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< Operational excellence >

Production Planning & Optimization

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IAMC Toolkit

Innovative approaches for the Sound Management of Chemicals and Chemical Waste

www.iamc-toolkit.org

Introduction

SMEs manufacturing chemical products often have to deal with fluctuations in overall demand from customers as well as the type of product. This leads to higher inventory costs, waste material due to change-overs and loss of productive capacity due to change-overs.

The reader will learn about typical challenges in production planning and key features of planning the production of different chemical products in a fixed facility. The reader will learn how to optimize production scheduling, sequencing and levelling of inventory in order to reduce waste and improve overall plant utilization.

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Topics

- Terminology
- Operating problems
- Operating modes
- Categories of chemical transitions
- Prerequisites

5. Example: polypropylene fixed sequence
6. Product wheel design and implementation
   - Components
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   - Key steps
7. Key messages

Challenges in Operations Management

- Challenges in operations management
- Causes of chemical inflexibility
- Consequences of chemical inflexibility
- The product wheel
- Example: polypropylene fixed sequence
- Product wheel design and implementation
- Key formulas

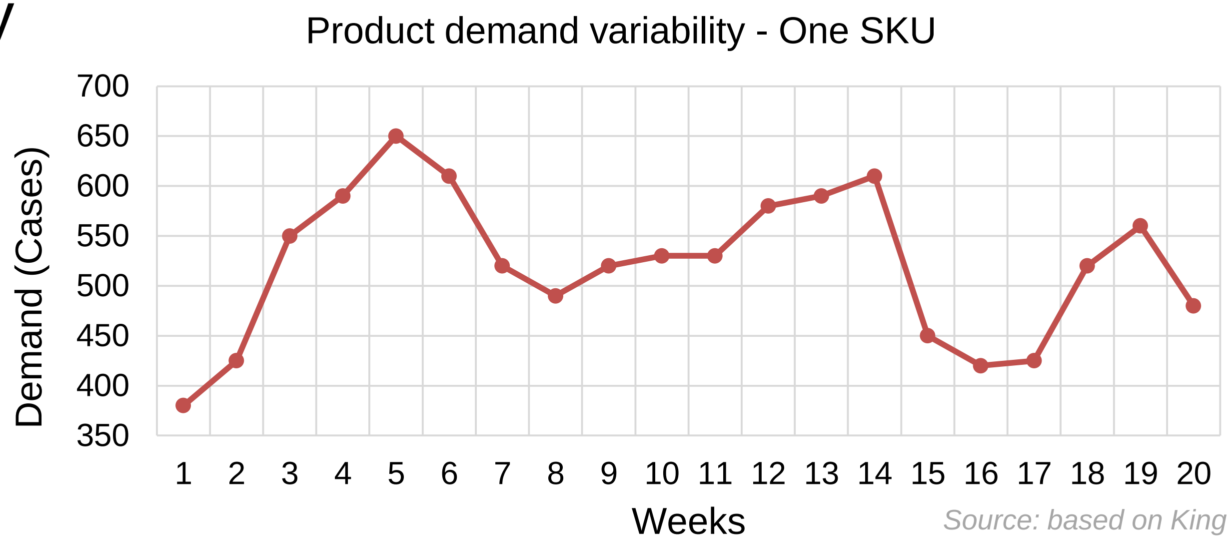
Challenges in Operations Management (1)

1. Challenge: averaging out product demand variation

- Customer demand is not constant
- Fluctuations in product flow create waste

⇨ Solution: uniform production at a level demand

⇨ Example: production fluctuations due to customer demand variability



Source: based on King

Challenges in Operations Management (2)

2. Challenge: finding the optimum production sequence

- Typical situation: one reactor for many products
- However, every transition means:
  - Loss of product ⇨ lowered resource efficiency!
  - Cleaning operations using additional chemicals and producing (hazardous) waste ⇨ more pollution!
  - Reactors not producing near rated capacity (e.g. some as low as 50% of rated capacity) ⇨ loss of profitability!

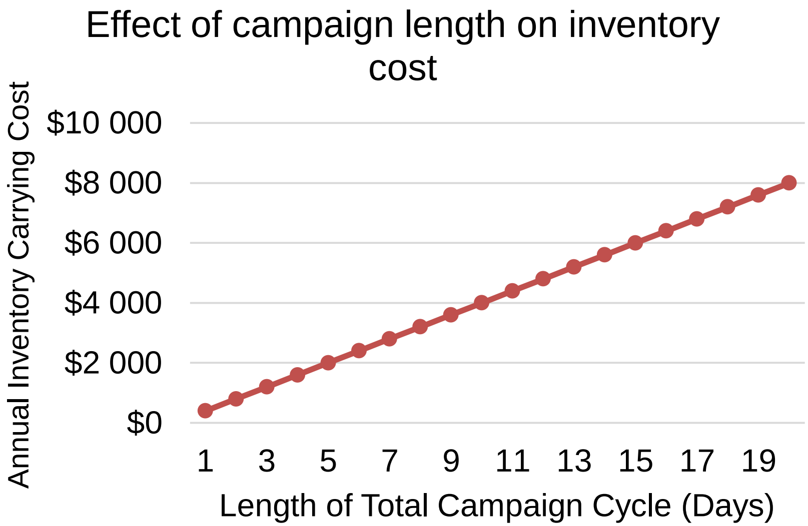
⇨ Consistent, repeated production sequence can improve transitions and minimize changeover difficulties, costs and time

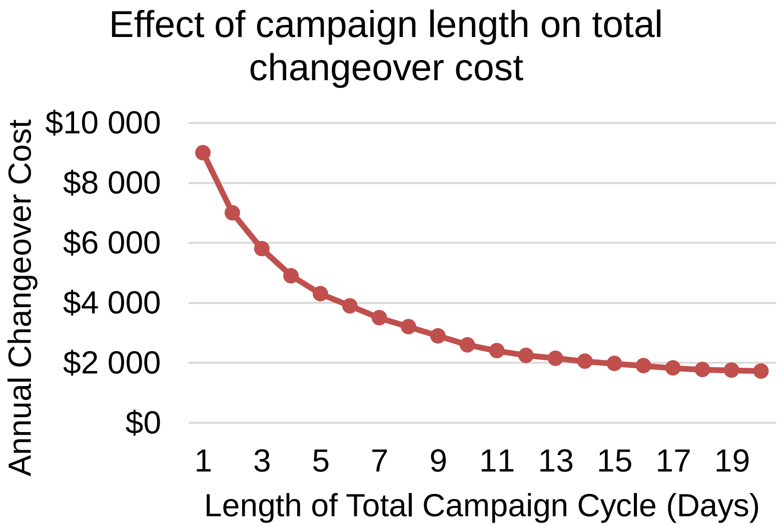
Challenges in Operations Management (3)

3. Challenge: finding the optimum production cycle time

- Short cycles need less inventory and allow more flexibility, however need more frequent changeovers

⇨ Optimum cycle balances inventory and changeover cost and minimizes total cost





Source: based on King

Learning Objectives

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Can you explain the three challenges in operations management?

