Manufacturing Instability
Managing the Supply Chain

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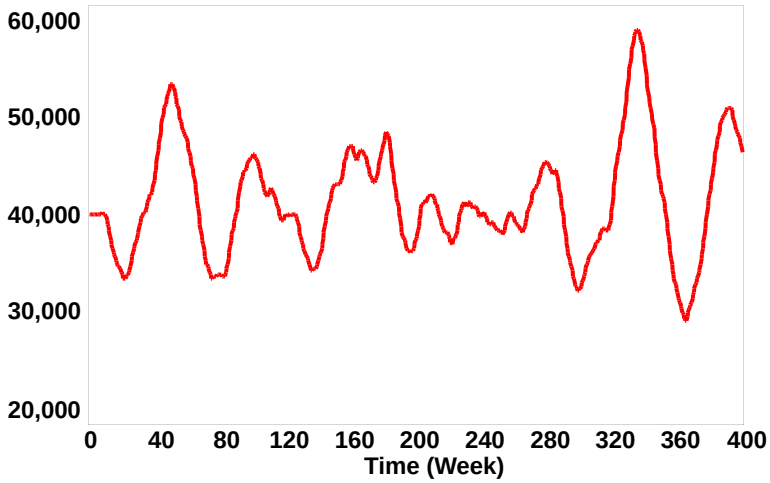
System Dynamics Example: Manufacturing Instability

- A manufacturing firm, Widgets, Inc., has experienced costly, chronic instability in its inventory level and production rate.
- Your client wants to understand:
  1. Why they have experienced these persistent oscillations?; and
  2. How to design effective policies for tempering the instability?

Inventory Instability at Widgets



System Dynamics Example: Manufacturing Instability

- The perspective you have taken is to focus on the degree to which the internal management policies of Widgets, Inc. create or contribute to instability.
- Your discussions with management and workers on the factory floor have revealed the following information about the management policies governing production:

Customer Demand and Shipments

- **Widget Inc.'s customers are very delivery sensitive. To supply customer demand, Widgets operates a make-to- stock system and carries significant inventories of finished product. The firm's inventory of finished goods is increased by production and decreased by shipments.**
- **Orders that Widgets can't deliver are lost forever as the customer finds an alternate source of supply (there is no backlog of unfilled orders).**
- **Whenever inventory becomes inadequate, shipments fall below the order rate. The lower the average inventory level relative to the target level, the greater the probability that individual items will be out of stock.**

Modeling Customer Demand and Shipments

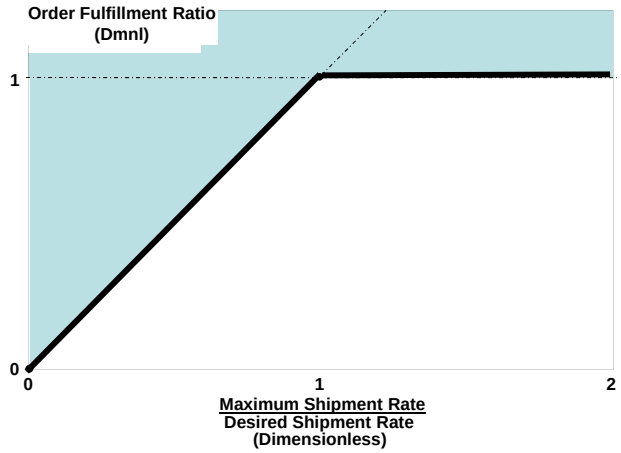
Simple Shipment Policy

Desired Shipment Rate = Customer Orders

Shipment Rate = MIN (Maximum Ship Rate, Desired Ship Rate)

Shipment Rate = Desired Ship Rate * MIN (1, $\frac{\text{Maximum Ship Rate}}{\text{Desired Ship Rate}}$)

Shipment Rate = Desired Ship Rate * Order Fulfillment Ratio



Shipment Policy

Shipment Rate = Desired Shipment Rate * Order Fulfillment Ratio

Order Fulfillment Ratio $= f\left(\frac{\text{Maximum Shipment Rate}}{\text{Desired Shipment Rate}}\right)$

