Inventory Analysis for Product Wheel Operations

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Product Wheels

**Purpose**
- To understand how inventory is calculated and impacts cost when running product wheels.
- Review of product wheels, safety stock calculations, and replenishment lead time “risk” considerations
- Basic understanding of inventory and inventory cost calculations when running product wheels
Product Wheels and Inventory
  The Basics
  Managing Principles
  Safety stock calculations
  Safety stock versus product wheel length
  Inventory calculations for supply chain networks
Product Wheel - Definition:

Production sequence used by a manufacturing operation when multiple products are made on a single line/piece of equipment

- Consistent sequence
- Repetitive time cycle (approximately the same time to get around the wheel each cycle)
- Caution: Some businesses do not run a repetitive sequence, but still refer to their planning cycle as their “product wheel”
- Batch: Size of one unit of production (in batch processes)
- Campaign: “spoke”, length of one segment of a product wheel, or a series of batches of same product
- Lot: subsets of campaigns to represent some quality commonality
- Cycle: planning length that includes multiple campaigns. Sequence, campaign lengths and gaps need to be specified.

- The amount of B produced must be enough to satisfy demand of B during the entire cycle, plus safety stock make-up
- The inventory left at the end of the B campaign must be enough to last through the remainder of the cycle until the next campaign of B starts.
Product Wheel: When should they be used?

Machines running multiple products:
- If transitions (setup) are costly in terms of...
  - Time
  - Yield loss
  - Labor
  - Materials
- If transition costs are impacted by sequence
  - Colors (black to white)
  - Dimensions (i.e., sheet width)
  - Material grades
  - Variations in process parameters (i.e., temperature)

Consider Product Wheels if either of the above conditions are true.
Product Wheel: Why?

When managed properly, Product Wheels provide effective discipline for meeting customer demand & service levels, while maximizing process responsiveness and minimizing required inventory

- Decreases cash flow cycle time
- Decreases controllable fixed costs
- Increases variable margin
- Provides framework for establishing customer order lead times (lead time > product wheel length)
- Provides understanding of relationship between transition cost and inventory cost
Inventory vs. Product Wheel Length

Product Wheel length:

Plan A = 4 weeks
Plan B = 1 week

- How does Product Wheel length impact average cycle stock?
- How does Product Wheel length impact capacity if product transitions require substantial downtime?
- Which plan is better?
Concepts & Definitions: Product Wheel Cycle Length

Cycle Stock

WHEEL TIME
CYCLE LENGTH
Objective:
Maintain *shortest reasonable product wheel cycle time* without sacrificing customer service

Why are shorter Product Wheels more desirable?
- Require less inventory and reduce wasteful behaviors

\[
\text{Peak Inventory} = \text{Average Demand} \times \text{Replenishment Time} \times (1 + \text{Safety Factor})
\]
Product Wheel Length: The Debate

**SHORT**
- Lower inventories
- Shorter ‘period of risk’
- Increased flexibility – respond faster to changes in customer demand

**LONG**
- Fewer transitions = higher equipment capacity
- More stable operations, potentially higher yields
- Perceived by operations as lowest cost

The balance we must maintain with a product wheel is transition (setup) cost vs. inventory cost – while meeting customer service requirements.
Total supply lead time = sum of the following

- \( t_m \) = Time from raw material order to receipt in raw material warehouse
- \( t_c \) = Lead time to produce
- \( t_1 \) = Lead time from production to source warehouse
- \( t_2 \) = Lead time from source warehouse to distribution warehouse
- \( t_3 \) = Lead time from distribution warehouse to customer
- \( t_p \) = Time from delivery to customer to receipt of payment

Note: All times includes order processing
In order to properly manage a product wheel, you need to understand all of the factors that influence the wheel.

**Internal Variables (and their variability)**
- Number of Products
- Production Rates
- Transition Times
- Downtime
- Yield & Rate Losses

**External Variables (and their variability)**
- Demand Rate
- Lead Time
**Lean Impact on Product Wheel Length**

Min. Product Wheel Length =

\[
\sum \text{Transition Time} - \sum_i^n \text{Demand Rate}_i \text{Production Rate}_i
\]

<table>
<thead>
<tr>
<th>Factor</th>
<th>Change</th>
<th>Effect on PW Length</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transition Time</td>
<td></td>
<td></td>
<td>More time available to make product; spin wheel faster</td>
</tr>
<tr>
<td>Uptime</td>
<td></td>
<td></td>
<td>More time available to make product; spin wheel faster</td>
</tr>
<tr>
<td>Demonstrated Rate</td>
<td></td>
<td></td>
<td>Less time is needed to produce same amount; shorter wheel</td>
</tr>
</tbody>
</table>
Any improvement that decreases product wheel length will **reduce inventory**.

