Production Planning and Master Production Scheduling

Making decisions is probably the most important thing people ever do.

Nothing happens until someone makes a decision….

Fortunately the ability and judgment necessary to make decisions can be acquired. Certain methods and practices can bring to us all greater skill in everyday, every-week, every-month opportunities to make decisions….

Collect facts and analyze and use them. Develop and weigh possible solutions to arrive at conclusions. Carry a decision into action with plans and controls. Follow up on the results of the decisions and action.

President Ezra Taft Benson[68]

Whether formal or informal, effective or ineffective, planning and decision-making processes are present within virtually all organizations. As President Benson states, we can acquire greater skill in our decision-making abilities, and this often starts by understanding basic planning processes.

In most organizations, planning occurs on several levels and at different frequencies. This is especially true in organizations that endeavor to push decision-making to the lowest levels possible (much like what we find within the Church and family).

Chapter Objectives

In this chapter we will take a look at basic planning processes, which apply in one form or another to manufacturing and service organizations. A common theme or objective of the basic planning processes is to find the best way to make supply (production) equal demand (customer volume and timing requirements). After studying this chapter you should be able to

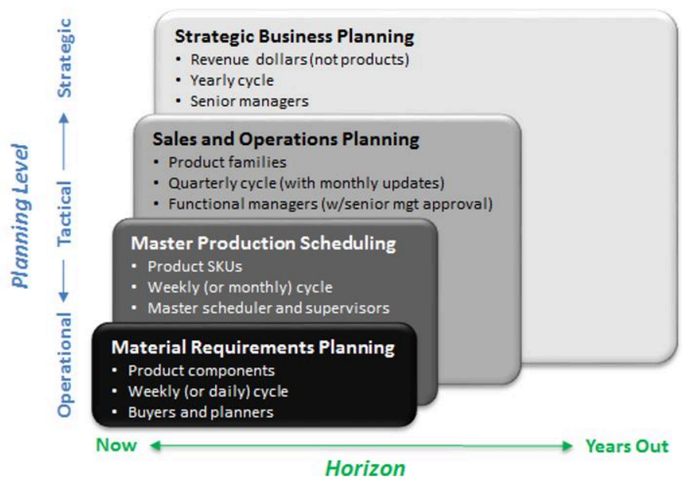
1. Distinguish among strategic business planning, sales and operations planning, master production scheduling, and **material requirements planning** processes.
2. Describe each of the three basic build plan strategies and the conditions under which each would be most appropriate for creating an aggregate production plan.
3. Create aggregate production plans utilizing each of the three basic strategies, including with the use of Excel's Solver function.
4. Describe master production scheduling and the different levels at which it should be expressed (including a 2-level MPS), depending on product structure.
5. Create a **master production schedule** and compute available-to-promise (ATP).
6. Describe ATP and its importance—especially to production and marketing.

Overview of Manufacturing Planning and Control System

Question: What planning processes are found within manufacturing planning

and control system?

A manufacturing planning and control system is composed of many levels of coordinated and connected planning activities, each focusing on different views or aggregations of products, occurring on various cycles, and driven by different levels of personnel. *Each planning level focuses on finding the best way to* ***make supply meet demand*** *(in other words, make supply = demand, a difficult task).*



Below is a brief description of each of the planning activities as depicted above, starting with the most strategic and working our way to the operational level.

- **Strategic business planning** is the process of creating a statement of revenue, cost, and profit objectives. Output from this process is translated into and synchronized with functional plans within the sales and operations planning process. Business planning usually speaks in terms of dollars, takes place on an annual basis, extends more than a year into the future, and is under the direction of senior management.
- **Sales and operations planning (S&OP)** is the process of creating tactical plans for functional groups, based on the strategic business plan. Its main outputs are the **sales plan** and the **production plan** (hence, "sales and operations planning"); however, other functions such as engineering, finance, and human resources participate and make their respective plans

as well. S&OP speaks in terms of product families, occurs on a monthly or quarterly basis, and is driven by functional managers.

- **Master production scheduling** takes the production plan (an output from sales and operations planning) as its starting point and then disaggregates that family-level plan into SKU or item-specific production schedules, typically by week. The master schedule is the hub of production planning activity, driving materials and **capacity** requirements while, at the same time, considering the availability of these key resources.
- **Material requirements planning is a process that** incorporates the master production schedule, inventory data, **bill of material** data, and other rules to make time-phased recommendations on the release of production and materials (purchase) orders.

In our further discussion of planning processes we will begin with sales and operations planning, as this is where functional-based personnel take charge (as opposed to strategic business planning where senior managers lead).

Sales and Operations Planning (S&OP)

A family-level production plan, in monthly (or quarterly) quantities, is one of the key outputs of the sales and operations planning process. Sales and operations planning is a coordinating activity not only among internal organizations, but it also looks at the capabilities of suppliers and logistics service providers. All internal and external **constraints** must be considered during this process when developing the production plan. Arriving at this plan requires considerable give-and-take among organizations as there are competing objectives that usually cannot all be met.

