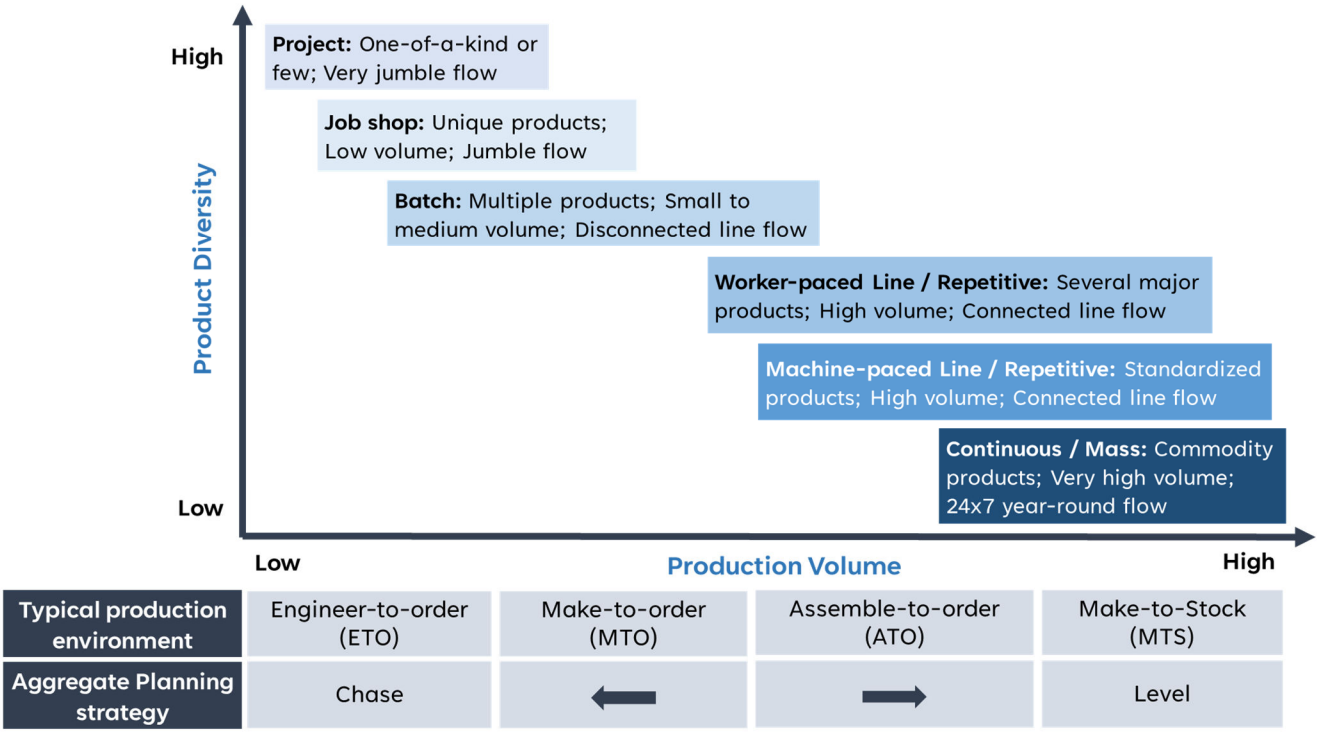
Manufacturing Value Added: Types of Production Processes, Manufacturing Environment, and Planning Strategies

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Businesses have a range of choices to make among different manufacturing modes (methods/processes), production environment, and planning strategies, depending on the nature of the product and the target market.

Ranges of Production Processes, Manufacturing Environment, and Planning Strategies