1. Challenge: averaging out product demand variation
   - Finding a compromise between the variation of customer demand and stable production
2. Challenge: finding the optimum production sequence
   - Consistent, repeated production sequence to improve transitions and minimize changeover difficulties and costs
3. Challenge: finding the optimum production cycle time
   - Optimum cycle balances inventory and changeover cost and minimizes total cost

Learning Objectives

?

Can you explain why chemical transitions need to be optimized?

- Every transition implies lowered resource efficiency, increase in pollution and loss of profitability
- Optimisation can increase available capacity and allow faster and more frequent production of the product portfolio

Can you name any examples from your own experience?

Causes of Chemical Inflexibility

- Challenges in operations management
- Causes of chemical inflexibility
- Consequences of chemical inflexibility
- The product wheel
- Example: polypropylene fixed sequence
- Product wheel design and implementation
- Key formulas

Causes of Chemical Inflexibility (1)

In general, chemical inflexibility results from two causes:

1. Chemical contamination

i.e. unintentional mixture of products and other substances

2. Unintended chemical conversions

i.e. conversion of raw material into something other than intended

Causes of Chemical Inflexibility (2)

Chemical contamination can occur in two different ways:

1. Product of one type remains in the reaction vessel and mixes with the next product in vessel

2. Materials, such as additives or modifiers used in a reaction to differentiate resulting product, remain in equipment during product changes and contaminate the next product

⇨ **In both cases, situation needs to be resolved to allow perfect production of new material**

Causes of Chemical Inflexibility (3)

Unintended conversions: conversion of raw material into output that is not the intended product (*although unintended, not unexpected)*

In continuous operations, it often results from a transition in operating conditions or transition to products

Example of a chemical transition:

- Typical to produce polyethylene with propylene as co-monomer.
- One customer wants 3% co-monomer, another wants 5% co-monomer. Produced in same reactor with continuous flow.
- The transition produces 4% - which is waste product in this case.

Consequences of Chemical Inflexibility

- Challenges in operations management
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Consequences of Chemical Inflexibility (1)

Chemical inflexibility associated with product changeovers may lead to:

- Waste material:
  - Material lost on restart while ramping process conditions up to specified temperature, pressure, speed, torque, etc.
  - Material losses after restart, while bringing product properties within specification
  - Process ingredients from the old product lost in flushing out
- Loss of productive capacity:
  - If the line is running at capacity, time lost during changeover represent revenue loss

Consequences of Chemical Inflexibility (2)

- Additional costs:
  - Cleaning solvents
  - Parts consumed in the changeover: filters, O-rings, screens, gaskets, etc.
  - Lab time and cost to ensure all contaminants are gone
  - Lab time and cost to ensure all product properties are within specifications

⇨ Moreover, supposed amortization of these losses through long production runs creates waste of inventory and reduces responsiveness and flexibility

Learning Objectives

?

Can you explain causes and results of chemical inflexibility?

- Causes:
  - chemical contamination
  - unintended conversions
- Results:
  - waste material
  - additional costs
  - loss of productive capacity
  - Moreover, long production runs intended to offset these costs create waste of inventory

Can you think of any examples from your own business?

The Product Wheel

- Challenges in operations management
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- Consequences of chemical inflexibility
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- Product wheel design and implementation
- Key formulas

The Product Wheel (1)

What is a product wheel?

- Management technique to minimize waste resulting from chemical transitions by production planning and scheduling (optimization)

How does it work?

- Organizes a fixed production cycle that sequences one product after another in a way that:

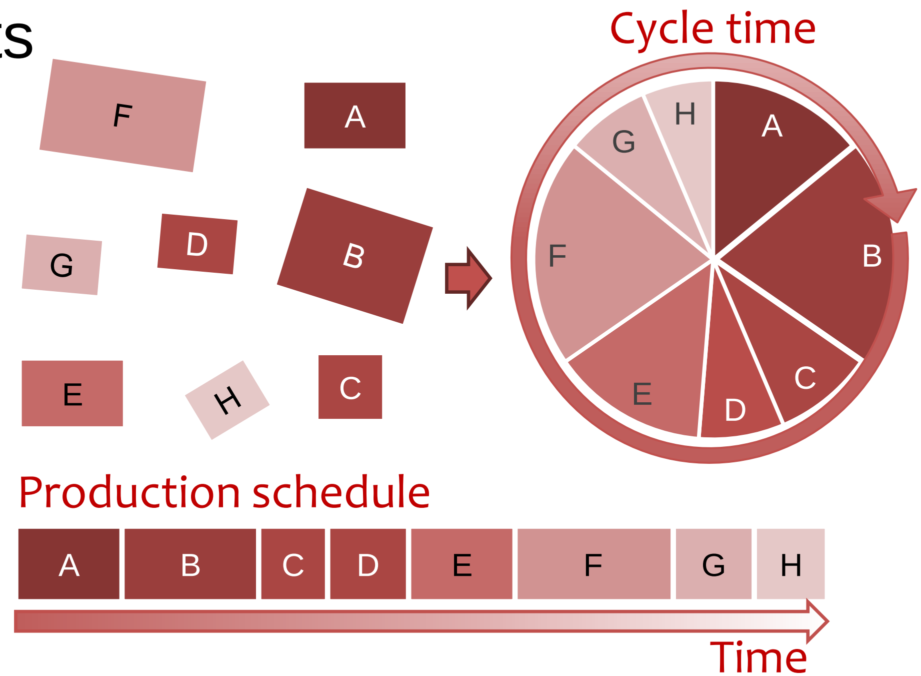
maximizes the number of transitions that have low cost and

minimizes the number of transitions that have high cost

The Product Wheel (2)