Question: What are some of the competing objectives when trying to manage the inherent conflicts between supply and demand?

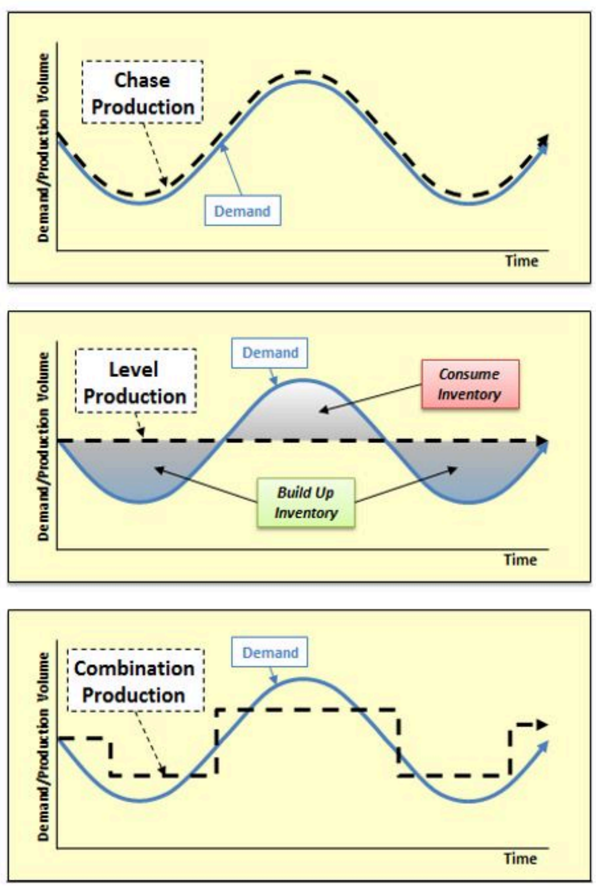
- **Senior managers** want to maximize profits while many **middle managers** want to make investments to improve their respective organizations (investments that may hurt short-term profitability).
- **Sales and marketing personnel** want to maximize product availability for customers—which means producing or acquiring lots of finished goods inventory—while **finance personnel** want to minimize inventory investment.

- **Customers** want to commit to purchases as late as possible and have the **flexibility** to make last-minute changes to their orders while **supply-side personnel** (production, purchasing, suppliers, human resources) desire stable, long lead-time demand (lots of visibility) to facilitate efficient operations.

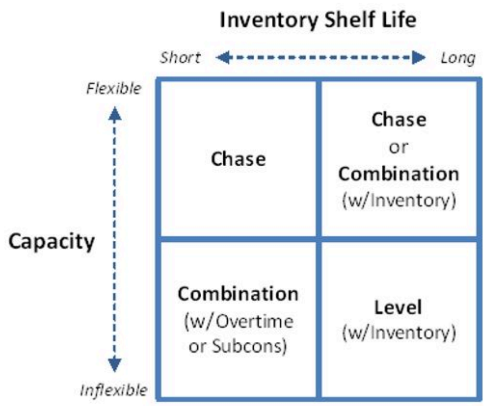
No matter where you find yourself in the business world, you should always be cognizant of these conflicting objectives. Sales and operations planning is the main coordinating vehicle for addressing these supply and demand challenges.

Question: What production plan strategies are used to address the competing requirements of supply and demand?

There are three primary build plan strategies for addressing the mid-range competing requirements of supply and demand.



1. Alter production levels to ***chase*** the demand ("chase" strategy).
2. Maintain ***level*** production while using **inventory** to buffer against the ups and downs in demand ("level" strategy).
3. Employ a ***combination*** of the chase and level strategies ("combination" strategy).



Several key factors drive the decisions regarding production plan strategy. While the use of pure strategies do exist (pure "chase" or pure "level" strategy), in reality, most organizations employ some sort of combination strategy. The graphic above provides a framework for when each strategy should be employed. Consistent with this framework, the table below adds detail and summarizes the main factors or characteristics which favor one strategy versus another.

Plan Strategy	Environmental Factors which Call for Production Plan Strategy
Chase	• Perishable demand • Short product lifecycles • Short shelf life or non-stock-able product or service (unable to prebuild and store inventory, as in a service offering. For example, how do you prebuild and store a haircut or doctor visit?) • Easy to increase capacity • Firm offers complementary seasonal products which utilize similar production processes (Think of Polaris which produces snowmobiles, ATVs, motorcycles, etc. Each product type can "chase" the demand within its given season.) • **Examples**: mid-tier manufacturers (suppliers) who cannot influence demand, service industries like grocery and consumer banking
Level	• Durable, changeable demand (through promotions, discounts, etc.) • Long lead-time demand, long product lifecycles • Stock-able product, long shelf life • Difficult to increase capacity (expensive and specialized equipment) • Stringent quality requirements best met with stable workforce • **Examples**: automobile manufacturing, hotels, airlines, chemical processing (where it is difficult to shut down and restart equipment)
Combination	• Most appropriate where demand is perishable • Can use some overtime or subcontractors to increase capacity • Modular product designs (to address short product lifecycles) • Some ability to stock subassemblies/modules • **Examples**: make-to-order personal computers, fast food restaurants (components precooked—level—then assembled to demand—chase)

Question: What *internal* and *external* tactics are commonly employed to alter or manage the supply and demand sides of the "make supply = demand" objective?

