within the larger context

Summary of Lesson

In this lesson we attempted to provide some realism to the mathematical content of the previous four lessons. While SCND problems are highly mathematical and depend on optimization, the majority of the problems that occur in practice have nothing to do with the actual models! It is usually a problem with the people involved: the objectives were not agreed upon or clearly stated, the scope kept changing, the wrong problem was solved, etc.

It is important to realize that SCND is just one problem in a larger set of supply chain problems that need to be solved. As shown in the figure below, SCND is a strategic decision that is conducted with multiple year time horizons and has a very high potential impact on Return on Assets or Investment. The transactional and tactical/operational problems are conducted more frequently but have a lower potential impact. All of these lower level solutions should align with the overall supply chain strategy and network design.



Source: Chainalytics

This lesson focused on four suggestions for conducting SCND initiatives within your own firm or for an outside firm. These suggestions were culled from my own experience as well as several other sources – especially Michael Watson and Steve Ellet. We summarized these lessons into four suggestions: Know thy project, Focus on the problem, Be experimental, and Separate the math from the decision.

Know Thy Project – It is important that you have a solid understanding of not only the physical supply chain (sources, facilities, products, flows, etc.), but also the people involved. You need to know the stakeholders but also the ultimate decision makers. There is an excellent article in the Harvard Business Review called “Who has the D?” that discusses how the decision making process in a firm can be

improved. It is important that you know “who has the D” – that is, the ultimate decision – for your project. Scoping meetings with all stakeholders are very critical here to establish the boundaries, objectives, and other rules of the road for a large project like a SCND.

Focus on the Problem - There is always tremendous pressure in a SCND engagement from the different stakeholders to explore every exception and essentially boil the ocean to explore every possible solution. This is impossible to do in reality. So, you need to know how to separate the important aspects from the trivial using segmentation and data aggregation as much as possible. Identifying the fewest possible number of products to model is critical – be sure to think of supply chain distinctions for products – not just marketing distinctions. Many managers (and your future stakeholders) will not understand that the model is a caricature of the supply chain, not a high-definition photograph! You have a variety of different analysis tools and techniques to address questions of varying importance: from large-scale MILP models to Side Scenario Runs to Quick Heuristic Analysis. Use them appropriately – if everything is equally important, then nothing is important!

Be Experimental – There are two aspects to this suggestion: building the model and using the model. When building the SCND model itself, I recommend using a spiral method (start small, test it, evaluate, adapt it, and repeat) versus the traditional waterfall method (collect all input, develop complete requirements, build the full model, test the complete model, release to users). By creating the model iteratively you build confidence in it, identify potential outliers, keep stakeholders engaged, and might end up with an early and unexpected solution. When running the model we recommend you try as many different scenarios and options as possible. This is why you go through the pain of creating these complex models! Running multiple scenarios allows you to: test and cost out competing ideas and strategies, understand internal trade-offs within the network, uncover opportunities for serendipitous discovery, and better communicate with stakeholders. Think of the SCND model as the ultimate “what if” machine that allows you to settle any arguments (or at least shed some insights) between competing stakeholders!

Separate the Math from the Decision – The final suggestion dealt with understanding the virtues of a mathematical model versus humans. Mathematical models are exceptionally good at making trade-offs between accurately quantified options. However, models will NEVER consider all factors and cannot fully represent reality. Humans are needed to determine what aspects are important and to provide the options and input for the model to consider. Also, because optimization models will do anything for a dollar (penny, euro, ruble, peso, or any other currency) the results should be scrutinized. The absolute lowest cost solution is rarely the right business solution. The key point is that mathematical models should be used for Decision Support not for the Decision itself. Executives and managers have additional experience and insights into the larger environment that need to be considered when making large and important decisions, like supply chain network design.

Additional References:

Watson, Michael, Sara Lewis, Peter Cacioppi, and Jay Jayaraman, Supply Chain Network Design, 1st Edition, FT Press, 2013.

Shapiro, Jeremy. Modeling the Supply Chain, 2nd Edition, Duxbury Applied Series, 2007.

Ellet, Steve, Conversations and Presentations, Chainalytics, 2005-2015.

Rogers, Paul and Marcia Blenko, "Who Has the D?: How Clear Decision Roles Enhance Organizational Performance," *Harvard Business Review*, January 2006.

Week 4 Lesson 1: Supply Chain Finance I – Accounting Fundamentals

Learning Objectives

- Understand the basics of financial reporting: the income statement and the balance sheet
- Understand the role of accounting
- Understand the impact of depreciation on the financial reports
- Become familiar with basic concepts used in accounting
- Understand some of the different choices open to an accountant

Summary of Lesson

This is the first lesson of four about Supply Chain Finance. This segment of the supply chain finance module focused on the components of the financial statements: the income statement, and the balance sheet. The lesson also provides a cursory overview of some of the most important concepts of accounting and finance from a supply chain manager's perspective including a short discussion of the role of accounting, the choices and accountant can make, the role and difficulties of depreciation, and an overview of basic accounting concepts.

Key Concepts:

The Income Statement

The Income Statement provides a summary of the flows in (revenue) and out (expenses) of the firm over a period of time; the net difference between the revenue and expense being the profit or loss of the firm. Put in another way, the income statement describes how the assets and liabilities are used during a particular period. You could also think of it as the sum of income-generating transactions, financial transactions over a stated period of time.

The three main components are:

- Revenues (turnover, sales, proceeds, 'top line') – the incoming flow
- Expenses (costs) – the outgoing flow
- Profit (income, earnings, 'bottom line') – the difference between incoming and outgoing flow

For a supply chain manager, there are several components to Expenses to be aware of:

- COGS (Cost Of Goods Sold, Cost of products sold) – these are the direct costs of producing the goods/services that are sold to generate revenues.
- Cost of Revenue (cost of sales) – Similar to COGS, but includes also costs outside of production, e.g. marketing expenses

- Depreciation – these are non-cash expenses associated with the use of capital equipment (for more about this, see below). Related is amortization – this a reduction in goodwill (goodwill is an intangible asset that arises when the firm acquires another firm at a price higher than the book value of the acquired firm)
- SG&A (Sales, General, and Administration) – overhead costs associated with generating revenue, including the sales force,
- Operating Expenses – the sum of COGS, Depreciation, and SG&A.

The Balance Sheet

The Balance Sheet presents the financial condition of the firm at one point in time. It lists the assets, which is something that is owned by the firm and has measured value. It also lists the liabilities, which are claims against the assets by other parties. You could also think of these as debts or obligations that the firm has to pay other people. The Balance Sheet gives a snapshot of the assets and obligations of the firm at a single moment in time. Assets always equal liabilities. Remember, the balance sheet report Book value, not Market value. These could be equal, but as we will see in the next lesson they may not be.

- Assets. You want to separate Current Assets from Long Term Assets. Current assets can be used on short-term to pay for obligations (e.g. cash, account receivables, inventories), whereas long-term assets are, as the name implies, long term (e.g. facilities, equipment – sometimes abbreviated PPE for Property, Plant and Equipment)
- Liabilities. Normally liabilities are divided into Current Liabilities, Long-term Liabilities (Dept), and Equity. Current liabilities generally have to be paid in the next accounting period and include, e.g., accounts payables. Long-term liabilities include e.g. loans, bonds, or mortgages. Equity is the capital that owners have put into the firm.

The Role of Accounting

The role of accounting is to record the transactions of a business. The accountant classifies the sources and use of funds.

There are primarily three types of reports prepared:

- Financial reports. These are intended for the firm’s investors, includes the income statement and the balance sheet.
- Tax accounting reports. These are provided for the government, in the US for the IRS.
- Product costing reports. These are used for management decision making.

There are certain choices that can be made, as long as the account follow generally accepted accounting practice.

Note that the financial reports provided to investors can differ from the tax reports. They serve different purposes. Financial accounting’s objective is to “present fairly the results of operations and the financial

condition of the company to its stockholders”, whereas corporate tax accounting’s objective is to “minimize current tax liability and defer payment of liability as long as possible”

This means that “the tax code allows companies to deviate from financial accounting in specific areas when calculating taxable income without having to change the corporate financial reports issued to stockholders”

Depreciation

Depreciation is a non-cash expense to the business. It can be thought of as the estimated cost of using an asset. For instance, if a machine is purchased to be used in a manufacturing setting, the depreciation of the machine represents the reduction in the value of the machine over the accounting period. This means that while depreciation is an expense, the value of the corresponding asset reduces by the same amount. So if the depreciation of a machine is \$10,000 in a year, this will impact the income statement (\$10,000 expense) as well as the balance sheet (-\$10,000 in long-term assets).

There are different ways to construct the rate of depreciation. Most common is straight-line depreciation, where the asset is reduced with the same value each accounting period until it reaches its residual value (its scrap value).

Since depreciation is an expense it will affect the taxable income of the firm. This will affect cash-flows, even though the depreciation itself is non-cash expense.

Basic Accounting Concepts

- Dual Aspect Concept - assets always equal liabilities
- Accounting Period Concept – Income Statement over a period of time
- Conservatism Concept - Choose recording method that results in the lowest asset or highest liability figures
- Accrual Concept – record revenues when they are earned (e.g. when the product ships) and record expenses when they are incurred.
- Cost Concept - record costs, not market value
- Materiality Concept - disregard immaterial transactions
- Realization Concept - recognize revenue when goods are delivered
- Consistency Concept – use the same method for recording transactions associated with specific assets/events
- Entity Concept - accounting for an entity, not individuals
- Going Concern Concept - assume continuing operations
- Matching Concept - match costs associated with revenue in same period
- Money Measurement Concept - money is the common measure

Accounting Choices

The accountant does have choices how to report different transactions; the same supply chain action can appear different ways in financial reports, and these can have different impact on the financial reports depending on how they are recorded.

There is in particular three sets of choices to be aware of:

- Product costing. The accountant is free to determine how to allocate overhead and how to categorize expenses to create as an insightful result as possible.
- Depreciation method. There are many ways to set the rate and period length for depreciation. For some types of assets, however, there are established accounting practices.
- Asset or expense. It is not always clear whether a transaction should be classified as a capital investment or an expense. One example is a prototype. The account has leeway in deciding how to classify this.