- Decrease transition time
- Increase uptime
- Increase production rate
- Cell Design - allocate products across parallel assets to assign each product to a single asset
  - Fewer products on each wheel
  - Shorter, less costly transitions

Lean Tool Box: 5S, SMED, TPM, Workplace Redesign, Activity Waste Analysis, Standard Work and Cell Design
Product Wheel: Design Components

Sequence
- Minimize transition cost and time
- Focus on transition from family to family

Length
- Primary “drivers” for determining length (cycle):
  - Minimize sum of inventory and transition costs
    - Inventory costs - capital, insurance, taxes, obsolescence, storage
  - Sufficient capacity to meet demand

Composition
- Every product (family) every cycle?
- Some products more or less frequently?
Other factors that impact Product Wheel design

- Minimum campaign lengths and batch sizes
- Sales constraints may strongly influence design
- Capability to do transitions – timing, run order, …
- Other technical constraints: cleanouts, catalysts, …
- Process capability
- Unscheduled down time: average and variability
- Lead time uncertainty
- Volume discounts
- Transportation economies
- Supplier policy
- Multiple-item purchases
Production Cycle

- **Cycle Stock**
  - Product Cycle, \( T = \frac{Q}{A} \)
  - Production Campaign Started

- **Safety Stock**

- **Inventory Level**
  - Slope = Demand rate, \( D \)

- **Kanban level for a pull system**

- **Slope = Production Rate (m) - Demand rate, (D)**
Lower inventory levels mean less investment and lower inventory carrying costs.

Running a product more frequently reduces the likelihood of stockouts (a fact that is not accounted for in the EOQ calculations).

From a “Lean” perspective – transition cost and time are factors to be reduced instead of “accepted” – to make lower inventories and more frequent transitions an accepted practice (and a competitive advantage).
Traditionally, cycle stock and safety stock calculations are carried out separately

One might imply that the two are independent

They are not!
Cycle stock (cycle inventory level) depends only on product wheel length.

Safety stock calculated to cover the entire period of risk – which includes the wheel length, and may include raw material lead time, shipping time, . . . (assuming the shipping time does not extend the delivery time past the next scheduled raw material ordering date!)
Fundamental Drivers of Safety Stock Requirements

- Inherent variability in demand and supply, along with the service goals are the drivers of safety stock requirements.
- Variability of demand that needs to be accounted in safety stocks is due to “forecast error” which is often approximated by variability of historical demand. Using forecast error instead can make a difference.
- Using the correct service level type for the service level targets is another critical component in determining the safety stock requirements accurately.
Service Level Types

- **Cycle Service Level, Alpha Service Level (APO), Non Stock-out Probability (SmartOps)**
  - Service level is shortfall event-oriented
    - Number of periods with complete delivery fulfillment/total number of periods
  - Useful if the customer accepts only complete deliveries (all or nothing), or if the fixed costs of subsequent deliveries are high

- **Fill-rate, Beta Service Level (APO)**
  - Service level is shortfall quantity-oriented
    - Quantity delivered in time/total demand
  - Useful if the customer also accepts partial deliveries or the fixed costs of subsequent deliveries are low

Please note that both Cycle Service Level and Fill-rate can be used when demand is non normal.
Safety Stock

\[
\text{Safety Stock} = Z \sqrt{R_{\text{avg}} \sigma_D^2 + D^2 \sigma_R^2}
\]


- Safety stock for cycle service level for Z value (1-tailed Normal coefficient), where:
  - \(D\) is demand during a period
  - \(\sigma_D\) is standard deviation of (forecast) demand during a period
  - \(R\) is periods in replenishment lead time, referred to later as “Period of Risk”. It’s absolute min. value = product wheel length.
  - \(\sigma_R\) is standard deviation (in periods) of replenishment lead time \(R\)

Note how safety stock increases with product wheel length!
The Necessity of Comparing Forecasts to Actual

- Forecast error is the difference between forecast and actual sales.
- Using standard deviation of historical demand substitutes forecast error by demand variability, and ignores existing time-varying forecasts.

Safety Stock - STDEV of Demand: If you forecast demand, use STDEV of forecast error.