There are many **options** available to companies as they balance supply and demand, and they fall into two basic categories: (1) focus on altering supply and (2) focus on altering demand. The table below contains a summary of the internal and external tactics which can be employed to alter both supply and demand.

Internal Tactics (focus on supply)	External Tactics (focus on demand)
To increase supply • Hire workers, including temporary workers. • Run overtime. • Subcontract a portion of production. • Build up inventory when capacity exceeds demand (to be consumed when demand exceeds capacity).	**To increase demand** • Lower prices. • Give quantity discounts. • Advertise. • Run promotions. • "Package" or "bundle" product offerings. • Take reservations (appropriate in service operations).
To decrease supply • Fire workers, including temporary workers. • Employ slack time (assign workers to non-production activities). • Change (lower) production rates.	**To decrease (manage excess) demand** • Increase prices. • Take reservations. • Pre-book orders. • Accumulate order backlog. • Decline orders.

Examples for Each Plan Strategy

With the above conceptual grounding for each production plan strategy, we are now prepared to examine examples of how the production plan would be developed for each. For our examples let's suppose that we are trying to develop the production plan for a small manufacturer of high-end toy cars and trucks. Cost and constraint data can be found in the table below. These data will be used to determine which production plan strategy has the lowest total cost.

Cost and Other Information	
Production rate (units/emp/qtr)	500
Max subcontract production/mo	3,000
Regular production cost/unit	$ 20
Subcontract production cost/unit	$ 20
Holding cost/unit/quarter	$ 2
Hiring cost/employee	$ 1,500
Firing cost/employee	$ 4,500

Chase Production Plan

The tables below provide the summary data for the "chase" production plan. With **chase production**, we create a plan that holds no inventory at the end of each quarter. In Q1 we subtract beginning inventory of 2,000 from the forecasted sales of 16,000 to get 14,000 units of regular production.

Employees are hired and fired as needed in order to match regular production capacity and output with demand. Based on the production plan in the first table we are able to calculate the costs in the second. For example, Q1 regular production cost = 14,000 units X $20/unit = $280,000. Q2 fire cost = 2 employees fired X $4,500 per fired employee = $9,000. Summing all costs for four quarters gives a total cost of $1,187,000 for this production plan.

"Chase" Production Plan

Supply and Demand		Q1	Q2	Q3	Q4
Forecasted sales		16,000	13,000	14,000	17,000
Regular production		14,000	13,000	14,000	17,000
Subcontract production		-	-	-	-
Ending inventory	2,000	-	-	-	-
Hired employees		4		2	6
Fired employees		-	2	-	-
Total employees	24	28	26	28	34

Calculated Costs	Q1	Q2	Q3	Q4	Year Total
Regular production cost	$ 280,000	$ 260,000	$ 280,000	$ 340,000	$ 1,160,000
Subcontract cost	$ -	$ -	$ -	$ -	$ -
Inventory holding cost	$ -	$ -	$ -	$ -	$ -
Hire cost	$ 6,000	$ -	$ 3,000	$ 9,000	$ 18,000
Fire cost	$ -	$ 9,000	$ -	$ -	$ 9,000
Total Cost by Period	**$286,000**	**$269,000**	**$283,000**	**$349,000**	**$1,187,000**

Level Production Plan

Continuing with this same process gives the numbers below for the "level" production plan. Notice that the production plan is level at 14,500 units per quarter. To arrive at this number, we take total forecasted sales, net out (subtract) beginning inventory, then divide by the number of periods: (16k + 13k + 14k + 17k – 2k)/4 = 14,500. When output exceeds demand, inventory is stored (as in Q1, Q2 and Q3). When demand exceeds output, stored inventory is consumed to make up the difference (as in Q1 and Q4).

"Level" Production Plan

Supply and Demand		Q1	Q2	Q3	Q4
Forecasted sales		16,000	13,000	14,000	17,000
Regular production		14,500	14,500	14,500	14,500
Subcontract production		-	-	-	-
Ending inventory	2,000	500	2,000	2,500	-
Hired employees		5	-	-	-
Fired employees		-	-	-	-
Total employees	24	29	29	29	29

Calculated Costs	Q1	Q2	Q3	Q4	Year Total
Regular production cost	$ 290,000	$ 290,000	$ 290,000	$ 290,000	$ 1,160,000
Subcontract cost	$ -	$ -	$ -	$ -	$ -
Holding cost	$ 1,000	$ 4,000	$ 5,000	$ -	$ 10,000
Hire cost	$ 7,500	$ -	$ -	$ -	$ 7,500
Fire cost	$ -	$ -	$ -	$ -	$ -
Total Cost by Period	**$298,500**	**$294,000**	**$295,000**	**$290,000**	**$1,177,500**

Combination Production Plan

For the "combination" production plan, we have used a level internal production of 14,000 units per quarter (after hiring 4 employees in Q1), subcontract production in Q2 and Q3, and stored inventory in Q2 and Q3 to help satisfy demand in Q4, where demand exceeds regular production.