LIFO vs FIFO

There are two very different ways to estimate the value of goods in an inventory:

- LIFO uses the most recent cost of inventory to assign to sales which results in lower stated profits (assuming material costs increase over time). As a result, the remaining inventory can be undervalued.
- FIFO uses the oldest cost of inventory which results in potentially higher profits but near term tax obligations. As a result, the remaining inventory can be valued at current replacement cost.

Additional references:

Hawkins, David, Corporate Financial Reporting and Analysis: Text and Cases 3rd ed., Irwin, 1986

Higgins, R. Analysis for Financial Management. 10th ed. McGraw-Hill Irwin, 2011 (or 11th ed., 2015), see Chapter 1

Anthony, R.N. and Breitner, L.K. Essentials of Accounting. 10th ed. Prentice Hill, 2009, see pages 1-66 [this is a workbook that you should work through, it is not enough just to read it!]

Anthony, R.N. and Breitner, L.K. Core Concepts of Accounting. 10th ed. Prentice Hill, 2010, see pages 1-43 [this book provides a summary of the Essentials book, but the reader should go through the Essentials book first for complete coverage of the material]

Week 4 Lesson 2: Supply Chain Finance I – Costing Systems

Learning Objectives

Introduce you to cost accounting/cost systems

Become familiar the principles of the different cost systems

- Understand some of the key tradeoffs in cost accounting
- Learn how to perform simple activity based costing (ABC)
- Become familiar with working capital requirements and the Cash Conversion Cycle

Summary of Lesson

This second lesson covered costing systems, and working capital requirements. Much of the lesson was spent on explaining the importance and difficulties of cost accounting, and we went through all the steps of conducting a small activity based costing exercise. The goal was just to make you conversant on the topic, not experts. The lesson finished with a discussion on working capital and how the cash-to-cash cycle can be a useful measure to understand working capital requirements.

Key Concepts:

Cost Accounting

While cost accounting is a type of reporting, it has a different purpose than the financial reports. The purpose of cost accounting is purely internal to the firm – it is designed to measure costs to enable performance analysis, decision-making and internal reporting. So, while in financial reporting, costs are classified based on type of transaction for external reporting; in cost accounting, costs are classified based on needs of management for internal use (decision-making support). This means that cost accounting does not have to follow generally accepted accounting practice.

Overhead and Other Types of Costs

There are many types of costs to consider in the cost accounting process:

- Fixed costs: these costs do not vary with volume.
 - Ex. Monthly payments for plant, property, equipment
- Variable & Semivariable costs: costs that vary with volume
 - Ex. Cost for materials used to produce a product; more materials are needed to make more units of production
 - Ex. Semivariable: cost for salaried employees who get commission on sales

- Direct costs: costs that can be attributed to the production of a specific product
 - Ex. Cost for raw materials or labor hours to produce the product
- Indirect costs (overhead): costs that cannot be attributed to the production of a specific product
 - Ex. Legal fees, SG&A, insurance

Much of the challenge of the cost system is to find a representative way to allocate the indirect costs – the *overhead costs*. These costs include depreciation of assets, supervision, quality control, and many other costs. To properly understand the cost of producing certain products/services, the cost to serve certain customers, or the cost to rely on certain suppliers, managers need to allocate these overhead costs in a representative way. This is not easy, since there is often no direct relationship between the cost and the product! Different cost system apply different logic for this allocation, as you will see below.

Traditional Cost Systems

The most common way to allocate costs is using a “traditional” cost system. With such a cost system, “standard costs” are calculated and used to allocate the overhead. The standard cost is the anticipated overhead cost for a process or product. A standard rate is then calculated based on some measure, e.g. throughput or labor hours. For instance, if total standard cost for manufacturing is \$100,000 and budgeted throughput is 1,000, the standard rate to be applied is \$100 per unit.

While these systems often perform well in many instances, there are certain instances where they are problematic. This includes instances when depreciation and other overhead costs account for a larger share and in complex environments with many (customized) products and/or processes.

Actual Cost Systems

Actual cost systems try to use actual costs or quantities to provide a more accurate picture compared to standard traditional systems. There are different variations:

- Actual cost using actual quantities and standard prices
- Actual cost using standard quantities and actual prices
- Actual cost using actual quantities and actual prices

It is however difficult to use actual prices since this will not be available until after the period is over.

Activity-Based-Costing (ABC)

An increasingly common way to handle the short-coming of the other costing systems is to use an activity based costing approach. With this approach, relevant activities are defined, and all overhead costs are related to these activities. Based on the nature of the activity, a cost driver is identified which is then used to calculate the overhead cost for different objects (e.g. products, customer, suppliers).

The general steps to follow when using ABC are the following:

1. *Identify all relevant (repetitive) activities* (a formal approach would involve creating a process model). Note that a relevant activity is often of the form “verb+object”, e.g. “schedule production”.
2. *Identify the resources consumed in performing the activities*. Based on interviews, reports, or other information, identify the relevant resources consumed in each of the relevant activities.
3. *Determine the costs of the activities*. Based on the insights from step 2, find the total cost for each relevant activity.
4. *Determine cost-drivers of the activities*. This is the “unit” that drives the cost of the activity: units produced, batches, orders, shipments, etc.
5. *Determine cost-driver rate for the activities*. Based on the total cost of the relevant activity, use its total activity level to determine the rate for the cost-driver. For instance, if “number of orders” is the cost-driver, find the total number of orders over the accounting period, this is the activity level. To find the driver rate, divide total activity cost with the activity level.
6. *Trace costs to (secondary) cost objects*. Once you have all driver rates, use the information you have about each object to multiple that objects activity level with the driver-rate.

Activity-Based Costing provides a different and potentially more accurate cost for producing products and providing services. ABC can be helpful for decision makers assessing the profitability of various products, services or segmentations of those by customer or geography.

Working Capital

The working capital is a basic measure of both a company's efficiency and its short-term financial health. It is defined as:

$$\text{Working capital} = \text{Current assets} - \text{Current liabilities}$$

Positive working capital enables the firm to continue its operations and to satisfy both maturing short-term debt and upcoming operational expenses. Basically, they can pay their current bills when due. Negative working capital means that there are not enough current assets (cash, accounts receivable, inventory) to satisfy their current liabilities (accounts payable, maturing short-term debt and upcoming operational expenses). This may be good, if the firm collects its bills before paying suppliers. But it may also be a bad thing: the company cannot convert assets into cash quick enough to pay off liabilities. A company can have assets & profits but lack liquidity if assets can't readily be converted to cash. Keep in mind that a firm can have a negative CCC and positive working capital.

Sometimes working capital is analyzed through the “current ratio”

$$\text{Current ratio} = \text{current assets}/\text{current liabilities}$$

If this ratio is somewhere between 1 and 2 it is considered a healthy company. Another test is called the “acid test”, and looks only at the current assets that can be quickly converted to cash:

$$\text{Acid test} = (\text{Cash} + \text{Accounts Receivables} + \text{short term investments})/\text{current liabilities}$$

If the acid test is less than the current ratio, the current assets are highly dependent on inventory.

A third important measure is the working capital turnover

$$\text{Working capital turnover} = \text{sales}/\text{working capital}$$

This describes how effectively a company is using its working capital to generate revenues. In general, a higher turnover is preferable.

Cash-to-Cash Cycle (CCC)

Also known as the Cash Conversion Cycle, the operating cycle or simply the cash cycle. This is a liquidity measure that can help a company plan its timing of working capital requirements. It measures the number of days that a company's cash is tied up in the production and sales process of its operations, and the benefit it gets from payment terms from its creditors. The shorter the cycle, the more liquid the company's working capital position.

The measure consists of the following three parts:

- Days Of Inventory Outstanding (DIO) – this is the average inventory in the system, expressed in number of days
- Days of Sales Outstanding (DSO) – this is the average number of days to collect revenues from a sale, that is, the credit time given to customers
- Days of Payables Outstanding (DPO) – this is the average number of days before paying suppliers

The Cash-to-cash Cycle, or the Cash Conversion Cycle, is then found as

$$\text{CCC} = \text{DIO} + \text{DSO} - \text{DPO}$$

Additional references:

Cost System Analysis, Harvard Business School Publishing, Product # 9-195-181

Measure Costs Right, Make the Right Decisions, Harvard Business Review, Sept-Oct 1988

Week 5 Lesson 1: Supply Chain Finance II – Supply Chain Cash Flows

Learning Objectives

- Review concepts from corporate finance
- Understand relevant cash flows and how to estimate them
- Understand and learn how to find free cash flows from the financial reports
- How to determine the free cash flows over time for an investment/project

Summary of Lesson

This third lesson on Supply Chain Finance focused on cash flows. We discussed the magnitude and timing of these cash flows, and started a discussion on how to describe supply chain designs in terms of cash flows.

We started the lesson by revisiting the three flows in a supply chain: the physical flow (goods), the financial flows (money), and the information flows (data). Since we may use contractors for many of our firm's operations, physical flows may not pass through our firm at all. Financial flows, however, will. Consequently, the design of the financial flows in the supply chain will have an impact on the value we are creating and therefore how valuable our supply chain designs are.

Key Concepts:

Investments and future cash flows

The primary source for capital for a firm is from its stockholders, or equity investors. These investors purchase stock in the firm to provide the firm with capital. The firm may then contract out with debtors, banks, or bond holders to raise additional capital that can be used for investments. There is a contractual agreement with these debtors. For instance, if you borrow money from a bank you will have a contract where you pay them back over a certain period of time. This is not the case with investors. For these, the firm hopes to make enough money to pay them back. How? By investing the capital in operational assets to generate future cash flows. The goal is to manage the assets in the supply chain well enough so that revenues are greater than expenses.

Investors compare a firm's result with the other investment options they have to create a portfolio of options that will give them future returns. So investors' investment in a firm is a part of their portfolio. Given the firm's ability to provide returns, it will be more or less attractive to investors.

Investment evaluation

Normally – those that have the money in an organization are also those that decides on which investments to make. Following general corporate finance guidelines, investments are evaluated according to the following steps:

1. Estimate the relevant cash flows – this includes also the cash outflow of making the investment
2. Calculate a figure of merit for the investment – this is to come up with the “value” of the investment
3. Compare the figure of merit to an acceptance criterion

Note that the same process may be used to evaluate projects.