Product wheel concept:

Organisation of several products that share common equipment in a repeating <u>production cycle</u> so that each transition requires the smallest possible change



Source: based on King

Sometimes

- A product might be incorporated more than once in a cycle
- A suboptimum transition is acceptable

The Product Wheel (3)

Product wheel applicability:

Product wheels apply…	…to entire product lines or single elements of process equipment
	…to any elements with changeover costs depending on the production sequence
	…as part of a comprehensive, well elaborated Lean plan

The Product Wheel (4)

Product wheel terminology:

Cycle: one complete run through the entire wheel

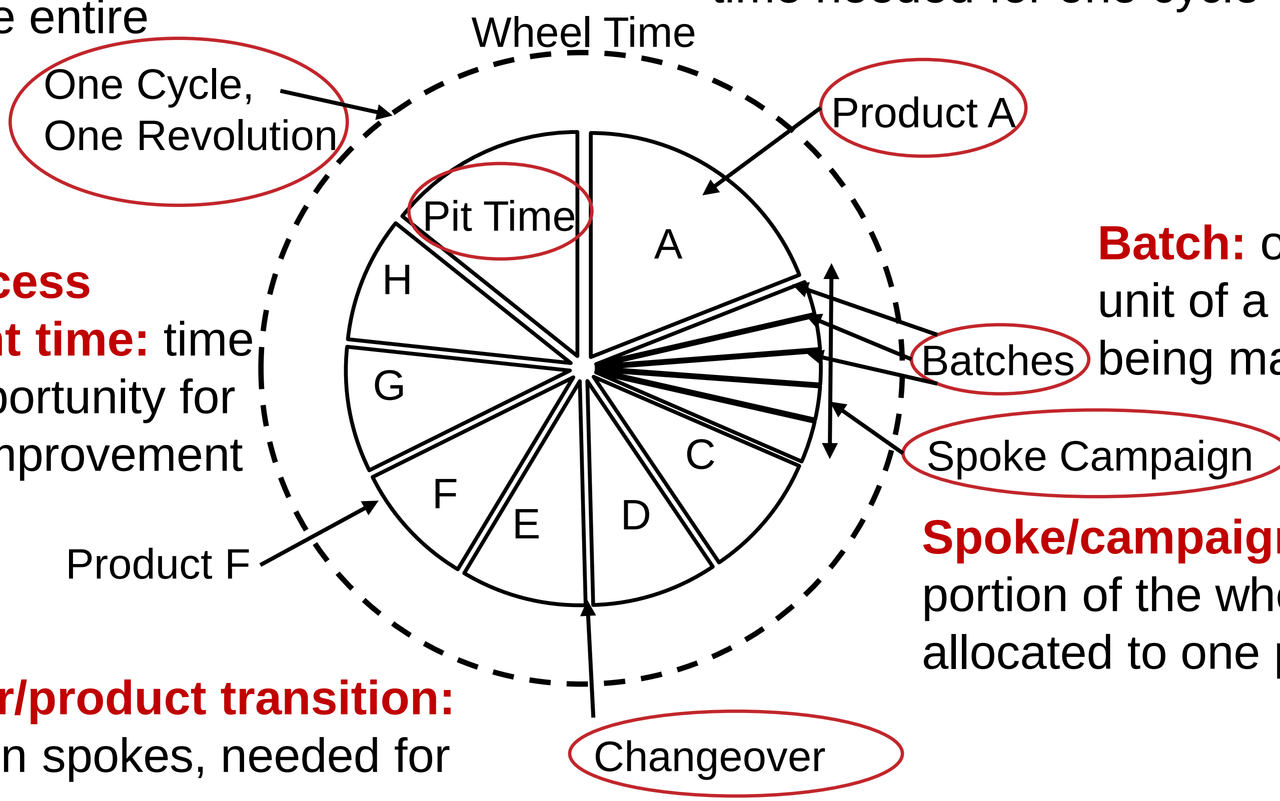
Cycle time/wheel time: time needed for one cycle

Pit time/process improvement time: time providing opportunity for continuous improvement

Batch: one lot or unit of a product being made

Spoke/campaign: portion of the wheel allocated to one product

Changeover/product transition: area between spokes, needed for setup



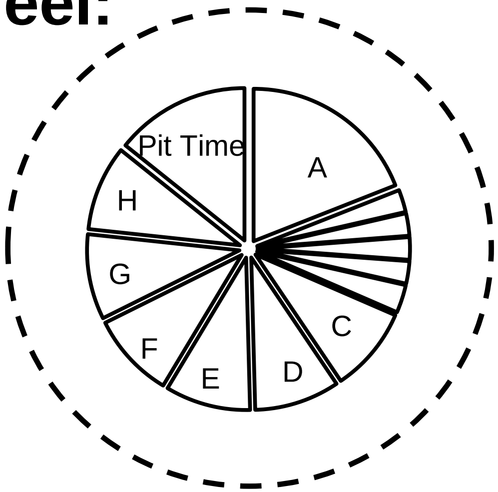
Source: based on King

The Product Wheel (5)

Operating modes within the product wheel:

Four possible manufacturing strategies:

- Frequency of 1: product is made on every cycle (high-volume product)
- Frequency of 2, 3, or 4: made on alternate cycles (medium volume)



Source: based on King

- Production in case inventory of a product falls below a certain trigger level (low volume)
- Products are made to order, i.e. only in response to a specific order (very low to unpredictable demand)

The Product Wheel (6)

Three categories of chemical transitions determine fixed product sequence and respective changeover time:

1. Changes in process conditions

- e.g. adjusting changes in T, p, or residence time ⇨ unintended conversion

2. Additives and modifiers

- magnitude of transition losses depends on quantity and compatibility of additives and modifiers

3. Changes in reactive chemicals

- product-to-product changes with fundamental change in chemistry, e.g. changes in co-monomers or catalysts
- losses also depend on material compatibility

The Product Wheel (7)

Prerequisites for product wheels:

Most of all, product wheels require a stable production process with predictable performance.