"Combination" Production Plan

Supply and Demand		Q1	Q2	Q3	Q4
Forecasted sales		16,000	13,000	14,000	17,000
Regular production		14,000	14,000	14,000	14,000
Subcontract production			1,000	1,000	-
Ending inventory	2,000	-	2,000	3,000	-
Hired employees		4	-	-	-
Fired employees		-	-	-	-
Total employees	24	28	28	28	28

Calculated Costs	Q1	Q2	Q3	Q4	Year Total
Regular production cost	$ 280,000	$ 280,000	$ 280,000	$ 280,000	$ 1,120,000
Subcontract cost	$ -	$ 20,000	$ 20,000	$ -	$ 40,000
Holding cost	$ -	$ 4,000	$ 6,000	$ -	$ 10,000
Hire cost	$ 6,000	$ -	$ -	$ -	$ 6,000
Fire cost	$ -	$ -	$ -	$ -	$ -
Total Cost by Period	**$286,000**	**$304,000**	**$306,000**	**$280,000**	**$1,176,000**

This "combination" plan gives us the lowest cost so far. Is this the lowest cost possible for a combination plan? To answer this question we'll discuss the use of advanced mathematical models to help in the creation of production plans.

Overview of Excel's Solver Function

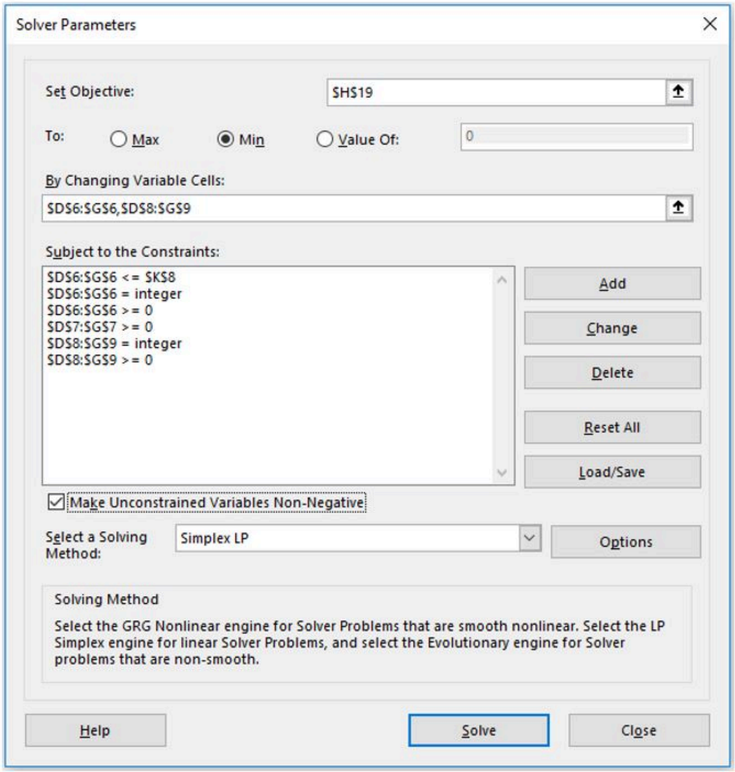
Companies will often employ complex mathematical models to optimize the tradeoffs among the many tactics which can be employed to make supply meet demand in the production plan. Such models are usually part of **Advanced Planning and Scheduling** (APS) software. An exploration of such applications is beyond the scope of this book, but we will take a look at Excel's "Solver" function to better understand how APS works.

Solver is a what-if analysis tool that can help you with planning, budgeting, and optimization. It consists of 4 components.[69]

- **Objective**—where you specify your goal within a target cell. For example, you may want Solver to minimize costs or maximize profit. The objective cell must be a formula.
- **Variables**—where you tell Solver which cell values can be changed to meet your objective. For example, you can tell Solver to maximize profit by changing product prices (data values within your variables cells).
- **Constraints**—where you set boundaries of what is acceptable for Solver to do with your variables.
- **Method**—where you select the type of "engine" that will be used to solve your problem. In this class we will use the "Simplex LP" engine.

Combination Production Plan with Excel's Solver Function

To use Solver on our production planning problem, we start with tables that are similar to the ones used in the previous examples. When we open Solver (from Excel's "Data" menu) we get a new window like this one below and are asked to provide a variety of information to help Solver compute an optimal answer.



- Our **objective function** is to minimize total plan cost (cell H19).
- The **variables** are subcontract production (cells D6–G6) and hiring and firing of employees (cells D8–G9), which affect regular production.
- The **constraints** can be seen in the graphic above. In this example we have told solver that all the variables must be integers (whole numbers) and that subcontract production must be less than or equal to 3,000 units per month (cells D6–G6 ≤ K8). We also specify that ending inventory must be greater than or equal to zero (cells D7–G7).
- We select the Simplex LP (linear program) as the **method** for this model.