EBIT and EBITDA

To separate different types of operating income, we will use the following concepts:

- EBIT – Earnings Before Interest and Taxes. These are the earnings, or the profit, before any financial aspects are added.
- EBITDA – Earnings Before Interest, Taxes, Depreciation and Amortization. These are the earnings, or the profit, before financial aspects as well as depreciation and amortization. That is, it is the gross income minus COGS and SG&A.

Projected cash flows

Cash coming in are considered positive cash flows; cash going out is considered negative cash flows.

To handle the cash flows in the evaluation models, they are aggregated in “bins” – normally each year is a bin. Common practice assumes cash flows occur at the end of the projected period, or bin.

The appropriate time horizon to consider depends – the decision makers simply have to come to an agreement. However, one must also consider cash flows at the end of the decision horizon – assets may be divested and, when they are, incur a salvage value.

Inflation

There are two different ways to think about inflation when evaluating cash flows:

- Nominal cash flow: incorporate inflation in price/cost. The inflation rates may differ between different components.
- Real cash flows: do not include inflation in price/cost.

The choice between nominal or real cash flows influences the discount rate used when calculating the figure of merit.

Relevant Cash Flows

We need to make sure that the cash flows we are projecting are relevant to the particular investment or project we are evaluating. So how do we determine what is a relevant flow?

1. Cash flow principle: only cash flows where money moves are relevant. That is, a cash flow either goes out of the firm or comes into the firm. For instance, depreciation is **not** a movement of money, so it is not a relevant cash flow. However, depreciation also affects taxes, which **is** a relevant cash flow.
2. With-without principle: only cash flows that are different with the investment compared to without the investment are relevant to the decision. Note that this is different from “before and after”, since we are looking into the future at two different worlds – we are only interested in the difference between those worlds. For instance, if revenues will not differ between our alternatives, then they are not relevant cash flows.

Note that this also means that sunk costs are not relevant cash flows. Opportunity cost of assets should, however, be included in the evaluation – it differs between the alternatives and is thus a relevant cash flow.

Free Cash Flows

The free cash flows (FCF) are the funds available to (the equity) investors after the firm invests capital and pays taxes. It provides a convenient way to calculate cash flows to compare investments, by relying on posts in the financial reports rather than separate line items.

For free cash flow calculations we need to consider revenues, COGS, operating expenses, and taxes as well as capital expenditures and working capital. Note that some of these are found in the income statement whereas others are found in the balance sheet.

Starting with the income statement, relevant cash flows include taxes. To make sure we capture the effect of taxes, we make use of the Net Operating Profit After Taxes (NOPAT). NOPAT is given by

$$\text{NOPAT}_t = (1 - \text{taxrate}) * \text{EBIT}_t.$$

Using NOPAT, which takes depreciation into account, we can find the relevant cash flows of the income statement by adding the depreciation “back again”, that is:

$$\text{Relevant cash flows from the income statement at time } t: \text{NOPAT}_t + \text{DA}_t$$

From the balance sheet, we get the capital expenditure and the change in net working capital requirement.

$$\text{Relevant cash flows from the balance sheet at time } t: \text{CapEx}_t, \Delta \text{NetWC}_t$$

Combing the data from the income statement and the balance sheet we get

$$\text{FCF}_t = \text{NOPAT}_t + \text{DA}_t - \text{CapEx}_t - \Delta \text{NetWC}_t$$

$$\text{FCF}_t = (1 - \text{taxrate}) * \text{EBIT}_t + \text{DA}_t - \text{CapEx}_t - \Delta \text{NetWC}_t$$

Working Capital Cash Flows

The working capital cash flow is the net change in working capital requirements from the previous period. For instance, a decrease in working capital requirements means that more cash is freed up (note the minus sign in the FCF formula).

Note that working capital cash flows occur when the change takes place. For instance, a change in inventory level affects working capital requirements when we next replenish stock.

Week 5 Lesson 2: Supply Chain Finance II – Discounted Cash Flow Analysis

Learning Objectives

- Understand the underlying reasons for discounted cash flow (DCF) analysis
- How to calculate the present value of a cash flow
- How to calculate the Net Present Value (NPV) and the Internal Rate of Return (IRR) of an investment, and how to use these figure of merits for evaluating investments
- How to handle inventory reductions in DCF analysis

Summary of Lesson

In the previous lesson we learned how to estimate future cash flows. In this lesson we focused on the two subsequent steps in investment evaluation: how to calculate a figure of merit based on the projected relevant cash flows, and compare this figure to an acceptance criterion.

The basic idea underlying these calculations is that today's money is worth more than money in the future. To correct for this when we make investment decisions, we use a discount rate to find today's value of future cash flows. Why is today's cash more valuable than tomorrow's? There are primarily three reasons:

- Opportunity cost – not having the money now results in foregone investment returns
- Inflation – this reduces purchasing power over time
- Risk/uncertainty – receipt of cash is not guaranteed over time

Owing to this, we need to calculate the present value of future cash flows when evaluating supply chain designs. As we saw in this lesson, there are several ways to do this. Common for all discounted cash flow analysis, is that it quantifies the value created by investments.

Key Concepts:

Figure of Merit

The figure of merit is a single number that estimates the economic value of an investment. This number can be compared with a criterion established by the firm. There is no universal criterion. There are also several different figures of merit, which you will see more of below.

Payback Period

The payback period is the time until the cumulative cash flow is equal to our initial investment.

Using this figure of merit, the acceptance criterion is to invest if the payback period is shorter than the cut-off point. The cut-off point is decided by the firm.

This is a fairly simple measure, which is easy to communicate. The main drawback is that it does not consider the timing of cash flows. For instance, cash up front is not valued differently than cash later. Neither does it consider cash flows after the payback-period, even though these may be significant.

Return on Assets (ROA)

The return on assets (ROA) is defined by

$$\text{ROA} = \text{Net income} / \text{Assets}$$

The acceptance criterion using this figure of merit is to make an investment if ROA is greater than some target return. "Assets" are for an investment the total investment in capital, which will depreciate over time. This means that later incoming cash flows are given a higher weight in the calculation, even though earlier cash flows are generally more desirable.

ROA is very much linked to the financial statement. However, it is based on accounting calculations and not cash flows. Also, just like the payback period, it does not consider the timing of cash flows.

Present Value

The present value of a future cash flows is given by

$$\text{PV} = \text{FV} / (1+r)^n,$$

where PV is present value, FV is future value, r is the discount rate for the period, and n is the number of periods. Note that you must have the same time period for your rate and your number of periods. Often, we stick to annual values.

The discount rate is based on investors' expected rate of return. This is sometimes referred to as the hurdle rate – it sets the hurdle by which we have to run our operations to exceed the expectations of our investors.

Net Present Value

The net present value is the sum of all discounted cash flows from all relevant future periods of an investment,

$$\text{NPV} = c_0 + c_1 / (1+r)^1 + c_2 / (1+r)^2 + \dots + c_T / (1+r)^T,$$

where c_i represents the net cash flow in period i . Note that we are not discounting the cash flow of period 0 – this is the present value already!

NPV is easily implemented in your spreadsheet software. If using the built-in function, keep in mind that period 1 is the first period in the function, period 0 cash flows need to be added separately.

The net present value is a figure of merit that can be used to evaluate an investment on its own or compare different investments with each other. The acceptance criterion for a single investment is that the NPV is greater than zero.

Internal Rate of Return

While the NPV has a lot of nice properties for a figure of merit, it is dependent on picking the right discount rate. The internal rate of return (IRR) addresses this problem by, instead of considering the NPV given a certain discount rate, considers the discount rate at which the NPV=0. Consequently, management can compare the target return with the IRR. The criterion of acceptance is thus to invest as long as the target rate of return is between zero and the IRR. The IRR is found as the solution to

$$0 = c_0 + c_1 / (1+IRR)^1 + c_2 / (1+IRR)^2 + \dots + c_T / (1+IRR)^T,$$

There is no closed form solution for this. There are however spreadsheet functions available to calculate this.

Terminal Value

We may want to consider how assets that last beyond our financial projections should be handled. We have touched upon the salvage value before. There may however be cash flows to consider even if the investment is not salvaged – maintenance, certain inventory policies, etc. The terminal value handles all the cash flows that are incurred after period T, which is the last period of our projections. After period T, cash flows are assumed to be stable. There are normally two approaches:

- Perpetuity: estimated value of stable cash flows that continue indefinitely
- Annuity: estimated value of stable cash flows for definite period beyond the unique projections

You can incorporate growth into the analysis as long as growth is stable.

A perpetuity is geometric series that converges to

$$PV = C/r,$$

where C is the stable cash flow per period. An annuity is the net present value of stable cash flows over a given number of periods. The annuity is thus given by

$$PV = C/r - C / r(1+r)^T.$$

Inventory Holding Cost

In inventory management we use a holding cost (or carrying cost) for calculating how much inventory to keep. This is an annual cost, and it consists of several components:

- Capital
 - Opportunity cost of capital
- Operating
 - Warehouse (power, property taxes...)

- Equipment
- Labor (handling, stock keeping,...)
- Disposal, scrap (direct or third party costs)
- Lost revenue
 - Obsolescence
 - Depreciation (real market value!)
 - Deterioration
 - Shrinkage
 - Damage
 - Insurance to prevent lost revenue

Oftentimes, we refer to the last two categories as non-capital holding costs. But how is this incorporated into discounted cash flow analysis?

Well, these cash flows have to be evaluated like any other cash flows:

- Opportunity cost of capital is implicitly included in the discount rate, and is not a relevant cash flow.
- The non-capital costs (operating cost, lost revenue) are relevant, projected cash flows

Consequently, when you reduce inventory, you get the working capital cash once to reinvest and you avoid operating expenses and/or lost revenue over time.

Week 6 Lesson 1: Supply Chain Sourcing I – Auction Theory

Learning Objectives

- Understanding the basics of Auction theory
- Understanding basic auction metrics
- Optimal bidding strategies in simple auctions
- Expected price from an auction
- Difference and similarities between simple auctions

Summary of Lesson

This first lesson on supply chain sourcing focused on auction theory. This is a wide and deep topic widely explored in the economics literature. This lesson merely scratches on the surface. However, since most procurement events are organized as auctions, it is advantageous to have a basic understanding of the underlying theory.