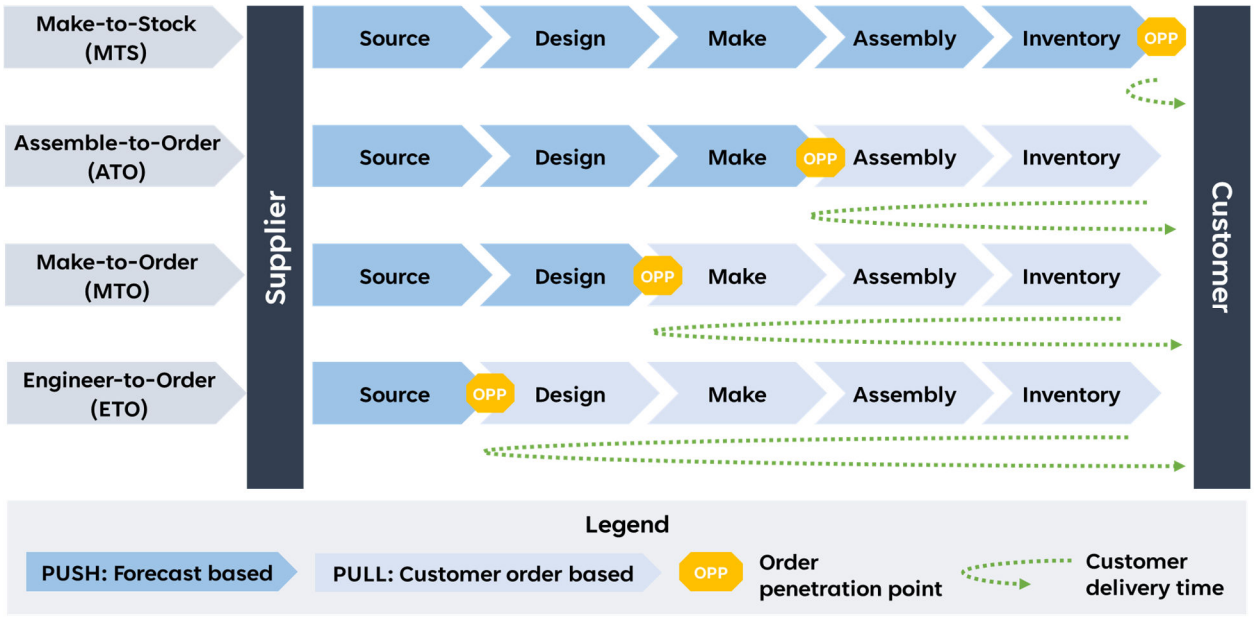
Source: Center for Supply Chain Research, The Pennsylvania State University (adapted from Academic Gain Tutorials 2021; Pereira, Oliveira, and Carravilla 2022; Spearman and Choo 2018; Wemmerlöv 1984)

SIX CLASSIC TYPES OF MANUFACTURING PROCESSES / MODES

- **PROJECT.** Project process is a one-off manufacturing process that meets very specific customer requirements in large contract, and that is typically too large to be moved once completed. Examples include construction of airports/roads/buildings, shipbuilding, movie production companies, and drilling oil wells (Academic Gain Tutorials 2021; Scott, Lundgren, and Thompson 2018).

- **JOB SHOP.** A job shop is also a one-off manufacturing process wherein production is done in multiple designated workstations or workshops instead of a single assembly line or production lines. Job shop process focuses on producing small amounts of custom products that meet the unique order requirements of customers. Examples include machine tool shops, luxurious yacht, and painting shops. When a job shop is specialized in a certain type of production, it is called a "repetitive job shop" (Academic Gain Tutorials 2021; Brush, Cole, and O'Donnell 2020; MetaOption 2022; Scott, Lundgren, and Thompson 2018).
- **BATCH.** Manufacturing using batch processes produces similar items on a repeat basis in which one batch, or a specific quantity of goods, is produced during a time frame. Batch processes have a disconnected line flow pattern where processes are divided into a chain of activities that take place after each other. When a batch is completed, the equipment is cleaned and prepared to produce the next batch. Batch processes, thus, are continuous in nature, but they permit a wider range of products than connected line flow and mass continuous processes (Brush, Cole, and O'Donnell 2020; Scott, Lundgren, and Thompson 2018; Spearman and Choo 2018).
- **LINE / REPETITIVE: Worker-paced and Machine-paced.** In a line manufacturing process, products are passed through a repetitive or same ongoing sequence of operations from the beginning to the end. It can be used when the products to be made are sufficiently high in volume, but individual discrete units. The product range is sufficiently narrow to have dedicated, connected production lines that create the same product, or collection of products, year-round (Bauto 2022; Scott, Lundgren, and Thompson 2018; Spearman and Choo 2018). As these few different products or variants are alternated in production, realizing a cyclic load of the line, it is also called *'repetitive.'* Line manufacturing can be *worker-paced* or *machine-paced*, the latter of which is often an automated assembly line process. Examples include automobile plants, food processing, and beer bottling (Academic Gain Tutorials 2021; Bauto 2022; Brush, Cole, and O'Donnell 2020; Grassi et al. 2020).
- **Continuous / Mass.** Continuous manufacturing, also known as mass manufacturing, process is designed to enable the mass production of the same product or collection of products year-round, often 24 hours a day continuously, before the customer demands them. Continuous manufacturing is similar to repetitive manufacturing, but the former is commonly used for commodity products. Examples include petrochemical refineries, edible oil refineries, steel making, paper making, beer brewing (Academic Gain Tutorials 2021; Bauto 2022; Brush, Cole, and O'Donnell 2020; Gourley 2020; LaMarco 2018; Scott, Lundgren, and Thompson 2018).