"Combination" Production Plan (using Excel's Solver)

Supply and Demand		Q1	Q2	Q3	Q4
Forecasted sales		16,000	13,000	14,000	17,000
Regular production		12,500	12,500	12,500	12,500
Subcontract production		1,500	500	3,000	3,000
Ending inventory	2,000	-	-	1,500	-
Hired employees		1	-	-	-
Fired employees		-	-	-	-
Total employees	24	25	25	25	25

Calculated Costs	Q1	Q2	Q3	Q4	Year Total
Regular production cost	$ 250,000	$ 250,000	$ 250,000	$ 250,000	$ 1,000,000
Subcontract cost	$ 30,000	$ 10,000	$ 60,000	$ 60,000	$ 160,000
Holding cost	$ -	$ -	$ 3,000	$ -	$ 3,000
Hire cost	$ 1,500	$ -	$ -	$ -	$ 1,500
Fire cost	$ -	$ -	$ -	$ -	$ -
Total Cost by Period	**$281,500**	**$260,000**	**$313,000**	**$310,000**	**$1,164,500**

Once all of these parameters are set we click on the "Solve" button and the model will return a value of $1,164,500. As expected, this is the lowest-cost option of the four examples above. Solver was able to quickly consider all the possible tradeoffs to arrive at an optimal plan.

Notice how this plan makes use of both inventory and subcontract production when regular production capacity is insufficient to meet demand. Again, Solver can explore all the options quickly, much faster than a human can do via trial and error—especially when dealing with real-life models which are much more complex than this simple example.

Build Plans Summary

After creating these four plans we can summarize their results (as shown below). We should note that the examples above merely provide a very simplified view of how production plans can be created and evaluated to help organizations make decisions on how to best meet customer demand.

Summary of Production Plan Costs

Costs	Chase	Level	Combination w/o Solver	Combination w/Solver
Hire cost	$ 18,000	$ 7,500	$ 6,000	$ 1,500
Fire cost	$ 9,000	$ -	$ -	$ -
Production cost	$1,160,000	$1,160,000	$ 1,120,000	$ 1,000,000
Subcontract cost	$ -	$ -	$ 40,000	$ 160,000
Holding cost	$ -	$ 10,000	$ 10,000	$ 3,000
Total Cost	$1,187,000	$1,177,500	$ 1,176,000	**$ 1,164,500**

<u>Question</u>: Are there additional considerations to be made when creating the production plan?

As is the case with many quantitative analyses, care should be taken to look beyond the numbers before making decisions. Following is a sampling of questions (not a comprehensive list) which might be considered when determining which tactics to employ in the production planning process.

- Will subcontract production meet our quality requirements? Will we be at risk of losing important intellectual property (IP) if we subcontract? Will they meet our schedule requirements?
- Will firing employees (to shrink **capacity**) have an adverse effect on the morale of those who aren't fired? How long will it take newly-hired employees to be able to match the quality of the long-time employees?
- Does our plan call for so much overtime that employees will get tired (and not even care about the overtime pay)? Does our plan have so much idle time that we would be better off to lay off some employees (even if morale might suffer)?
- If we plan to build up inventory (when capacity exceeds demand), do we run the risk of the inventory going bad or becoming obsolete? Have we properly accounted for all the costs related to storing the inventory?
- Are there additional measures that can be taken to manage the quantity and timing of demand (through the "demand management" process) and thereby make it easier for us to make and keep commitments to customers?

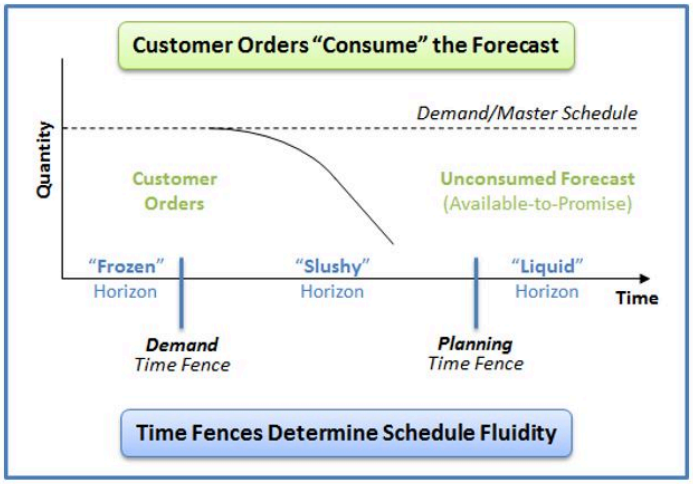
Master Production Scheduling (MPS)

The master production schedule (or simply, the master schedule) is the next step in an organization's planning hierarchy. The key input into the master schedule is a finalized production plan that is an outcome of the sales and operations planning process.