In a procurement auction, suppliers or service providers are bidders. The buying firm is the auctioneer, and the auctioneer wants to choose the best supplier given certain criteria. In many other auctions, the auctioneer is the seller of an item, and in most of this lesson we focused on this more traditional situation. In all the material presented, we had one auctioneer, multiple bidders, and one item.

We went through auction metrics, different types of auctions and how they are related, optimal bidding strategy and the expected payoffs from auctions, the winner's curse, and some practical considerations. Some of this we will return to when we continue our discussion on procurement events in the next lesson.

Key Concepts:

Auction

An auction is an allocation and a pricing mechanism – it determines who should get the good and at what price.

Auctions also elicit information about how much buyer(s) are willing to pay.

Auction metrics

The following auction metrics are relevant for the auctioneer:

- Revenue – auctioneers may look for the auction that will yield the maximum revenue for an item

- Efficiency – an auction is efficient if the bidder that values the item most *ex post* actually get the item
- Time and effort – many business to business auctions involve many items with bids from multiple suppliers
- Simplicity – keeping the rules simple, especially knowing that many suppliers have to respond to hundreds of auctions every month, helps increase bidders' participation

The “win” of an auction

It is assumed that each bidder has a value for the item being sold. Being the person that gets to purchase the item does not equate a win. It is only a win if the bidders' value is lower than the purchase price.

Information distribution

In all auctions, bidders tend to be uncertain about the “true value” of an item is. We separate between three different types of auctions:

- Private value auctions – each bidder knows his/her own value, but no bidder knows the valuation of other bidders
- Common value auctions – the value is the same for all bidders
- Interdependent value auctions – bidders modify their estimate during the bidding process; these auctions have both common and private elements

Types of auctions

The following are four simple single item auctions:

- Open bids:
 - English auction – auctioneer calls increasing price until one bidder is left. The bidder pays the price at that point (Japanese auction is a version)
 - Dutch auction – auctioneer starts high and lowers the price. First bidder to call gets the item
- Sealed bids:
 - First price – highest bid wins and pays the price in the bid
 - Second price – the highest bid wins but the winner pays the second-highest bid

A few things ought to be noted. First, English auctions provide information about bidders' valuation of an item. In a Dutch auction, the only information you get is the valuation of the highest bidder. Also, for both private and common value auctions, the Dutch auction leads to the same price and allocation as a sealed-bid first price auction (in expectation); while for private value auctions, English auctions and sealed-bid second price auctions lead to the same price and allocation (also in expectation).

Bidding strategy

In a second price (sealed-bid) auction, the optimal (dominant) strategy for any bidder is to bid his/her true valuation. Bidding above one's valuation may lead to having to pay more than the valuation, while bidding below one's valuation may lead to losing the auction.

In a first price (sealed-bid) auction, it is optimal to “shade” the bid to avoid paying too much. In theory, you want to bid just enough to win the auction but not more. When there are n bidders with random, i.i.d. valuations drawn from $U(0,1)$, the optimal strategy is to bid

$$b^* = (n-1)/n * v$$

where v is the bidder's valuation.

Revenue equivalence

If we assume all bidders in an auction are risk-neutral and have private, i.i.d, valuations drawn from $U(0,1)$, then, for both first price and second price auctions, the expected revenue (the expected price paid by the winner) is given by

$$E[p] = (n-1)/(n+1),$$

where n is the number of bidders. This is referred to as the revenue equivalence theorem. Note that this is in expectation. Also note that the results mean that the expected price is increasing the number of bidders.

Winner's curse

In a common value auction, all bidders will get the same value from the item but have different information about what this true value is. Therefore, all bidders must make a “guess”. If you win the auction, it means you guessed the highest value, which is generally bad news – if no one guessed as high as you, you are probably wrong, which means you are overpaying! This is the winner's curse. To compensate for this, the optimal strategy is to shade the bid in common value auctions.

Practical considerations

In practice, there are some differences between different types of auctions that need to be taken into consideration:

- Strong and weak bidders – bidders may draw from different distributions. In an open auction, strong bidders may bid aggressively to outbid weak bidders. In sealed-bid auctions, all bidders have incentives to bid closer to their true valuations.
- English auctions are more susceptible to predatory behavior and collusion. Since it is an open auction, bidders can signal during the process. This is not possible in a sealed bid auction.

Week 6 Lesson 2: Supply Chain Sourcing I – Procurement Strategy

Learning Objectives

- How to map items based on risk and spend
- How to differentiate procurement strategy based on the mapping
- Understand the structured sourcing process
- How to handle volatility in procurement
- How to think of capital goods purchasing
- How to incorporate CSR in procurement

Summary of Lesson

In this lesson, we discussed procurement and sourcing, which are the processes for buying the materials and services needed for the company to conduct its business. We covered several items. We started by explaining the importance of procurement, then talked about mapping the value, because not everything should be treated in the same way. We talked about the process itself. We talked about capital goods, and outsourcing, and how to handle volatility. Finally we mentioned some issues related to corporate social responsibility that are tied to the procurement process.

Key Concepts:

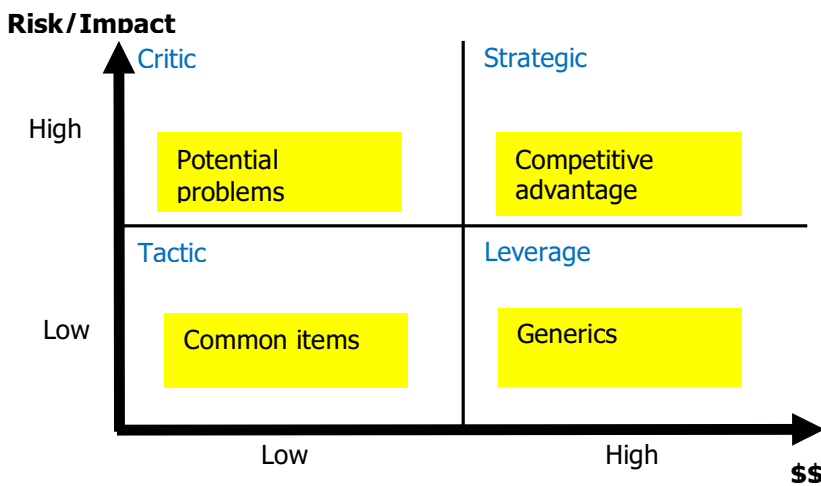
The Price Iceberg

While many purchasers focus on the price of a component or raw material, this is only part of the total cost of the purchase. This is illustrated by the “price Iceberg” – while we tend to only see the price paid upfront, there are many aspects that determine the total cost to our business of making the purchase.

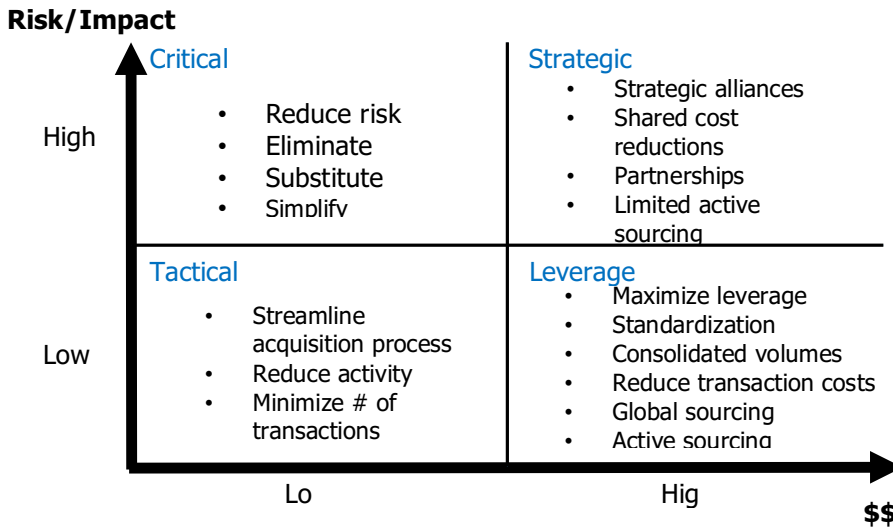


Value and Risk Mapping (risk-spend framework)

One way to differentiate the purchasing portfolio is by considering where an item falls along two dimensions: 1) the supply risk and, 2) the annual spend (or profit impact on business). Based on this, a two-by-two matrix can be created to describe all items.



For each quadrant, different types of procurement strategies are suitable.



The Sourcing Process

On a very general level, the sourcing process consist of the following steps:

- Internal assessment. This is to confirm category definition, validate baseline information and understand the key constituents. That is, focus is on the own business.
- Market assessment. This is to analyze market dynamics and identify which potential suppliers that may be of interest. It also includes understanding what competitors do.
- Collect supplier information. In this step information is collected to understand which criteria to use in the process as well as to understand current spend.
- Sourcing strategy. After the initial assessments, the sourcing strategy is developed. This specifies the approach, the specifications, and how to approach the subsequent steps.
- Bidding process. In the bidding process, RFPs are developed and sent out. The buying firm decides on a bidding format and short-list suppliers.
- Negotiate, select. After the bidding process is over, the buying firm negotiates with selected short-listed suppliers. This step ends with a selection.
- Contract Implement. This involves developing category implementation plan, communications plan as well as measurements and audit plans.

There is also a feedback loop, consisting of

- Measure and report
- Capture lessons
- Ensure compliance

Value-Based Sourcing

Value based sourcing is the name given to the practice of going beyond the purchase price in a procurement event. For instance, instead of focusing on price, focus is on value; instead of focusing on total cost of ownership, focus is on total contribution.