Manufacturing Environment / Strategies: Push-Pull Views and Order Penetration Point



Source: Center for Supply Chain Research, The Pennsylvania State University (adapted from Tamlander 2016; Ivanov, Tsipoulanidis, and Schönberger 2021; Wemmerlöv 1984; Willner et al. 2014)

PUSH-PULL VIEW OF PRODUCTION STRATEGIES

The push-pull view of the production strategies categorizes manufacturing environment based on whether they are executed in response to a customer order **(pull)** or in anticipation of customer orders **(push).** The **GENERAL PHILOSOPHY** of **pull strategies is to produce as much as needed**, while that of **push strategies is to produce as much as possible**. The push-pull view is further described as follows (Altiok 1997; Cheng et al. 2012; Ivanov, Tsipoulanidis, and Schönberger 2021; MTC 2021):

- **In PULL strategy,** production processes are initiated based on customer orders. It is demand-driven where downstream activities (customer order) signal their needs to upstream activities (production) and often requires highly flexible system in order to be responsive to changes in demand. Advantages of the pull strategy are responsiveness and a higher degree of customer-oriented product customization.
- **In PUSH strategy,** production processes are initiated based on forecast in anticipation of customer orders. It is considered to be the traditional strategy of manufacturing. The advantages of push strategy are economy of scale and high capacity-utilization (low manufacturing costs), and short customer delivery times (high level of inventory for order fulfillment). However, in highly uncertain demand situation, it is difficult for a push production to react quickly to match supply with demand, causing either supply shortage or excessive inventory build-up.
- A **HYBRID PUSH-PULL strategy** can also be used to provide a balance between the efficiency offered by the push system and the flexibility offered by the pull system.

ORDER PENETRATION POINT (OPP) AND MANUFACTURING ENVIRONMENT CLASSIFICATIONS

Along the push-pull view boundary is the **placement of the order penetration point (OPP)** which defines the point after which the production is assigned to a sales order. Depending on the placement of the OPP, the **degree of interaction between the firm's production function and the customers of the firm** differs, which affects production planning strategy and production process choices, can greatly affect the lead time experienced by the customer, and influences how much an individual customer can affect the product design. The OPP positioning, in turn, determines the classifications of production environments, including **Make-to-stock (MTS), Assemble-to-order (ATO), Make-to-order (MTO), and Engineer-to-order (ETO).** These manufacturing environments are further described below and their characteristics are summarized in Table 1 (Barbosa and Azevedo 2018; Ivanov, Tsipoulanidis, and Schönberger 2021; Tamlander 2016; Wemmerlöv 1984; Willner et al. 2014).

- In a **MAKE-TO-STOCK (MTS)** manufacturing environment, product specifications are set long before the customer makes the decision of ordering the products. The MTS strategy is the classic manufacturing principle, where products are produced for stock, based on forecast or minimum stock refill (the latter is typically calculated based on forecast or historic consumption). In MTS, the sales orders are placed in the finished goods inventory, and the inventory is either replenished based on forecasts or by replenishment orders triggered e.g., by re-order points. MTS is a typical choice when the **demand is high and predictable**, and **product variability is low**. The MTS strategy is appealing due to **low unit production costs, high capacity-utilization, and short customer lead times**. MTS strategy brings **inventory risks** however. Forecasts might not be accurate which leaves products to be unsold and working capital can be high depending on the inventory levels. Thus, accurate forecasts and good inventory management is the key for success in this environment (Barbosa and Azevedo 2018; Ivanov, Tsipoulanidis, and Schönberger 2021; Microsoft 2023; Tamlander 2016; Willner et al. 2014).
- In an **ASSEMBLE-TO-ORDER (ATO)** manufacturing environment, the final products are often designed to be modular, consisting of standard parts, components, and subassemblies that are typically acquired or produced to stock based on forecasts or replenishment orders. The schedules for remaining components, subassemblies, and final assembly are not executed until detailed product specifications have been derived from booked customer orders. In ATO, the sales orders are placed in the final assembly. Then, various premanufactured or pre-acquired parts, components, and subassemblies are assembled according to each customer specifications, after which the final products are tested, packed and delivered. The basic philosophy behind ATO manufacturing is to defer "as long as possible" the commitment of material and capacity to any product, and thereby increase the flexibility of combining components and subassemblies to meet each customer order specification. At best, the ATO strategy enables **higher degree of product individualization** due to the numerous final assembly options, **relatively short lead times of customer delivery**, and **lower inventory risks** (Barbosa and Azevedo 2018; Ivanov, Tsipoulanidis, and Schönberger 2021; Tamlander 2016; Wemmerlöv 1984; Willner et al. 2014).