Recommended foundational elements:

Highly motivated, well-trained workforce

- Well-trained operators with value for standard work and some understanding of Lean

Standard work

- Standardized and documented work and processes

Visual management

- Real-time, interactive display boards as management instrument

Total productive maintenance (TMP)

- Improving manufacturing performance by improving the way equipment is maintained

The Product Wheel (8)

Elements which facilitate the implementation and improve the performance of a product wheel

A value stream map

- Well-constructed value stream map to visualize process flow and scheduling issues

Single-minute exchange of dies (SMED)

- Resulting in shorter and less expensive changeovers

Stock keeping unit (SKU) rationalisation – portfolio management

- Ongoing analysis of the product portfolio in order to sort out obsolete products

Bottleneck identification and management

- Smooth continuous flow with little interruptions

Cellular manufacturing and group technology

- Grouping products into families and dedicating them to specific equipment

Quality control

- Six Sigma and statistical process control (SPC)

Learning Objectives

?

Can you describe the product wheel concept?

- Organisation of several products that share common equipment in an optimized, fixed cycle
- Maximizes the number of transitions that have low cost and minimizes the number of transitions that have high cost

When is it suitable for application?

- For entire product lines or elements of process equipment
- For elements with changeover costs depending on the production sequence
- As part of a Lean plan

Learning Objectives

How can it be explained that a fixed cycle does not reduce your capability to respond to market needs (in comparison to random sequencing)?

- Each cycle reduces capacity lost during transition and capacity consumed to make inventory
- Therefore, the effectively available capacity increases
- As a consequence, the entire product portfolio can be produced faster and more frequently
- Fixed cycles respond to customer demand from production rather than from inventory

Learning Objectives

?

Which three categories of chemical transitions have to be taken into account when defining a fixed cycle?

- Changes in process conditions
- Changes in reactive chemicals
- Additives and modifiers

Can you think of any examples which might be of importance in your business?

Learning Objectives

?

Can you list some of the foundational elements which should be in place before product wheel design?

- Quality control
- Standard work
- A value stream map
- Visual management
- Total productive maintenance
- Single-minute exchange of dies
- Portfolio management
- Bottleneck identification and management
- Highly motivated, well-trained workforce
- Cellular manufacturing and group technology

Example: Polypropylene Production in a Fixed Sequence

- Challenges in operations management
- Causes of chemical inflexibility
- Consequences of chemical inflexibility
- The product wheel
- Example: polypropylene fixed sequence
- Product wheel design and implementation
- Key formulas

Example: Introduction

We use a polypropylene (PP) production process from a real plant for our example

PP is a typical commodity plastic and has been widely used in many application fields, due to its excellent properties such as:

- stiffness
- heat resistance
- process ability
- light weight material density
- relatively low price

Different grades of PP possessing different properties are produced depending on type of catalyst used, operating conditions and additives.

The following example shows how to develop an optimum sequence for PP production to minimize waste time and materials while maximizing plant utilization and profit margins

Example: Polypropylene Fixed Sequence (1)

Step 1: Determine the most important parameters (using design of experiments) affecting transition losses.

1. **Changes in reactive chemicals**: catalyst used to initiate reaction (three different catalysts used) ⇨ highest cost transition
2. **Changes in process conditions**: melt flow index (MFI) which is an indirect measure polymer molecular weight (MW) and is typically a customer specification. Involves changes in operating conditions (p, T, residence time) ⇨ medium cost transition
3. **Additives and modifiers:** Incorporation of chemical modifier or additive into product typically ⇨ lower cost transition

Example: Polypropylene Fixed Sequence (2)

Step 2: Depending on these parameters, visualize the production cycle as nested levels:

Level 1: Each product cycle had three big campaigns, one for each catalyst

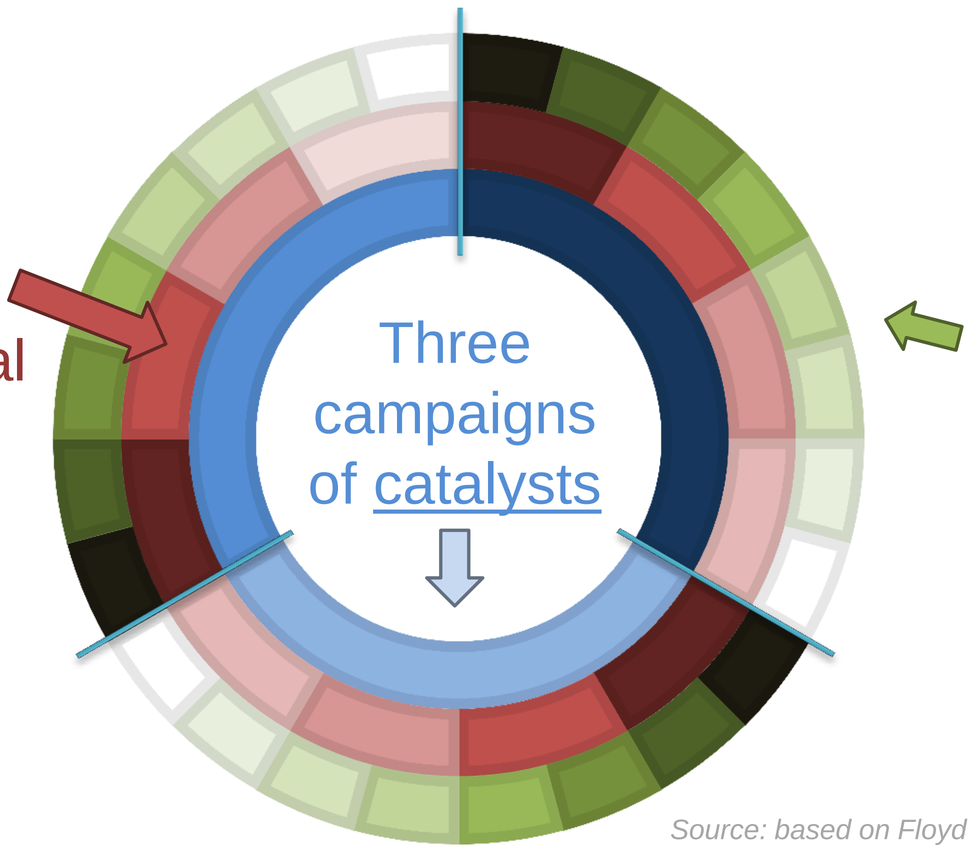
Level 2: Within each catalyst campaign, cycled through phases of additives and modifiers according to mutual compatibility

Level 3: Within each phase of additives, product ranges were produced within a range of MFI value (high to low or low to high) by changing reactor conditions

Example: Polypropylene Fixed Sequence (3)