Financial Hedging

There are primarily three ways to hedge financially when buying materials with high price volatility:

- Simple hedge: Negotiate long term, fixed price contract in the company's preferred currency
- Forward contract: buy/sell the commodity or a related one for future delivery on a given date at a given price
- Option: a call/put option is the right to buy/sell at a certain price at a certain future date

Physical Hedging

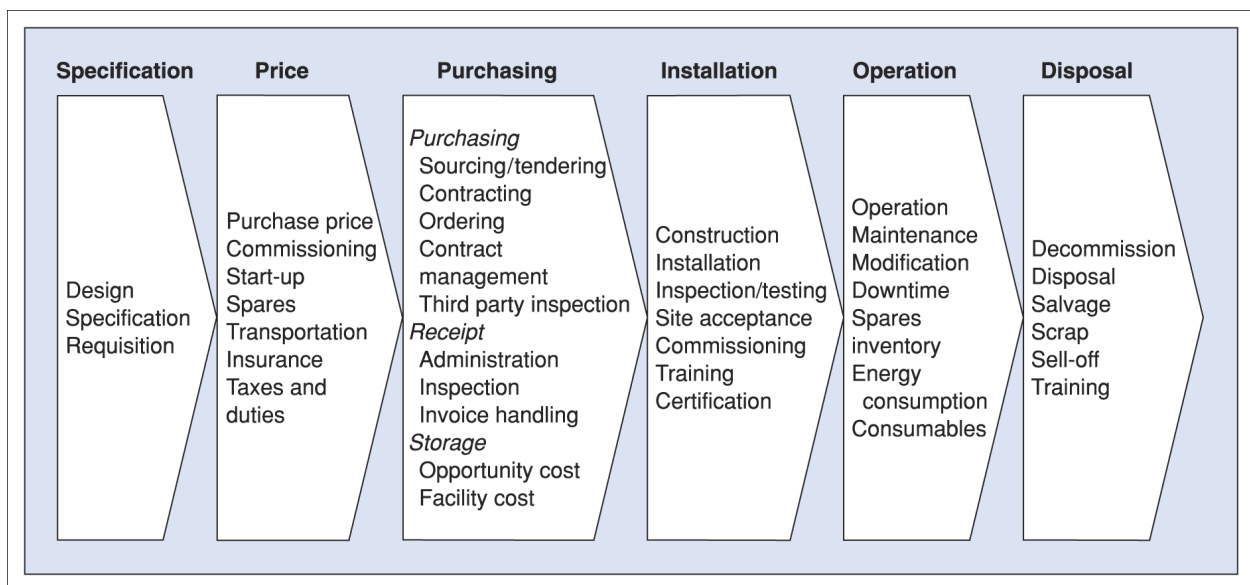
Apart from financial hedging, a firm can use physical hedging to handle volatility. Create conditions in which the fluctuations are mitigated "naturally." (used mainly for currency hedging)

Examples:

- Build a plant in countries where labor rates and currency are not expected to appreciate
- Manufacture and sell in the same country
- Actually buy a commodity when the price is low

Capital Goods Purchasing

Sourcing of capital goods go beyond standard purchasing in several ways. First, one must focus much more on the total life cycle of the good. One must also more explicitly consider the expected value of the good at the end of its useful life. Further, aspects such as training, trials, and subsidies may have a large impact on the total cost of the good. The lifetime cost of capital items are summarized in the figure below (source: AT Kearney)



Outsourcing

There are several reasons as to why firms outsource. These include:

- External supplier has better capability
- External supplier has greater or more appropriate capacity
- Freeing resources for other purposes
- Reduction in operating costs
- Infusion of cash by selling asset to provider
- Reducing or spreading risk
- Lack of internal resource
- Desire to focus more tightly on core business
- Economies of scale of supplier

When outsourcing, the contract is extremely important. A well written contract makes sure to not just have clear decisions about how to handle disputes and how to measure and reward, but also how to handle IP, how to define the service to be performed, and how to handle the evolution of the relationship.

Outsourcing is subject to considerable risk. Some of the key risks are:

- Creating a competitor
 - 1914 – The Dodge Brothers turn from a Ford engine supplier to a competitor
 - Japanese consumer electronic industry – started with contracting for US firms for radio receivers (also adopted transistors faster)
 - Japanese aircraft industries?
- Losing control of the channel to a supplier
 - IBM in 1980 designed the PC, the manufacturing process and the value chain
 - Contracted to Microsoft and Intel
 - “Window Machine” and “Intel Inside”
- Losing control of the channel to a customer
 - P&G and Wal-Mart => “Wal-Mart Outside”?

Purchasing Social Responsibility

Corporate social responsibility has a wide range of underlying objectives. These include philanthropy, brand image, HR attraction, mission support, social business and profitable business. Based on these, companies work in different ways, including using extensive codes of conduct, audit suppliers, train supplier or work hard to ensure supply chain transparency.

Independently of activity, there is a hierarchy for the different responsibilities within CSR. The top responsibility for all firms is the economic responsibility – a firm cannot survive in the long run if it does not meet this responsibility. After the economic responsibility follows, in the following order, Legal responsibilities, ethical responsibilities, and discretionary responsibilities.

Week 7 Lesson 1: Supply Chain Sourcing II – Procurement Optimization

Learning Objectives

- Introduce procurement optimization when one evaluates bids for many items from several potential suppliers
- How to take service criteria into account
- How to take systems attributes into account
- How to use combinatorial auctions in presence of economies of scope

Summary of Lesson

This lesson focused on procurement optimization. In a way, every procurement is an optimization process in the sense that the procurement department or the company tries to get the best set of suppliers to serve you. In this lesson however we tried to formalize this in simple MILP models when procuring multiple items.

We investigated how adding different types of attributes and real-life issues, such as capacity constraints or supplier constraints, affected the solution. We then went on to deal with combinatorial auction, which is a way to deal with economies of scope. We saw that also this could be managed through spreadsheet when in small scale.

Key Concepts:

Item-supplier (lane-carrier) specific constraints

Item-supplier specific constraints are constraints that apply to one of the products at one of the suppliers. For instance, when procuring transport services for a number of lanes in a network, each carrier may have capacity restrictions for a given lane.

In the MILP-formulation of the problem, these constraints are easily implemented as a separate matrix.

Optimizing with service attributes

Service attributes are often associated with an individual item at a given supplier. For instance, “on time delivery performance” may vary between different suppliers for a given item as well as between different items from the same supplier.

There are many type of service attributes that may be important evaluation criteria in the procurement process. These can be incorporated into the MILP-problem, either as constraints or by attaching a dollar value to the service level. For instance, if a certain service measure is believed to represent \$10 per %-unit of service, an LOS-adjusted cost can be minimized.

System attributes/constraints

System attributes are not tied to a specific item. Such constraints are usually concerned with constraints on the suppliers as a group. Examples:

- Minority suppliers should get 25% of our business
- Incumbent suppliers should get at least 50% of the business
- My brother-in-law should get at least \$1 Million out of this auction...

These are not as straight-forward to implement in the MILP-formulation as the item-supplier specific constraints. One has to investigate each case individually, and may need to introduce binary variables for different suppliers and/or items.

Implementing certain system constraints in the model is also useful for making sensitivity analyses. For instance, it enables an analysis of how reducing the supplier base would affect total cost.

Economies of scope

In many cases the bid one receives for an item depends on whether or not the supplier believes it will be supplying another item. For instance, when buying transport services, a supplier may be willing to offer a lower price for a lane if he also gets the return transport on the lane. Similar economies of scope may appear in all procurement situations.

Combinatorial auctions

Combinatorial auctions is a way to capture the potential economies of scope. In essence, the idea is to let all supplier bid for all possible combinations of related products.

Week 7 Lesson 2: Supply Chain Sourcing II – Supply Contracts

Learning Objectives

- Introduction to supply contracts
- The problems of normal wholesale supply contracts
- How to design contract parameters of certain contracts to coordinate a channel (supply chain)
- Understand the benefits of buyback contracts, revenue sharing contracts, and real options

Summary of Lesson

In this lesson, we covered a different aspect of the buyer-seller relationship. Rather than looking at an auction, we looked at the type of contract, or the type of relationship with the buyers and seller. That is, once the procurement department, or the buyer, decides how much they are going to buy from the supplier, the question is how the contract should be designed, and what type of contract to have.

As it turns out, there are quite a few types of contracts. So in this lesson, we first went through contracts in general. We discussed supply contracts and what the problem is with them. This was mainly covered through what is called wholesale price contracts. Then, we continued this discussion by introducing buyback contracts, revenue contracts, and option contracts, which are contracts that are designed to alleviate some of the problems resulting from straightforward wholesale price contracts.

Throughout the lesson, we focused on a particular scenario. We had one supplier selling to one retailer, and the retailer was selling into some uncertain market.

Key Concepts:

Wholesale price contracts

This is a contract where the buyer pays a price per unit for every unit ordered. Normally, this price is lower than the retail price (hence the term wholesale price).

Overage cost and underage cost

Overage cost: The cost per unit of ordering more than needed in a sales period. When products are sold in a single sales period (like newspapers, which are sold only for one day), the cost of having too many products at the retailer is the purchase price minus any salvage value.

Underage cost: the cost per unit of ordering less than needed in a sales period. When there are fewer products than there is demand, the cost of not having enough products for the retailer is the product margin – this is the amount the retailer would have received if there was enough goods.

Optimal order quantity in a single period model

Consider a retailer selling products over a single sales period. The forecasted demand has cdf $F(x)$. In such a situation, the retailer's optimal order quantity is found from balancing expected underage and expected overage costs.

The (informal) explanation is the following: consider an arbitrary potential order quantity Q . Given this Q there is a probability $F(Q)$ that demand is less than Q and a probability $(1-F(Q))$ that demand is greater than Q . If demand is less than Q , the retailer will incur overage costs. If Q is low, there is a very low probability of this, so the *expected overage cost* is low. If instead demand is greater than Q , the retailer will incur underage costs. If again Q is low, there is high probability for this, so the *expected underage cost* is high. Clearly, by increasing Q , the expected overage increases while the expected underage decreases. If expected overage increases less than expected underage decreases, then increasing Q leads to higher expected profits. At some point, the two expected costs are equal. This is the optimal order quantity Q^* . That is,

$$c_o F(Q) = c_u (1 - F(Q))$$

With a wholesale price w , a retail price r , and a salvage value s , we can solve for $F(Q)$:

$$F(Q) = c_u / (c_u + c_o) = (r - w) / (r - s).$$

This is often referred to as the critical fractile or the critical ratio. Taking the inverse of the cdf yields the optimal order quantity.

Channel (supply chain) coordination

A channel or supply chain is said to be coordinated when the individually optimal order quantity is the same as the channel optimal order quantity. For a normal wholesale price contract, this means that the critical fractile for the retailer must be the same as the critical fractile for the integrated channel. It is easily seen that this is only the case if the wholesale price is equal to the marginal cost of the supplier – in that case the supplier makes no profit.