- In a **MAKE-TO-ORDER (MTO)** manufacturing environment, standard products are made to order or finished to order. Products are configured such that they contain a set of pre-defined parameters and attributes that the customer can choose from. Thus, in MTO, engineering design and specification is generally completed before the customer order is received. However, not only the final assembly from some standard modules can be individualized, but also that the modules and components can be manufactured individually for each particular customer. It is noted that while the MTO strategy enables customer individualization at the module/component level, the customer still has to select his desired product design within a pre-defined solution space. As in the case of ATO, the pre-production of standard module/component might be done by using the MTS strategy. Then, manufacturing and assembling according to the selected configuration of the product only occur after the order has been confirmed. That is, the sales order initiates the production. The inventories typically consist purely of raw materials and sales order specific work-in-process (WIP) inventories. The MTO strategy can be recommended when **production quantities are low, products are highly sophisticated, product variability is high, and demand fluctuation is high**, The MTO strategy requires **higher investments in flexibility** and incur **longer lead times** than ATO, but it enables relatively **higher degree of product individualization and lower inventory risks** (Barbosa and Azevedo 2018; Ivanov, Tsipoulanidis, and Schönberger 2021; Microsoft 2023; Tamlander 2016; Willner et al. 2014).
- In an **ENGINEER-TO-ORDER (ETO)** manufacturing environment, the customer order is placed at the initial design of the product – thus, designing, manufacturing and assembling the products occur when the order has been confirmed. The ETO strategy, **typically addressed by a project**, produces products that are customized according to customer specifications through the execution of engineering activities in which the actual products that are required fulfill the order are designed and described. The necessary degree of customization can vary considerably, ranging from a mere customer specific extension of the product parameter range to the complete development of a new product according to customer requirements. An example of ETO strategy application is the production of an aircraft, railway vehicle, or a house building where the customer is involved in the engineering and production processes right from the beginning and can select not only individual components, but also materials and designs. The ETO strategy offers **highest degree of customizability** for the customer, and is recommended for **unique and complex products of high value where customer individualization is crucial**. The ETO strategy requires **high investment in flexibility** since product specifications are uncertain. Another downside of the ETO strategy is the **long customer lead time**, which include everything from design, material acquisition, production, assembly, testing, and packing. In short, the ETO environment is characterized by **different levels of customization, long lead times, and high variability in terms of demand, product specifications, lead times and process duration** (Barbosa and Azevedo 2018; Ivanov, Tsipoulanidis, and Schönberger 2021; Microsoft 2023; Tamlander 2016; Willner et al. 2014).
- **MULTIPLE AND HYBRID MANUFACTURING ENVIORNMEN: TWO-STAGE MTS-MTO HYBRID COMMON.** It is noted that companies often implement **multiple manufacturing strategies**, depending on the product characteristics where some are produced to stock and others to

order, etc. Moreover, **hybrid manufacturing via a two-stage strategy** has received attention from academia and industry, and is frequently encountered in practice. In this case, **two-stage MTS-MTO strategies** is one of the most dominant production strategies in which a company manufactures semifinished products in an MTS fashion in the first stage and stores them as intermediate inventories. Then, end products are produced corresponding to customer requirements in an MTO mode in the second stage. The hybrid MTS–MTO production strategy can contribute to shortening order fulfillment lead time relative to the pure MTO production because end products are made from semifinished goods, rather than raw materials or components. It can also contribute to lowering inventory costs because inventory is held for semifinished products, not end products as in the case of pure MTS (Barbosa and Azevedo 2018; Ivanov, Tsipoulanidis, and Schönberger 2021; Kim and Min 2021; Tamlander 2016; Wemmerlöv 1984).

Table 1: Summary of Characteristics of MTS, ATO, MTO, and ETO Manufacturing Environments

Aspect	MTS	ATO	MTO	ETO
Interface between production function and customer	Low	Medium	High	High
Customer delivery time	Short	Medium	Long	Long
Production volume of each sale unit	High	Medium	Low	Low
Basis for production planning and scheduling[1]	Forecast / Base stock	Forecast / Base stock and Backorder	Backorder	Backorder
Order promising	Based on available of finished goods inventory	Based on available of major subassemblies and components	Based on available capacity for manufacturing	Based on available capacity for manufacturing and engineering