Simplified product wheel:

Within each campaign of catalysts, several waves of additives and modifiers



Within each additive wave, multiple products with increasing or decreasing MFI values

Source: based on Floyd

Example: Polypropylene Fixed Sequence (4)

Achieved benefits (various case studies):

- Reduction of transition losses by 90%
- Increased reactor utilization from 50% to >85%
- Increase in plant capacity and capability
- Increased profit margins

Fixed sequence production is one of the most important management practices to improve a plant’s resource efficiency and profitability

Product Wheel Design and Implementation

- Challenges in operations management
- Causes of chemical inflexibility
- Consequences of chemical inflexibility
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- Key formulas

The Four Product Wheel Components

Product wheel components

Fixed sequence:

maximize low cost transitions and minimize high costs transitions ⇨ minimal cost for total portfolio

Inventory policy:

provides enough material to meet customer demands throughout product cycle without causing interruptions

Variable volume scheduling:

products are produced in different volumes in a fixed sequence ⇨ increase in operational stability and flexibility in production

Continuous improvement:

lower waste (time, material, cost) due to transitions and concentration on improving transition efficiency

Design and Implementation Process (1)

Process overview (17 steps):

Step 1: Begin with an up-to-date, reasonably accurate value stream map (VSM)

Step 2: Decide where to use wheels to schedule production

Step 3: Analyse product demand volume & variability - identify candidates for make to order

Step 4: Determine the optimum sequence

Step 5: Analyse the factors influencing overall wheel time

Step 6: Determine overall wheel time and wheel frequency for each product

Step 7: Distribute products across wheel cycles – balance the wheel

Step 8: Plot the wheel cycles

Step 9: Calculate inventory requirements

Design | Implementation

Design and Implementation Process (2)

Process overview:

Step 10: Review with stakeholders

Step 11: Determine who “owns” (allocates) the PIT time

Step 12: Revise the scheduling process

Step 13: Develop an implementation plan

Step 14: Develop a contingency plan

Step 15: Get all inventories in balance

Step 16: Put an auditing plan in place

Step 17: Put a plan into place to rebalance the wheel periodically

Design | Implementation

Design and Implementation Process (3)

Step 1: Begin with an up-to-date, reasonably accurate value stream map (VSM)

- How does the product flow through the process, how is it transformed?
- What are throughput, performance, product line-up etc.?

⇨ Visualize the entire manufacturing process

Step 2: Decide where to use wheels to schedule production

- Where are product wheels appropriate and beneficial?
- Entire product line or individual piece of equipment?

⇨ Use value stream map

Step 3: Analyse product demand volume and variability – identify candidates for make to order

- What are volume and variability of demand for each product processed in this line or equipment?
- Which products shall be made to store, which to order?

Design and Implementation Process (4)

Step 4: Determine the optimum sequence

- Which parameter changes are necessary for product transitions?
- Which changeover times and losses are they associated with?
- Which product sequence minimises them?

Step 5: Analyse the factors influencing overall wheel time

- What is the fastest wheel time practically possible?
- What is the most economical wheel time possible?
- Are there any product shelf life limits (e.g. for food products)?
- Is there strong product demand variability?
- What is the minimum lot size?

Step 6: Determine overall wheel time and wheel frequency for each product

- What is the optimum overall wheel time?
- Which frequency is suitable for each of the lower-volume products?

⇨ Use findings of step 5 to define the best solutions

Design and Implementation Process (5)

Step 7: Distribute products across the wheel cycles – balance the wheel

- On which cycles shall products with a frequency greater than one be made?
- How can this be realized with the total planned production being relatively balanced from cycle to cycle?

⇩

Step 8: Plot the wheel cycles

- How can the wheel cycles be visualised in the form of charts or diagrams?

⇨ Gives a feel for structure and operation of the wheel, especially to those not involved in the design process

⇩

Step 9: Calculate inventory requirements

- How much inventory is necessary to support the wheel?
- Has the correct balance between inventory and changeover frequency been found?
- Are any modifications necessary?

⇨ Ideally, this step is a confirmation of the approximations made in step 5

⇩

Design and Implementation Process (6)

Step 10: Review with stakeholders

- Does everybody involved in product scheduling understand the consequences for their work?

⇨ Includes people in production, maintenance, accounting, warehousing, marketing, etc.

⇩

Step 11: Determine who "owns" (allocates) the PIT time

- Which specific person or team is responsible for the allocation of PIT time to different activities?

⇩

Step 12: Revise the scheduling process

- How can wheel design, schedule, and operating parameters be incorporated into the enterprise resource planning system (ERP)?

⇩

Design and Implementation Process (7)

Step 13: Develop an implementation plan

- How is the design going to be implemented?

⇨ Plan, schedule and staff tasks necessary for implementation

Step 14: Develop a contingency plan

- What could go wrong?
- How can it be recognized and remedied?
- If the wheel has to be broken, how can it be resumed quickly?

⇨ Plan in advance for the case of a crisis

Step 15: Get all inventories in balance

- Do inventories cover all needs before starting the wheel?

⇨ Avoid stock-outs by increasing inventories which are too low

Design and Implementation Process (8)

Step 16: Put an auditing plan in place

- Is the wheel operating as intended?

⇨ Monitor performance on a regular, standardized basis

⇨ Collect and analyse wheel-braking events, customer service performance, stock-out frequency, or other parameters

Step 17: Put a plan into place to rebalance the wheel periodically

- Does the wheel need to be rebalanced?
- Have major changes occurred which affected wheel performance?

⇨ Plan to regularly re-examine the wheel, being proactive rather than reactive

Key Steps – Step 1 (1)

Step 1: Begin with an up-to-date, reasonably accurate VSM

Within all VSM parameters, the following are of most interest for product wheel design:

- C/O (changeover) time: The longer the changeover time, the stronger a candidate for product wheel introduction
- C/O (changeover) loss: Changeover losses are even more important than changeover times
- Number of SKUs (stock keeping units): The more product types, the more changeovers associated with time and loss

Key Steps – Step 1 (2)

Within all VSM parameters, the following are of most interest for product wheel design:

- Takt and effective capacity: They are necessary to calculate the overall wheel time (both the shortest and the most economic one)
- EPEI (Every part every interval): EPEI can be improved significantly by the introduction of product wheels
- Utilization/Utilize: Low utilization (e.g. 70% or less) indicates potential for much shorter wheels, as time for more changeovers is left

Key Steps – Step 2

Step 2: Decide where to use wheels to schedule production

- Analyse VSM on the basis of the following criteria:
  - Number of SKUs or product types
  - Changeover times and losses
  - Every part every interval (EPEI)
  - Steps with a large inventory following that step

- Secondary criteria:
  - High yield losses
  - Low uptime/Overall equipment effectiveness (OEE)

Key Steps – Step 3

Step 3: Analyse products for a make-to-order strategy

⇨ Products of small volumes with no predictable pattern in demand should only be made to satisfy specific orders.