Buyback contract

With a buyback contract, the supplier offers the retailer to buy back all unsold items. This reduces the retailer's risk of overage – if there are unsold items at the end of the season they can be sold back to the supplier. The retailer's optimal order quantity is thus given by the solution to

$$F(Q) = (r - w) / (r - b),$$

where w is the wholesale price and b is the buyback rate. The channel is coordinated when the retailer's critical fractile is equal to the integrated channel's critical fractile, which means that the channel is coordinated when

$$b = (r - s) / (r - c) - (r - c) / (r - c),$$

where c is the marginal cost of the supplier. Note that this means that the channel is coordinated for many different combinations of w and b . However, a higher wholesale price requires a higher buyback rate for the channel to stay coordinated. Note also that as the wholesale price (and the buyback rate) grows, the supplier's share of the profit increases.

Revenue sharing contract

Revenue sharing is another type of contract that can reduce the retailer's risk of overage. With this contractual setup, the supplier lowers the wholesale price but takes a percentage $(1-r)$ of the revenue. With this, the retailer's optimal order quantity is given as the solution to

$$F(Q) = (pr-w)/(pr-b),$$

where p is the percentage revenue kept by the retailer. As with the buyback contract, the channel is coordinated when the retailer's critical fractile is equal to the integrated channel's critical fractile,

$$p = w(r-s)/(r(c-s)) - s(r-c)/(r(c-s))$$

In practice, these contracts may be difficult to implement in many industries since the supplier must keep track of retailer revenues.

Real options

With a real options contract, the retailer buys Q call options at price w , giving the retailer the right to buy no more than Q units. Exercising an option, once demand is known, comes at an extra fee of E . As with the other buyback and the revenue sharing contracts, this reduces the retailer's risk of overage so that the channel can be coordinated.

Additional references:

Cachon, G. P. (2003). Supply chain coordination with contracts. *Handbooks in operations research and management science*, 11, 227-339.

Week 8 Lesson 1: Production Planning – Fixed Planning Horizon

Learning Objectives

- How to coordinate the internal information flow of a firm
- How to use demand information to create the master production schedule (MPS)
- How to express the MPS as a fixed planning horizon problem
- How to solve the fixed planning horizon problem (FPH) using several different algorithms

Summary of Lesson

In this lesson we started investigating the information flow within a firm, and the coordination and planning of production. What is being coordinated? Well, what we want to achieve is to match the demand of our customers with the supply from our firm which requires components from our suppliers. For this match to be possible, information about future demand should be used for the creating of the master production schedule, which is then used to determine the materials requirements.

Much of the lesson was spent on how to develop the master production schedule (MPS). This is the overall production plan of the company, determining how to meet demand for a given time horizon. This led us to develop the fixed planning horizon (FPH) problem, which was solved using several different methods, both heuristics and optimal methods. The lesson closed by discussing some of the benefits of the different methods.

Key Concepts:

Master Production Schedule (MPS)

The MPS is the basic communication between the market and manufacturing. It is a statement of production – not demand. It is a plan to meet the forecasted demand, not a forecast of demand.

There are several manufacturing or production strategies that determine what the MPS can look like.

Level production strategy. This is a strategy aiming at even production levels over time. The major benefit is a smooth and stable operations which reduces switching costs and minimizes the need for outsourcing, overtime, or other flexibility measures. The downside is that it leads to heavy inventory build-up when demand is low, and possible shortage when demand is high.

Chase demand strategy. With this strategy the aim is to let production quantities follow demand as closely as possible, so that more is produced in times of high demand and vice versa. The benefit of this is that inventory is kept at a minimum, and so is obsolescence. On the other hand, it tends to lead to large swings in production quantities and labor needs.

Hybrid strategy. A hybrid strategy tries to combine the benefits of the level production strategy and the chase demand strategy, by balancing the costs associated with the strategies. This can be done in several ways. Below we report in more detail how this is handled when there is a fixed planning horizon.

Fixed planning horizon (FPH) problem

The FPH problem considers the problem of finding the lowest cost production plan over a fixed horizon with multiple time periods. Demand is considered deterministic but can vary between periods.

There are several ways to solve the FPH problem:

Simple heuristics. These are simple decision rules, for instance that you run only one production run (One time run heuristic), that you produce in every period exactly what is demanded (lot for lot), or that you produce either a fixed “optimal” quantity or according to fixed “optimal” intervals. These heuristics are simple making decision-making fast, although the results are not necessarily particularly good.

Specialized heuristics. There are several more sophisticated heuristic developed for the FHP, including the Silver-Meal (SM) heuristic, the least unit cost heuristic and the part-period balancing heuristic. In this course we focus on the SM heuristic. This heuristic searches through the periods to find the lowest cost per period. It first tests if it is less costly per period to produce next period’s demand in this period. If it is, it sees if it also less costly to include the period after next period in this period’s production. It continues this process until the cost per period increases. When it does, say in period k , it starts over by considering production in period k , and sees if cost period is reduced by including also the demand from $k+1$ in the production of period k . It continues like this until the end of the horizon. While more sophisticated, it is not guaranteed to find a very good solution.

Optimal methods. The Wagner-Whitin algorithm provides the optimal solution by relying on dynamic programming. This is an efficient method for large problems. For smaller problems, a spreadsheet MILP model is a quick way to find the optimal solution. (see further below)

In summary - there are many methods available. Heuristics are fast and easy to implement, but are not always good in the sense that they provide a near-optimal solution. Specialty heuristics are more sophisticated, a bit harder to set up, but tend to provide better “real-world” results. Optimal methods require more time and data, allow for several constraints and give the optimal solutions. However, keep in mind that the information fed into the model is often not exact.

Production planning MILP

The FHP can be set up as a MILP problem, similar to the problems discussed in the first three weeks as well as last week.

With a MILP formulation, the objective is to minimize the total costs, which consist of setup costs for every production run/batch, and holding costs from finished goods inventory. Index denotes time period. We let Z_t be a binary decision variable indicating production in period t , and Q_t be the decision variable determining production quantity in period t . We thus have that

$$\text{Min } z = \sum_t c_{\text{setup}} Z_t + \sum_t h I_t$$

s.t.

$$I_0 = 0$$

$$Q_t - D_t + I_{t-1} - I_t = 0 \quad \forall t \in T$$

$$M Z_t - Q_t \geq 0 \quad \forall t \in T$$

$$Q_t \leq \text{CAP}_t \quad \forall t \in T$$

$$I_t, Q_t \geq 0 \quad \forall t \in T$$

$$Z_t = \{0,1\} \quad \forall t \in T$$

where c_{setup} is the setup cost, h is the holding cost per unit and time period, I_t is inventory level at the end of period t , D_t is the (forecasted) demand in period t , M is a large number, and CAP_t is the production capacity in period t .

In the above formulation, the initial inventory is zero. As before, we have a conservation of flow constraint as well as a linking constraint. The conservation of flow states that the difference in inventory between the end and the start of the period must be equal to the difference between demand and production quantity in that period. The linking constraint forces Q to be zero if Z is zero in the same period.

Week 8 Lesson 2: Production Planning – Material and Distribution Requirements Planning

Learning Objectives

- Understand how to determine available to promise (ATP)
- Understand how material requirements planning (MRP) and distribution requirements planning (DRP) work
- Understand the bill of materials (BOM)
- How MRP can be used to coordinate production with suppliers
- Understand benefits and limitations of MRP and DRP

Summary of Lesson

Last lesson focused on the master production schedule and how this system is used to tie the market demand to the production plan. In this lesson, continued that discussion.

In the previous lesson we saw that the MPS takes inputs from the sales and operations plan. So it gets those inputs for knowing how much to make of the end items. In the first segment in this lesson we talked about how sales can use this to come up with something known as the availability to promise. How much can they promise to their customers based on the current production plan?

We then moved upstream to understand how to coordinate this production with the suppliers of the items, components, and subassemblies that go into the final item. How do I interface with production and procurement to bring in all the components to make my end item? This is the MRP or Material Requirements Planning Process.

After this we moved downstream towards the customers and saw how we can use the distribution requirements planning -- which is almost a mirror image of the MRP -- to plan how our product get distributed out to the market.

Key Concepts:

Available to Promise (ATP)

The portion of existing inventory and/or planned production that is not committed or consumed is considered to be Available to Promise. This means that these units can still be sold to customers.

There are two slightly different ways to calculate this:

Discrete – meaning that each production cycle is planning independently. Inventory from one production run is not carried over to the next run.

Cumulative – meaning that inventory is carried over between periods. That is, inventory from the first production run which is unsold at the start of the second production run can still be sold during and after the second production run.

Time Fencing is often used to stabilize production planning (demand and planning)

- if $t < \text{Demand_Fence}$ then use only committed orders for MPS
- if $\text{Demand_Fence} < t < \text{Planning_Fence}$ then limited MPS overrides
- if $t > \text{Planning_Fence}$ then all MPS changes allowed (within limits)

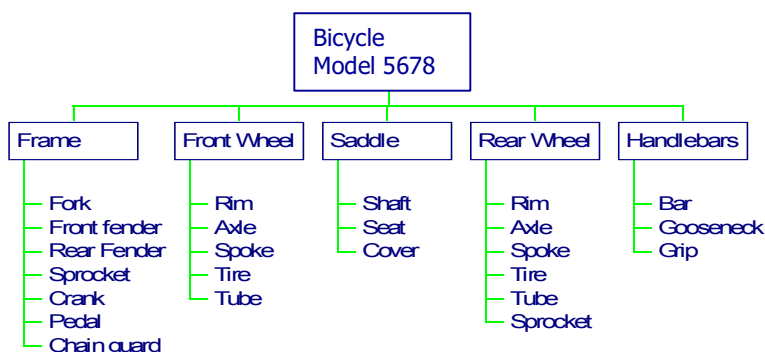
Materials Requirements Planning (MRP)

Material Requirements Planning (MRP) systems ensure that all components and parts required for an end item are on hand when needed. These systems are intended to answer questions about what should be ordered or manufactured, how much, and when. These questions are answered by feeding the MRP with the MPS, inventory records, and the Bill of Materials (see below).