The quantities in the master schedule should match those of the production plan, although at a more detailed level of granularity. Within the master scheduling process, the production plan—typically expressed at the product family level in monthly or quarterly buckets—is "disaggregated" into item-specific, "buildable" or "sellable" products, expressed in weekly production quantities. This additional granularity or detail enables the master schedule to become the primary "interface" between the production system and external customers, providing an item-specific statement of supply against which commitments to customers can be made. The master schedule should extend far enough into the future to cover the longest cumulative lead time of the items being produced (usually three months or more).

Question: How are forecasts and customer orders treated within the master schedule?

Along with the production plan, forecasts and customer orders—the two components of demand—are also important inputs into the master schedule. Given customers' general reluctance to commit to purchases long in advance of the need date, companies must rely on forecasts (not merely customer orders) to drive decisions regarding the use of production-related resources (personnel, materials, equipment, etc.). The graphic below provides a conceptual view of a demand profile, where customer orders "consume" the **forecast** and drive the master schedule in the near term, while unconsumed forecast drives the master schedule further out in the future.



Question: What are time fences and planning horizons, and how do they relate to the master schedule?

Time fences are policy triggers which are used to note where restrictions or changes to operating procedures take place. The **demand time fence** separates the "frozen" planning horizon from the "slushy" **planning horizon**; the **planning time fence** separates the "slushy" from the "liquid" planning horizon.

- Within the **frozen horizon** the master schedule is considered unchangeable or "frozen" because changing the schedule in this period puts existing customer commitments at risk and wreaks havoc on production execution (productivity). Typically only senior managers can authorize changes in the frozen horizon. In this horizon the forecast is often ignored such that customer orders alone drive master schedule calculations.
- The **slushy horizon** spans from the demand time fence to the planning time fence. Changes to the schedule in this horizon require management approval and extensive analysis by supply management personnel—production planning, production supervisors, purchasing (suppliers)—to make sure such changes can be supported. The master schedule is driven by the combination of customer orders and unconsumed forecast.
- The **liquid horizon** begins at the planning time fence and extends into the future. The planning time fence is set equal to or slightly larger than the cumulative lead time of the product (including its components). In the

liquid horizon customer orders may be booked and changes to the master schedule can be made within the constraints of the production plan, without management approval.

<u>**Question**</u>: What is the **Availible-to-Promise** (ATP) and how is it calculated?

As can be seen in the graphic on the previous page, the available-to-promise represents that portion of the master schedule which is uncommitted to existing customer orders. In other words, this uncommitted supply is "available to promise" to new customers. The ATP provides invaluable information to production and sales personnel as they work to schedule customer order shipments. Calculating ATP can be confusing. The example of MPS-related data in the table below will help us understand how ATP and projected available balance (PAB) are calculated.

MPS/ATP Example

Week	0	1	2	3	4	5	6	7	8	9
Forecast		80	80	80	70	70	70	70	70	70
Customer Orders		83	78	65	61	49	51	34	17	11
Projected Available Balance (PAB)	110	27	99	19	99	29	109	39	119	49
Available-to-Promise (ATP)		27	7	-	40	-	65	-	122	-
Master Production Schedule (MPS)		-	150	-	150	-	150	-	150	-

For this example we will assume there is a 2-week demand fence, meaning we will ignore any forecasts in week 1 and week 2. Only customer orders will be used to calculate both ATP and PAB within this frozen planning horizon. In fact, throughout the horizon, ATP makes its calculations only from (1) beginning on-hand inventory in week 0, (2) MPS replenishments throughout the schedule, and (3) customer orders on the demand side. The PAB, on the other hand, will incorporate the greater of forecast and customer orders, outside the frozen period (week 3 and beyond), not just customer orders. Let's walk through some specific examples.

- ATP in week 1 is calculated by taking the beginning inventory and subtracting customer orders up until the week of the next MPS replenishment (which is in week 2). Hence, ATP in week 1 = 110 – 83 = 27.
- ATP in week 2 is calculated by taking the MPS quantity in week 2 and subtracting all customer orders from week 2 until the next MPS replenishment (which is in week 4). Hence, ATP in week 2 = 150 – (78 + 65) = 7. ***Note that the ATP calculation is not cumulative.*** It goes from one MPS period to the next.

- ATP in week 4 = 150 – (61 + 49) = 40.

What should you do if a customer requested 39 units in week 3? Three options come to mind.

- See if the customer would be willing to accept 34 units in week 3 (27 + 7 = 34 from previous period ATPs) and the balance of 5 units in week 4 (to be drawn from the week 4 ATP of 40.
- See if sufficient materials and capacity are available to increase the week 2 master schedule by 5 units in order to ship all 39 units together in week 3.
- If neither of the two previous options will work, then do not take the order.

Below are some examples of how projected available balance is calculated, both inside and outside the demand fence.

- PAB in week 1 (inside the demand fence) is calculated by adding PAB from the previous period to the MPS in week 1 and then subtracting customer orders from week 1. PAB in week 1 = (110 + 0) – 83 = 27.
- PAB in week 2 (again, inside the demand fence, so forecast is ignored) = (27 + 150) – 78 = 99.
- PAB in week 3 (outside the demand fence, so we subtract the greater of forecast and customer orders) = (99 + 0) – 80 = 19. ***Note that a projected available balance is shown in each week,*** not just in the weeks when there is an MPS replenishment (as is the case with ATP).