Therefore, analyse for each product

a) Demand volume

b) Demand variability

Source: based on King

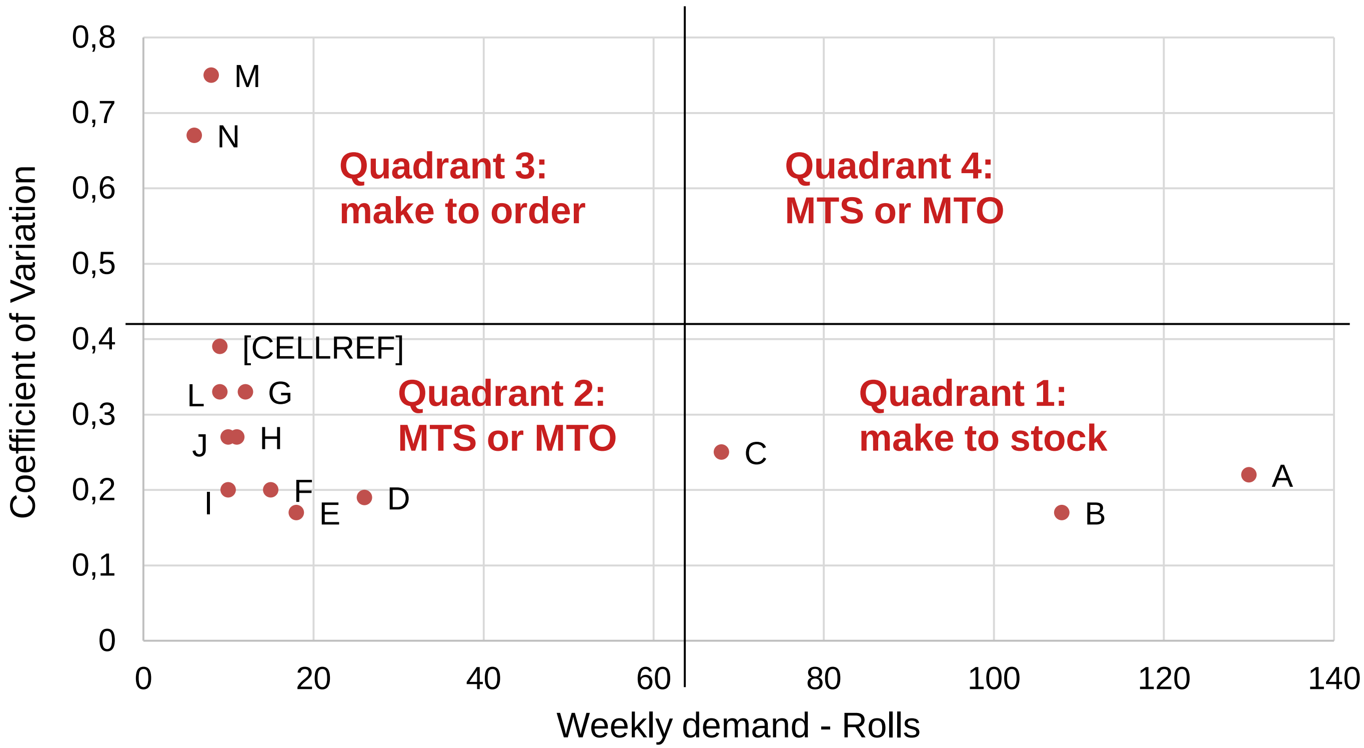
And elaborate a

a) Decision matrix

Key Steps – Step 3

Decision matrix to elaborate a production strategy for each product:

c)



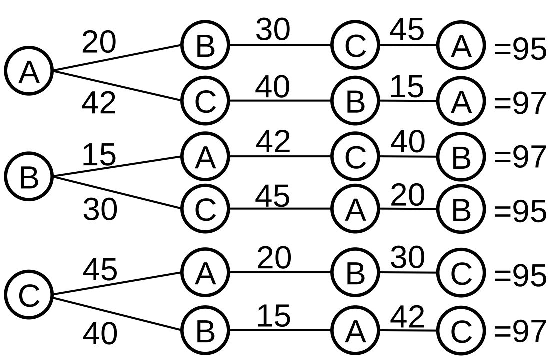
Source: based on King

Key Steps – Step 4

Step 4: Determine the optimum sequence

- Decide on whether to optimize changeover times or losses
- Visual techniques such as spreadsheets listing products and changeover times or from/to matrices can be helpful
- In more complex cases,
  mathematical calculations
  help finding the optimum
  solution

		To		
		A	B	C
From	A		20	42
	B	15		30
	C	45	40	



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Key Steps – Step 5

Step 5: Analyse the factors influencing overall wheel time

- Take into account at least the following criteria:
  - Time available for changeovers – The shortest wheel possible
  - Economic order quantity (EOQ) – The most economic wheel
  - Short-term demand variability
  - Minimal practical lot size
  - Shelf life

- Out of all the different answers, find the optimum decision

Key Steps – Step 5

Shortest wheel possible – the lower limit to cycle time

$$\text{Total available time} - \text{Total production time} = \text{Time available for changeovers}$$

$$\text{Wheel cycles per period} = \frac{\text{Time available for changeovers}}{\text{Sum of changeover times}}$$

$$\text{Wheel time} = \frac{\text{Total available time}}{\text{Wheel cycles per period}}$$