- Benefits of MRP
 - Leads to lower inventory levels
 - Fewer stock outs
 - Less expediting
 - Fewer production disruptions
- Limitations of MRP
 - Scheduling, not a stockage, algorithm
 - Does not address how to determine lot size
 - Does not inherently deal with uncertainty
 - Assumes constant, known leadtimes
 - Does not provide incentives for improvement

Bill of Materials (BOM)

The Bill of materials (BOM) shows which parts, subassemblies, and components that make up a given product to be produced. For illustrative purposes, the BOM can be shown as a tree-diagram, with the completed product at the top, and all parts and components being the roots. One example for a bicycle is shown below.



MRP coordination

There are different way to coordinate the MRP between a firm and its (independent) suppliers. In this lesson we went through three different approaches:

Simple MRP rules. This means using simple rules also for coordination with the supplier. For instance, if there is a lead time of x weeks to get a component from the supplier, order release is scheduled x weeks before the units are needed for the assembly at the firm. The supplier uses this as the demand input for its own production planning.

Sequential optimization. With this approach, the firm optimizes his production first, and then feeds the requirements to the supplier who optimizes his production.

Simultaneous optimization. With this approach, the firm and the supplier's production is optimized simultaneously. This means that firm's or the suppliers' costs may increase, while total costs will decrease.

Distribution Requirements Planning (DRP)

DRP can be thought of as the application of the MRP principles to distribution inventories. It is used for inventory control in a distribution environment with many products, many stockage locations, and multiple echelons. In practice, it is an algorithm for scheduling and stocking, however, it does not determine lot size or safety stock.

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Week 9 Lesson 1: Connecting Sales to Operations

Learning Objectives

- Understand the fundamental concepts of Sales & Operations Planning in balancing supply and demand
- Able to formulate and solve an aggregate planning model
- Understand trade-offs and levers available for making aggregate planning decisions
- Appreciation for the trade-offs that can be made between sales and operations in terms of supply versus demand and volume versus product mix

Summary of Lesson

This lesson focuses on the interface between sales/demand and operations/supply. Specifically, we explore how the Sales & Operations Planning (S&OP) process within a firm can be used to find the right balance between operational capacity and demand.

The aggregate planning model was introduced. Used in the 3 to 18 month planning timeframe, the aggregate planning model allows a firm to set various operational and sales levers in order to determine the best trade-offs to make to maximize profitability. The primary levers on the operational side are: workforce, outsourced production, inventory, internal production levels, backlogs, and overtime hours. There might be more levers for specific situations, of course. On the demand side, we discussed how sales changes and promotions can be used to shape demand and how the aggregate planning model can help determine the operational impact. The optimization model can also be used to test out different strategies and potential policies.

We finished the lesson describing the standard monthly Executive Sales & Operations Planning process. We outlined a five-step process that engages the sales and marketing, production and operations, and senior leadership of a firm. The main take-away from the process is that a formal, structured set of meetings with both top and bottom buy in are required to be successful.

Key Concepts:

Aggregate Planning Model

The aggregate planning model is used to plan for the mid-term 3-18 month time frame. It takes as input the proposed demand as well as starting inventory, workforce, and costs for different options. The longer horizon planning involves more strategic decisions – such as network design etc. – while the closer time frame is planned using the Master Production Schedule. The planning unit for the aggregate planning model is typically not the individual SKU, but rather a family or related SKUs or general flow unit – such as tons, or composite units.

The model is used to find the best mix of Production, Inventory, Workforce, Outsourcing, and Capacity Levels in order to maximize the firm's profit over the 3-18 month planning horizon given the forecasted demand over the planning horizon by changing:

- Production Rate – how much produce each month
- Workforce – how many employees to hire or lay off each month
- Overtime – how many overtime hours to plan for each month
- Machine capacity – how much capacity should be allocated to production lines each month
- Outsourcing – how many items to produce using contract or outsourced manufacturing each month
- Backlog – how many units each month should we allow to be backlogged
- Inventory on hand – how much inventory should we plan on holding each month
- Pricing – how should the product pricing be changed (promotions, discounts etc) each month

The output from the aggregate planning model is essentially the production (and pricing) plan. Two basic strategies that can be implemented are: Chase and Level. The chase strategy implies that production is made as close to the point of demand as possible. This leads to low inventory costs but generally higher production (overtime, workforce, outsourcing) costs needed to adjust the production to meet demand peaks. The level strategy attempts to keep the production level for the entire time period and let the inventory build up to cover any demand peaks. The hybrid strategy that combines these two extreme solutions is generally used.

Model Formulation

$$\text{Min } z = \sum_t (c_W W_t + c_H H_t + c_F F_t + c_O O_t + c_I I_t + c_B B_t + c_M P_t + c_C C_t)$$

s.t.

$$P_t - \left(\frac{HW_t + O_t}{L} \right) \leq 0 \quad \forall t \in T$$

$$W_t - W_{t-1} - H_t + F_t = 0 \quad \forall t \in T$$

$$I_t - I_{t-1} - P_t - C_t + D_t + B_{t-1} - B_t = 0 \quad \forall t \in T$$

$$O_t - MW_t \leq 0 \quad \forall t \in T$$

$$W_t, H_t, F_t, O_t, I_t, B_t, P_t, C_t \geq 0 \quad \forall t$$

where the decision variables are:

H_t = Number of employees to hire at start of month $t \quad \forall t$

F_t = Number of employees to fire at start of month $t \quad \forall t$

W_t = Number of employees in month $t \quad \forall t$

I_t = Number of units of inventory on hand in month $t \quad \forall t$

O_t = Number of overtime hours to work in month $t \quad \forall t$

B_t = Number of units to put on backorder in month $t \quad \forall t$

P_t = Number of units to manufacture internally in month $t \quad \forall t$

C_t = Number of units to outsource to contract mfg in month $t \quad \forall t$

The input data are:

W_0 = Size of workforce at start of planning period (month 0)

W_T = Size of workforce at end of planning period (month T)

I_0 = Amount of inventory at start of planning period (month 0)

I_T = Amount of inventory at end of planning period (month T)

B_0 = Amount of backlog at start of planning period (month 0)

B_T = Amount of backlog at end of planning period (month T)

D_t = Demand in month t (units) $\forall t$

c_M = Cost of raw material per (\$/unit)

c_I = Cost of holding inventory (\$/unit/month)

c_B = Cost of a backorder (\$/unit/month)

c_F = Cost of firing one employee (\$/person)

c_H = Cost of hiring one employee (\$/person)

c_W = Cost of employee (\$/person/month)

c_O = Cost of overtime (\$/hour)

c_C = Cost of outsourcing to a contract manufacturer (\$/unit)

L = Number of hours required to make each item (hours/unit)

H = Number of hours each employee can work per month (hours/person)

M = Maximum hours of overtime allowed per employee per month (hours/person)

Aggregate Planning Model Levers

The aggregate planning model is mainly used to determine the best mix or both operational and sales based strategies. The operational levers control the supply while the sales levers influence the demand. On the operational side, we can manage Supply by controlling inventory (Common Components and Pre-build Inventory) and/or capacity (Workforce Flexibility, Seasonal Workforce, Outsourcing production, or Product Flexibility).

Managing Demand is a little less direct. The objectives on the demand side are to (1) Grow Market, (2) Steal Market Share from competitors, or (3) Shift Buying Patterns of the customers. The levers available are:

- Pricing – incentives (discounts, MOQ's, etc.),
- Advertising – increasing brand awareness, and
- Promotions – price reduction over short period of time.

Demand Elasticity

The concept of Demand elasticity with respect to price is useful in determining how a change in price will impact the demand.

$$e = \frac{\text{Percent Change In Demand}}{\text{Percent Change In Price}}$$
$$= \frac{\frac{D_{New} - D_{Old}}{D_{Old}}}{\frac{P_{New} - P_{Old}}{P_{Old}}} = \left(\frac{P_{Old}}{D_{Old}} \right) \left(\frac{D_{New} - D_{Old}}{P_{New} - P_{Old}} \right)$$

Recall that the elasticity will almost always be negative. That is, a negative change in price (a discount) will lead to higher demand. The elasticity of demand for many goods can range from -0.01 to as high as -10 or more. The way to interpret an elasticity of, say, -2.5 is that for every 1% change in price, the demand will increase by 2.5%.

Monthly Sales & Operations Planning Process

There are many flavors of S&OP out there. Most feature a set of structured meetings where specific tasks are performed by different functions within the firm and eventually are presented with recommendations to senior leadership to make a final decision.

We described a five-step process as follows:

Step 1: Data Gathering – the core data on the most recent month's demand, inventory, production levels, sales, etc. is gathered, cleaned, and made ready to distribute. This should be accomplished in the first few days of a new month.

Step 2: Demand Planning – The demand planning team from the sales/marketing organization develops the initial set of forecasts. These include their expert opinions on modifications to any numeric forecasts that were made.

Step 3: Supply Planning – The supply planning / operations team receives the initial forecast and the most recent set of data and develop a resource plan to meet the proposed demand forecast. Any conflicts or restrictions are noted.

Step 4: Pre-Meeting – The supply and demand plans are brought together and compared. This larger group makes suggestions and recommendations. Any conflicts that cannot be solved at this level are identified.

Step 5: Executive Meeting – The senior team makes decisions on any outstanding conflicts – they have a go no go decision authority.

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Week 9 Lesson 2: Customer Coordination and Collaboration

Learning Objectives

- Understand how firms should collaborate to improve overall efficiency
- Understand the Bullwhip Effect, how it is caused, the impact, and how to mitigate it
- Familiarity with different initiatives on collaboration to include Vendor Managed Inventory, Continuous Replenishment, and Collaborative Planning, Forecasting, and Replenishment programs.

Summary of Lesson

This lesson focuses on coordinating the interface between a firm and its immediate downstream partner – or customer. The coordination requires exchanging information and understanding the impact of one firm's actions on the other.

The Bullwhip Effect was introduced. Essentially the Bullwhip Effect is when the upstream variability of demand is greater than the downstream variability. This can occur for many reasons to include: order batching, demand forecasting updates, rationing and shortage gaming, and price fluctuations. The concept was pioneered initially by Jay Forrester and was observed in practice in the supply chain by P&G in its disposable diaper line. The effect in supply chains was first described and quantified by Lee, Padmanabhan, and Whang in 1997.