<u>**Question**</u>: What is a two-level master schedule and when is it used?

In an **assemble-to-order** (ATO) production environment, a two-level master schedule is used for end products or families which contain multi-option **features**. One level of the master schedule is used for the base product or family and the other level focuses on the features. It may sound complicated, but this approach *greatly* simplifies planning for products which offer many features and options. It also enables organizations to more effectively market products based on component availability.

Feature	Bread	Meat	Cheese
Option 1	White	Roast beef	American
Option 2	Wheat	Turkey	Swiss
Option 3	Oat	Chicken	Provolone
Option 4	Parmesan	Cold cuts	Pepper jack

To help illustrate how a two-level master schedule is used, let's look at a sandwich shop (think of Subway) that uses an assemble-to-order process for its main product offering—sandwiches. For this example one level of the master schedule will be for the sandwich (base product) and the other level will be for all of the features and options.

With this simplified product structure, how many unique sandwiches can be produced? The answer is 64 (4 bread types X 4 meat types X 4 cheese types = 64 combinations). If we were to include all the options for each of the features above, and if we were to include other features with their numerous options (vegetables, condiments, toasted or not, etc.) we would end up with *literally thousands* of potential unique sandwich combinations or products. In such environments, where thousands of unique end products are possible, it becomes virtually impossible to accurately forecast demand for each of these end products.

A two-level master schedule allows each base product and each feature to be forecasted and planned separately. In other words, instead of forecasting and planning for 64 unique sandwich combinations, the sandwich shop merely has to (1) forecast or plan the number of sandwiches to be sold per day and (2) apportion that number across the options within each feature, probably using historical averages for each option.

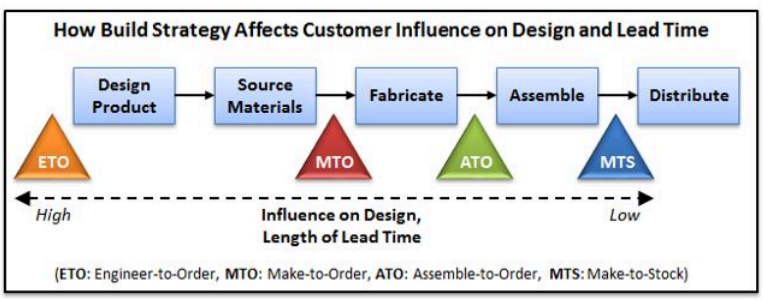
The table below shows a simple product structure and the percentage breakdown of demand across each option. Notice that in this example the sum of the option percentages for each feature exceeds 100% (sum of bread options, meat options and cheese options are 105%, 103%, and 104%, respectively). This "overplanning" is done intentionally as a "mix hedge" to provide flexibility at the component or option level in case the actual option demand or mix is different than what is forecasted. In other words, it is much easier, more practical, and more cost-effective to stock excess supplies of components than it is to stock extra finished goods (finished sandwiches).

Feature	**Bread**	**Meat**	**Cheese**
Option 1	35% - White	33% - Roast beef	24% - American
Option 2	25% - Wheat	30% - Turkey	35% - Swiss
Option 3	15% - Oat	25% - Chicken	20% - Provolone
Option 4	30% - Parmesan	15% - Cold cuts	25% - Pepper jack

Another benefit of this 2-level approach is that it provides valuable information that can be used by marketing. For example, let's say that the sandwich shop made a large, heavily-discounted forward buy on roast beef and they wanted to use it all up before its expiration date. They may want to run a special on all roast beef sandwiches in order to steer demand in that direction. They could also use pricing to steer demand away from components that may be short. A **modular bill of material** and option-level planning process enables this type of agility. Dell Computer is a master of this.

Question: How does the selection of build strategy affect customer input into the design of the finished product (and lead time)?

If we stick with our food examples, it's easy to see the varying degree of customer input that is facilitated with each build strategy (as shown in the graphic below).



- **Make-to-stock** items allow for virtually no customer input into the design of the item. Think of a package of cookies on a convenience store shelf. You can't change the design of the product. It has been designed in response to marketing research, produced in response to a forecast and stocked on a shelf until purchased. A major benefit of this build strategy is very short lead times as the finished product is available on store shelves.
- **Assemble-to-order** items allow customers to provide input as to how the semi-finished goods or subassemblies are configured. Again, think of Taco Bell where it is fairly easy to request changes that differ from a standard product (for example, extra sour cream), however, those changes are limited to adjusting the mix of existing subassemblies. This build strategy