Source: Discerned from Altiok (1997); Barbosa and Azevedo (2018); Ivanov, Tsipoulanidis, and Schönberger (2021); Microsoft (2023); Tamlander (2016); Wemmerlöv (1984); Willner et al. (2014)

Aggregate Production Planning Strategies

Aggregate production planning (APP) is a type of medium-term capacity planning that usually covers a time horizon of 3 to 18 months and its aim is to determine optimal level of production, inventory, and human resources regarding the limitations of production resources and other constraints. APP is a hierarchical planning process that translates annual business plans and demand forecasts into a

[1] In production planning under a **backorder-driven policy**, production takes place only after orders are received, and not earlier. In contrast, under a forecast-driven policy, production may continue as long as the inventory level in the warehouse is below a target level. That is, it stops as soon as the inventory level reaches its target, and it restarts when the level drops below the target. This principle of operation is known as the **base-stock policy** in the classical production-inventory theory (Altiok 1997).

production plan for all products. The aggregate demand is determined based on forecasts of future demand, customer orders, special promotions, and safety stock requirements. This forecast of demand is then used in APP to: (1) determine **overall level of each product category** to meet fluctuating and uncertain demand in near future, and (2) set policies in regard to the **aggregate utilization, production rate, workforce levels, subcontracting, inventory balances or backlogs, and available production resources**. Costs relevant to the aggregate planning decision include inventory cost, set up cost, machine operating cost, hiring cost, training cost, overtime cost, and costs incurred for hiring part-time and temporary workers to meet peak demand (Jamalnia et al 2019; Wisner, Tan, and Leong 2022).

THREE BASIC AGGREGATE PRODUCTION PLANNING (APP) STRATEGIES

There are three basic APP strategies that firms use for completing the aggregate plan, including the **chase strategy, the level strategy,** and the **mixed strategy**. The primary difference between the two pure strategies is the lever, that is, the parameter that is manipulated to achieve equality of supply and demand over the aggregate planning period in which **capacity is the chase strategy lever**, while **inventory is the level strategy lever.** The two pure strategies are depicted below and further discussed in turn (Addis 2020; Swamidass 2000; *Welp Magazine* 2020; Wisner, Tan, and Leong 2022):

Chase Production Planning Strategy **Level Production Planning Strategy**

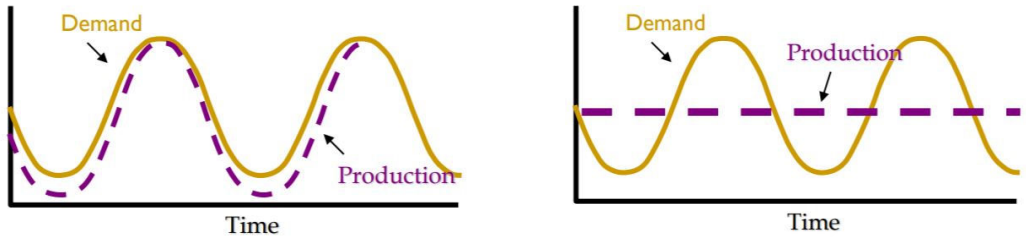


Image credit: Studious Guy (n.d.)

- The **CHASE production planning strategy uses capacity, in the form of machine or personnel capacity, as the lever** in which capacity is adjusted to match the demand pattern. By chasing demand, the **level of finished goods inventories is very low**, but the workforce fluctuates in response to the demand pattern which can increase management costs. **Hiring, training, and termination costs** are significant cost components in the chase production planning strategies. This strategy works well for MTO manufacturing environment since they cannot rely on finished goods inventory to satisfy the fluctuating demand pattern.
- A **LEVEL production planning strategy** relies on a constant output rate and capacity while **using inventory and backlog levels as a lever** to handle the fluctuating demand pattern. Thus, this strategy is characterized by the fluctuating inventory and/or backlog level while the workforce and production capacity remain constant. More specifically, in MTS environment, the level production planning means that finished goods inventory levels will grow during low demand periods and decrease during high demand periods. In MTO or ATO environments, the backlog of orders will

increase when demand is high and decrease when demand is low. Using a level production strategy enables a company to have **lower production costs**. However, if demand is highly variable, this plan will result in periods marked by backorders or stockouts and other periods when the supply chain carries a high level of inventory. **Inventory carrying and stockout costs**, hence, are major cost concerns in the level production planning strategy. In general, this strategy works well for MTS manufacturing environment, which typically emphasize immediate delivery to off-the-shelf, standard goods at relatively low prices and which demand for a product is relatively stable.

- A **MIXED production planning strategy** combines chase and level strategy to strive optimal balance between demand and production and inventory costs by **using both capacity and inventory levers**.

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