The Bullwhip Effect is essentially a signal that a supply chain is not coordinated. The costs of this lack of coordination includes:

- Increased manufacturing costs
- Higher inventory levels & costs
- Longer replenishment lead times
- Higher transportation costs
- Lower product availability
- Deteriorates trading partner relationships
- Lowers supply chain profitability

The lesson discusses approaches to counteracting the Bullwhip Effect to include: Improve forecasting methodology, Design single-stage replenishment control, Shorten lead and review period times, Reduce batching of orders, Reduce the incentive of forward buying, and Better sharing of information.



Key Concepts:

The Bullwhip Effect

The Bullwhip Effect is the situation where the variability of demand in the supply chain increases as one moves upstream from the consumer to suppliers. It is primarily caused by four factors and is exacerbated by the observation that supply chains consist of multiple independent firms and that individual firms will tend to operate in order to maximize their own profits.:

- Demand Forecasting – where forecasting relies on the demand each firm sees from its immediate downstream partner or customer and not the end downstream demand
- Rationing and Shortage Gaming – where suppliers ration supply and customers, knowing this, inflate orders or submit phantom orders however, orders evaporate when supply is made available. The net effect is false demand signals that ripple and are amplified upstream
- Order Batching – where customers bunch or batch orders for many different reasons to include:
 - Ordering set up costs
 - Optimal lot-sizing
 - Periodic review policies
- Price Fluctuations – where the retailer incentivizes behavior from its consumers by changing prices that in turn causes batching of orders. These include:
 - Volume discounts
 - Minimum order quantities
 - Limited transportation mode options
 - Forward buying

Quantifying the Bullwhip Effect

We can measure the rough impact of the Bullwhip Effect under certain conditions:

- One retailer selling one item replenished by one wholesaler DC
 - Daily demand at store is $\sim N(100, 10)$
 - Daily review period with (R,S) inventory policy (order up to)
 - $S_t = \mu_t L + k \sigma_t \sqrt{L}$
 - μ_t = expected daily demand estimated at time t
 - σ_t = standard deviation of daily demand estimated at time t
 - L = leadtime in days
 - k = Safety factor
- Forecasting uses simple moving average of the last M time periods which implies that μ and σ will change each period based on new forecast and impact the order up to level and safety stock.

Then, we can see that:

$$\frac{Var[\text{RetailOrders}]}{Var[\text{CustomerDemand}]} \geq 1 + \frac{2L}{M} + \frac{2L^2}{M^2}$$

Counteracting The Bullwhip Effect

There are several methods or approaches to counteracting the Bullwhip Effect. These include:

- Improve forecasting methodology
 - Eliminate multiple forecasts that only use immediate partner order data
 - Employ point-of-sale or end consumer data, if possible
 - Avoid “nervous” forecasting techniques
- Design single-stage replenishment control
 - Have upstream partner manage its downstream partner’s inventory
 - Referred to as Vendor Managed Inventory (VMI) or Continuous Replenishment Programs (CRP)
 - Bypass the downstream stages – consumer direct policies
- Shorten lead and review period times
 - More frequent review and faster delivery reduces impact
 - Less time for uncertainty to build
 - Incent orders to be better distributed over time
- Reduce batching of orders
 - Reduce the fixed cost of order set up and delivery (lower friction)
 - Shift from minimum order quantity (MOQ) of individual SKUs (or families) to minimum volume quantity of a wider assortment of products
 - Reduce transportation costs by using: milk-runs, multi-zone trucks (ambient, refrigerated, and frozen), 3PL solutions . . .
- Reduce the incentive of forward buying
 - Be selective on the use of price promotions
 - Analyze the true costs of a promotion using ABC accounting
 - Shift sales incentives from “Sell-To” to “Sell-Through”
 - Use supply chain risk and other contracts to coordinate sales
- Better sharing of information
 - Allowing visibility into POS or end customer demand
 - Sharing of plans and intentions – sometimes called Collaborative Planning, Forecasting, and Replenishment (CPFR)

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Week 10 Lesson 1:

Organizational, Process, and Performance Metric Design

Learning Objectives

- Understand how supply chain organizations are typically and can be organized and why
- Learn strengths and weaknesses of centralized versus decentralized organizations
- Gain insights into supply chain processes
- Able to develop and design performance metric systems for supply chains

Summary of Lesson

This lesson focuses on three areas of “soft” design: organizations, processes, and metrics. Each of these could warrant an entire series of talks – we will only touch upon the key points in this lecture.

Organizational design for supply chains has evolved as the profession has changed. Supply chain organizations started as separate silo-ed functions or activities spread out across different larger divisions, such as finance, manufacturing, and marketing. The areas started combining into materials management (covering the flow of inbound materials) and physical distribution (covering the movement of final products to customers). Logistics groups emerged later to bring these two functions together in order to work out trade-offs between the sometimes conflicting goals of inbound and outbound management. Currently, there are various forms of organizations used across different companies. The main perspectives differ in terms of viewing supply chains or logistics as a set of functions, as a program, or within a matrix. The matrix form is most common in larger global firms. In these cases, logistics is a horizontal function that interacts directly with each vertical business unit providing shared services.

The key trade-off involved with supply chain organizational design is whether to centralize or decentralize different activities. Centralization implies that all decisions are made at a headquarters while decentralization moves this to the regions or individual business units. Each has a role with the general rule of thumb shifting most procurement, long-range planning, and new product activities to central and keeping daily operations decentralized.

Processes within supply chains are essentially transformations of inputs into outputs. Procurement transforms an order into product. Transportation converts material at a DC to product at the customer location. Each of these processes can be managed individually or looked at as within a greater system. The different processes within the supply chain should be designed to complement each other.

Metrics follow the process structure. All metrics can be boiled down to utilization, productivity, or effectiveness metrics. Utilization measures inputs compared to some norm (capacity, standard, etc.). Productivity or efficiency compares inputs to outputs. Effectiveness compares output to some norm value. The different metrics can be evaluated for robustness, integration, usefulness, and validity.

There is not single best metric, however, they will all have trade-offs between these criteria. This is why systems of metrics should be used in a balanced scorecard framework.

Key Concepts:

Centralization vs. Decentralization

Organizational design centers on whether to centralize or decentralize an activity. Each has a place and there are basic trade-offs involved.

Centralized

- Leverages economies of scale
- Harmonizes policies and practices
- Allows for optimal (global) solutions

Decentralized

- Allows decision making to be closer to customer
- Allows decisions to reflect local cultures and customs
- Allows for optimal solutions within a region
- Allows business units to act autonomously

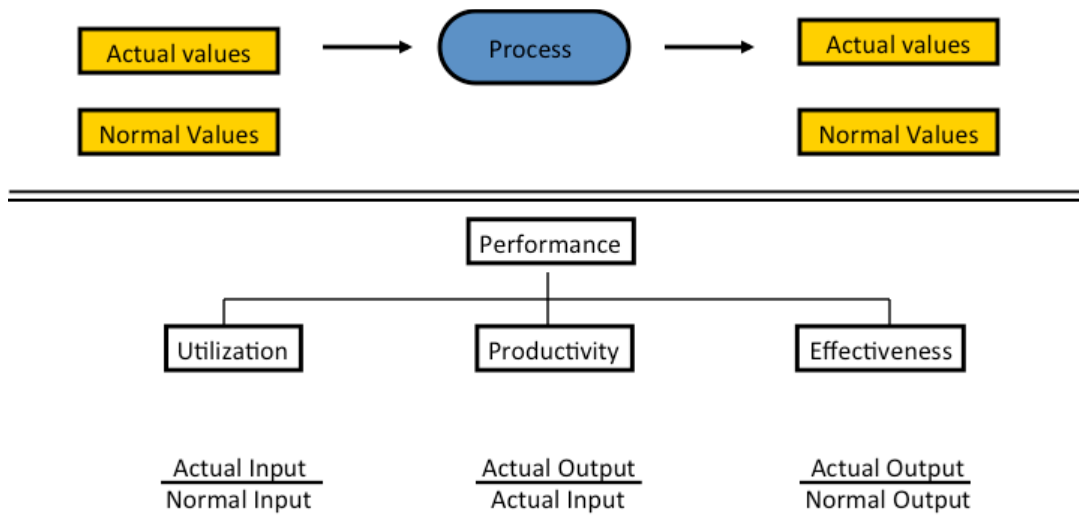
Supply Chain Processes

Supply chain processes can be thought of transformations of one flow unit to another.

Process	Flow Unit	Transformation
Order Fulfillment	Orders	Receipt of order => Delivery of product
Production	Products	Receipt of materials => Completion of product
Outbound Logistics	Products	End of manufacturing => Delivery to customer
Procurement	Supplies	From issuing a purchase order => Receipt of supplies
Customer Service	Customers	Arrival of customer ⇒ Departure
New Product Development	Projects	Product development start ⇒ Launch
Cash Cycle	Cash	Expenditure of funds ⇒ Collection of revenue

Performance Metrics

Metrics can be divided into Utilization, Productivity, and Effectiveness measures.



Performance Metric Criteria and Trade-offs

Metrics can be evaluated according to several metrics – but they will always have trade-offs.

Robust

The metric is interpreted similarly by all users, is comparable across time, location and organizations, and is repeatable.

Valid

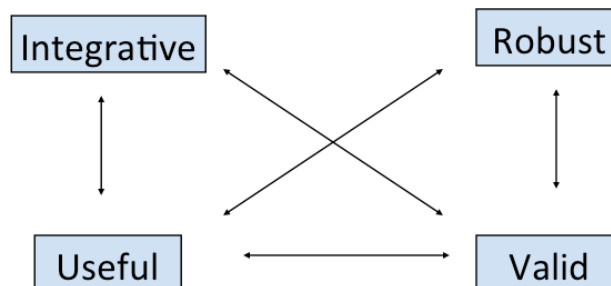
The metric accurately captures events and activities measured and controls for exogenous factors.

Integrative

The metric includes all relevant aspects of the process and promotes coordination across functions and divisions (and even enterprises).

Useful

The metric is readily understandable by decision makers and provides a guide to action.



Balanced Metrics

Metric systems should be designed to balance across three key areas: Asset utilization (utilization metrics), Efficiency (productivity metrics), and Customer Response (effectiveness metrics). Different industries will emphasize different aspects of process performance.