Key Steps – Step 5

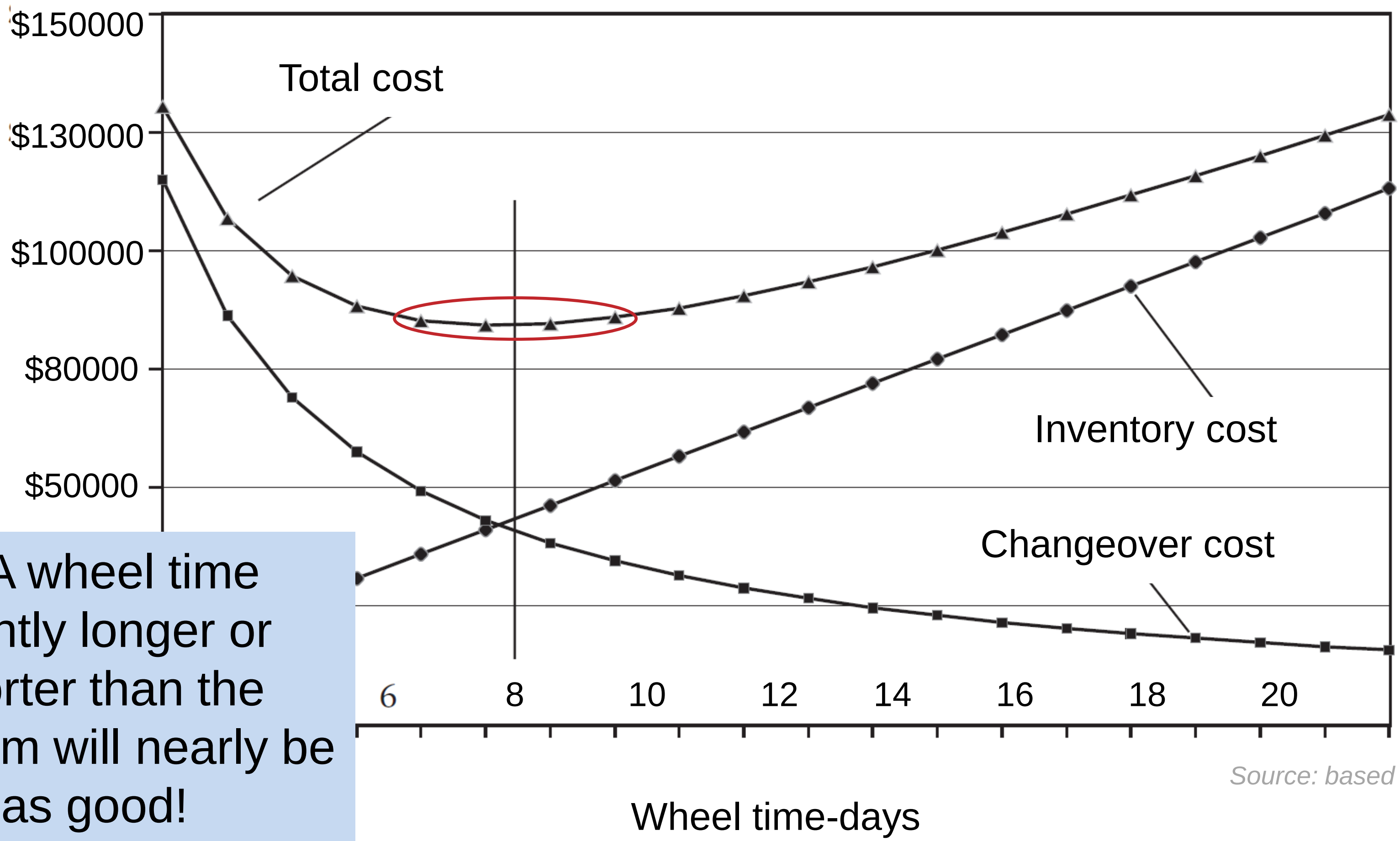
Economic order quantity (EOQ) – balancing out inventory costs and changeover costs

$$\text{EOQ} = \sqrt{\frac{2 \times COC \times D}{V \times r \times (1 - \frac{D}{R})}}$$

EOQ: economic order quantity
COC: changeover cost
D: demand per period
V: unit cost of the material
r: percent carrying cost of inventory per period
PR: production rate

Key Steps – Step 5

Example: forming machine 3, product G



⇨ A wheel time slightly longer or shorter than the optimum will nearly be as good!

Source: based on King

Key Steps – Step 5

Practical lot sizes of each material

⇨ Minimum lot sizes below which production is not reasonable

EOQ analyses recommend impractically short cycles for:

- Very expensive materials
- Inexpensive changeovers

⇨ In these cases, minimum lot sizes outweigh EOQ calculations

Key Steps – Step 5

Shelf life

Shelf life specifications may limit wheel time, e.g. in the food industry:

Long wheel time

Product varieties, e.g. allergen-free versions require extensive cleaning

⇨High changeover costs

Shelf life requirements by customers, distributors and retailers

⇨Little time left for production

Short wheel time

⇨ Find a balance between shelf life limitations and changeover effects

Key Steps – Step 6

Step 6: Put it all together – determine overall wheel time and wheel frequency for each product

- Overall wheel time generally depends on:
  - EOQ of high-volume products
  - Shortest wheel cycle time possible
  - Shelf life constraints

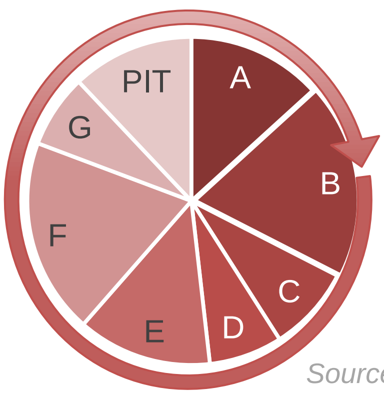
- The frequency for a specific product will depend on:
  - EOQ
  - Minimum lot size, if applicable
  - Short-term variability, if applicable