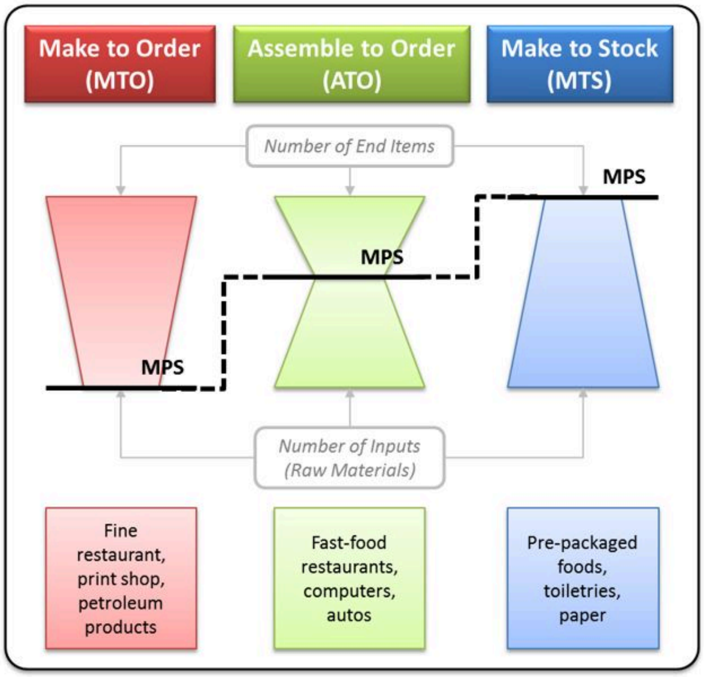
balances the benefits of increased product variety with relatively short lead times.

- **Make-to-order** items allow for extensive input by customers into the design process, limited by acceptable design constraints and available raw materials. In a fine restaurant customers can make requests down to the ingredient level as many or most dishes are prepared from scratch, not merely assembled from existing semi-finished goods.
- **Engineer-to-order** items allow maximum input by customers into the design process. This would be analogous to designing any food item and then having the freedom to procure materials from wherever is necessary.

Question: How does product structure (or the **bill of materials**) affect the master production schedule?

Consider our ATO example above (sandwiches) where production is planned at the ingredient level, prior to assembly of the final product. The number of ingredients is much smaller than the number of possible finished sandwiches **configurations**. Hence, it is better to forecast and plan production of sandwiches at the ingredient level, or the narrowest point in the bill of material (as seen in the graphic below).

Likewise, each of the basic build strategies calls for the MPS to be created at different points in the product structure. The "shape" of a product's bill of material (**BOM**) can vary greatly, with the three basic shapes shown in the graphic below, and each requiring a slightly different approach to master scheduling. For example, the shape for the **MTS** item (far right side of the graphic) denotes that many raw material inputs will result in a relatively small number of sellable products. (The shape is broader at the base than at the top.) The master schedule for such products (pre- packaged foods, etc.) is expressed at the finished product level. For instance, the schedule would tell how many of a specific sellable item would be produced per week.



The middle "hourglass" can best be explained by Taco Bell. A relatively small number of semi-finished goods—represented by the narrow part of the shape—are mixed and matched to create a much wider variety of finished goods. The master schedule is more generic than the previous example, being expressed in terms of how many base products (tacos, burritos, etc.) will be sold and how much of each semi-finished ingredient will be needed.

Such an approach to master scheduling is much simpler than trying to schedule production for the many, many end items—as represented by the top of the shape. (For a fun exercise, go to Taco Bell and see how many unique end items they can produce and compare that number to the total number of ingredients that they use. You will find that the number of ingredients is much smaller than the number of unique items they can produce.)

Finally, the **MTO** shape represents those many items that can be made from few common ingredients. For example, a fine restaurant can mix and match a relatively small number of ingredients into a nearly limitless variety of gourmet dishes. Likewise, petroleum can be refined into many, many products (gasoline, motor oil, Vaseline, plastics, etc.). In such build environments, planning is done at the ingredient level.

Chapter Summary

Below are some of the main points you should have garnered from the study of this chapter.

- **Planning processes will differ by industry and by company**, but most organizations will employ, in one form or another, multi-level planning processes similar to those discussed in this chapter. From most strategic to most granular, **the basic planning processes are** (1) strategic business planning, (2) sales and operations planning, (3) master production scheduling, and (4) materials requirements planning.
- **Sales and operations planning** (S&OP) is a monthly or quarterly planning activity focused on aligning supply with demand at a product family level. To achieve this objective or alignment, functional managers must often make tradeoffs among competing objectives.
- **A key output from S&OP is the production plan**, which will employ one **of three build plan strategies:** (1) chase, (2) level, or (3) combination. Organizations often employ sophisticated mathematical models (usually within specialized software packages) to help create optimal production plans.
- The family-level or "aggregate" production plan is "disaggregated" and converted into an SKU-level master production schedule (MPS). The MPS becomes a statement of supply and interface against which commitments to customers can be made.
- A product's **bill of material** structure and selected build strategy (ETO, MTO, ATO, or MTS) can have a huge bearing on lead time, flexibility, and customer input into the design process.

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[68] Ezra Taft Benson, *God, Family Country: Our Three Great Priorities*, (Salt Lake City: Deseret Book Co., 1997), 145-46.

[69] Refer to Microsoft Excel Help or Google "solver" to learn more about using this powerful function.