<table>
<thead>
<tr>
<th>Month</th>
<th>Demand</th>
<th>Forecast</th>
<th>Actual Demand</th>
<th>Average Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>70</td>
<td>80</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>110</td>
<td>120</td>
<td>130</td>
<td>140</td>
<td>150</td>
</tr>
</tbody>
</table>

- STDEV of Forecast Error = 5.2
- STDEV of Historical Demand = 19
It is a business decision on how to mitigate these types of variability

Special Cause
- Rare and unpredictable variation

Common cause
- Statistically predictable variation

Safety Stock - STDEV of Demand: Take out “Special Cause” Events
Safety Stock – There to be “Used”

- Inventory should be expected to frequently (about 50% of cycles) consume safety stock – and occasionally (consistent with targeted customer service level) drop to zero. (Does this “frighten” anyone???)
- Product wheel lengths are often set using some sort of EOQ related calculation (upper bound of wheel length!)

- Given the fact that EOQ cost changes slowly as we move away from the “optimum” – savings in safety stock may warrant running shorter (than EOQ) product wheels!

- The cost is more transitions – the payoff is less inventory (cycle stock and safety stock) and better customer service.
**Period of Risk:** For how long a period does your “Make Plan” have to cover demand?

- If you can change plans right up until production starts and the product gets to your customer “instantly” (How likely is that?), then your replenishment lead time is your wheel length. You’re at risk because you can’t produce to respond to the market during this “Period of Risk”.

**WHEEL TIME**

**CYCLE LENGTH**
Period of Risk: For how long a period does your “Make Plan” have to cover demand?

- If there’s a raw material lead time, then once you’ve ordered raw material, the product you have + make using the ordered raw material, must cover sales until the next time you order raw material.
- Period of Risk = wheel length + raw material lead time
**Period of Risk:** For how long a period does your “Make Plan” have to cover demand?

- **Cycle Inventory Level**
- **Order Raw Mat'l**
  - **WHEEL TIME**
  - **CYCLE LENGTH**
  - **Ship Time**
  - **POR**

- Period of Risk (replenishment lead time) may include raw material lead time + wheel length + shipping time (and possibly other times!)
**Period of Risk:** For how long a period does your “Make Plan” have to cover demand?

- Since all of these time delays impact safety stock requirements, consider how much they are interrelated.
- For instance, **stocking long lead time raw materials** could allow you to **hold less finished inventory** (because inventoring raw materials can cut out some or all of the raw material lead time requirement!)
The previous slides have concentrated on safety stock held at one location for demand placed on that location.

In our modern interconnected world, life is frequently more complicated! Many times we need to consider supply networks.

The mathematics can get considerably more complicated!
Simple example:

- Assume $\sigma_b$ and $D$ are the same for Region A and Region B (and demand is normally distributed and independent between A and B).

- Also assume that the replenishment lead time (period of risk) is a constant 1 time unit (month) => time to produce and ship product is always exactly 1 month.
If we hold all of the inventory in regional warehouses, we’ll need safety stock for each of the 2 warehouses:

\[ SS = z \sqrt{\left( \sigma^2_D R + D^2 \sigma^2_R \right)} \]

- Total \( SS = 2_{\text{whs}} \times z \sigma \)
  because \( R = 1 \) and std. dev. of \( R = 0 \)
What if we could ship to customers in regions A & B, direct from the Plant Whs?

SS = \( Z \times \text{std. dev. of total demand on Plant Whs} \)

\[
SS = Z \sqrt{(\sigma^2 + \sigma^2)}
\]

\[
SS = Z \sqrt{2} \sigma = Z1.414\sigma
\]
This simple exercise just provides an example of what we knew already – that for a given set of customers, we can keep less safety stock the more customers we serve from the same warehouse.
However, there are lots of reasons why we need regional warehouses:

- Delivery times from the plant warehouse exceed competitive order lead times
- Customers want local sourcing
- Delivery times are too variable to satisfy customer service requirements
- Cheaper to bulk ship to a region and break apart shipments for individual shipments to customers
The analysis gets much more complex very quickly when we look at questions like:

- How many regional warehouses – and where
- How much to keep in each warehouse
- Consider trans SHIPPING between certain warehouses for certain customers . . .
There are commercial tools that can address these complex network problems. Tools that I’m aware of include:

- SmartOps
- LamaSoft
- APO (limited capability)
Another approach is to develop a simulation model of the supply chain (or potential supply chain):

- Test varying locations and inventory levels at each location
- Use an simulation optimizer such as OPTQUEST to search for good results with larger problems
- Note that for very large problems, a tool, designed for solving inventory network problems, is your best option.
Questions?

Comments?