Key Steps – Step 8

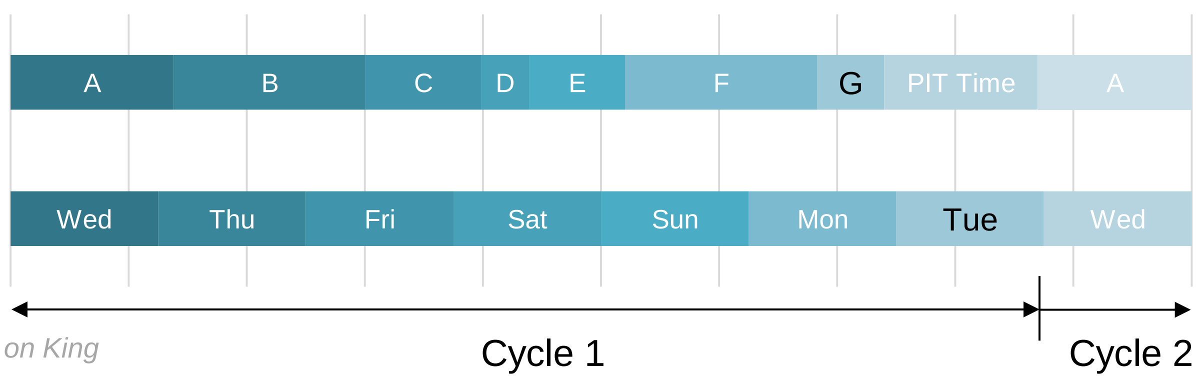
Step 8: Plotting the wheel cycles

A visual representation of the elaborated cycle supports:

- Communication of the concept, its features and consequences
- Understanding of the schedule to be followed
- Discussions and questions



Cycle 1



Source: based on King

Key Steps – Step 9

Step 9: Calculate inventory requirements

⇨ Some inventory is needed to support a product wheel.

Inventory for each product will consist of two components:

a) **Cycle stock:** average demand per unit time x wheel time x cycle frequency

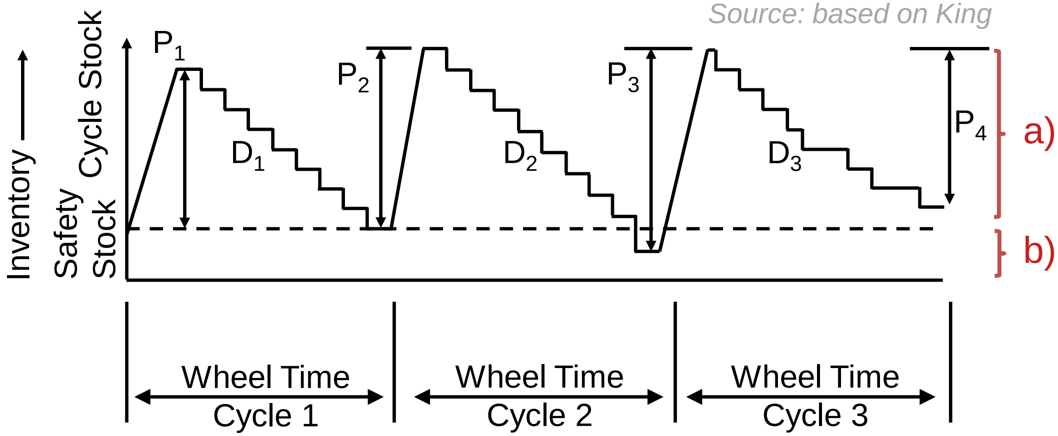
b) **Safety stock:** Z x σ

- Z: Factor representing the customer service level goal
- σ: Standard derivation expressing demand variability

Key Steps – Step 9

Examples of required inventory:

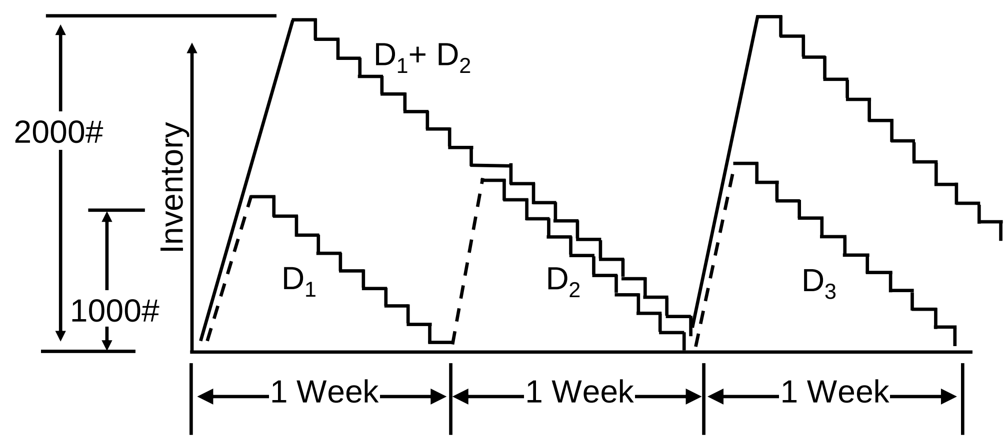
Source: based on King



P = Production to begin a wheel cycle
D = Demand during the wheel cycle

⇨ Inventory needed increases with longer wheel time

⇨ If the demand was always the average, no safety stock would be needed



Source: based on King

Key Messages

Key Messages (1)

SMEs manufacturing chemical products often have to deal with fluctuations in overall demand from customers as well as the type of product. This leads to higher inventory costs, waste material due to change-overs and loss of productive capacity due to change-overs.

- Causes of chemical inflexibility include chemical contamination and unintended chemical conversions.
- Consequences of waste include waste material, loss of productive capacity, extra costs related to cleaning and changeover activities

The product wheel is a management technique to minimize waste resulting from chemical transitions by production planning and scheduling (optimization). It organizes a fixed production cycle that sequences one product after another in a way that:

- maximizes the number of transitions that have low cost and
- minimizes the number of transitions that have high cost

Key Messages (2)

Product wheel components

Fixed sequence:

maximize low cost transitions and minimize high costs transitions ⇨ minimal cost for total portfolio

Inventory policy:

provides enough material to meet customer demands throughout product cycle without causing interruptions

Variable volume scheduling:

products are produced in different volumes in a fixed sequence ⇨ increase in operational stability and flexibility in production

Continuous improvement:

lower waste (time, material, cost) due to transitions and concentration on improving transition efficiency

Key Messages (3)

The design and implementation of a product wheel consists of the following key steps:

- Use a basic value stream map and decide where to use product wheels to schedule production
- Analyse product demand volume & variability and determine the optimum sequence
- Determine overall wheel time and wheel frequency for each product and balance the wheel by distributing products across wheel cycles
- Calculate inventory requirements
- Review with stakeholders and agree on who ‘owns’ the changeover process (i.e. pit time).
- Develop and execute the implementation plan

Sources

Sources

- CSD Engineers, Switzerland / ISSPPRO, Germany, 2015
- King, P. L.: Lean for the Process Industries: Dealing with Complexity, 2009
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Images

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