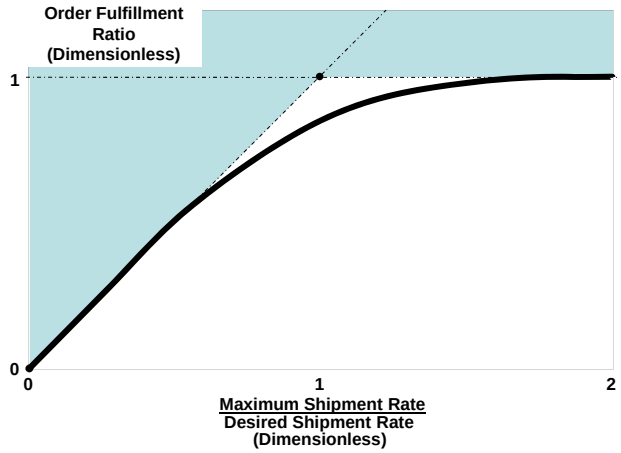
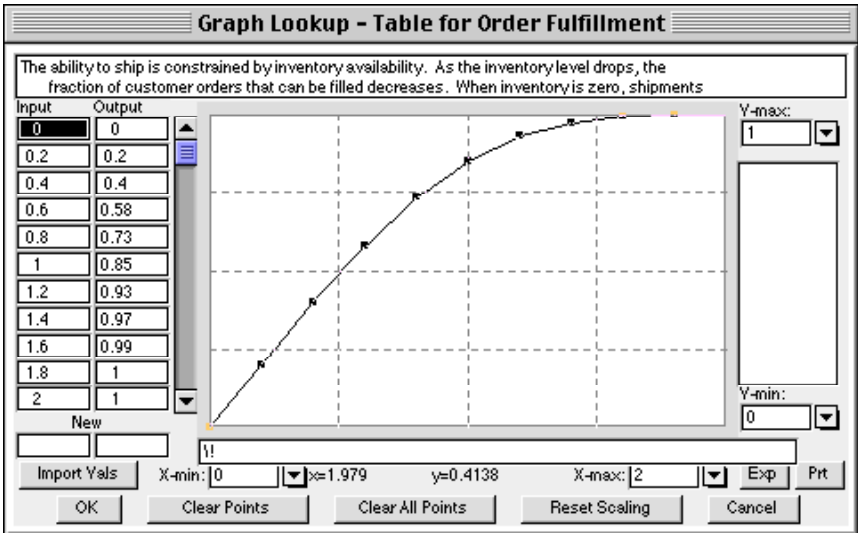
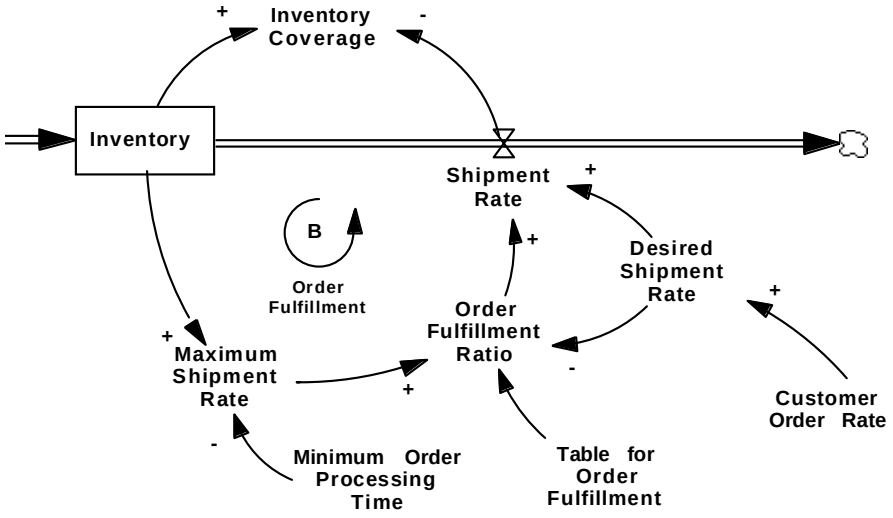


Table for Order Fulfillment



Model Structure: Inventory and Shipments

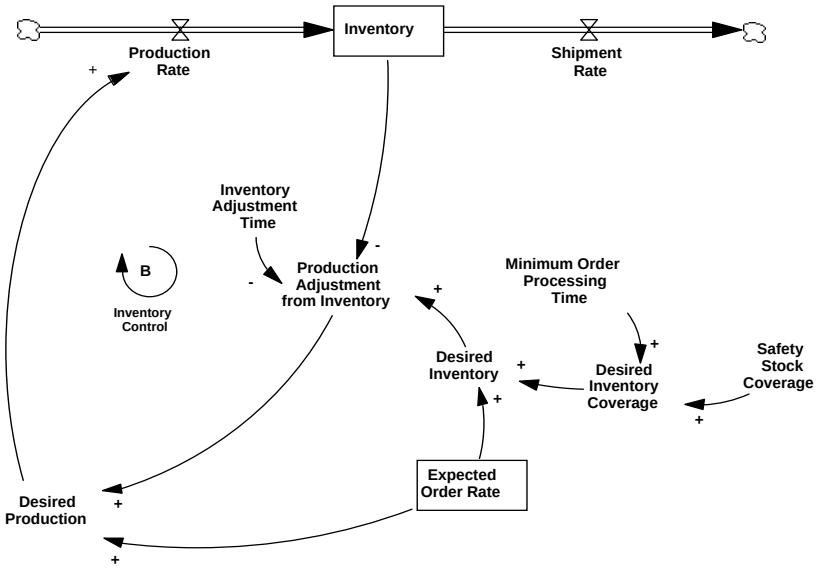


Modeling Inventory Inflow: Production Scheduling and Inventory Control

Production Scheduling and Inventory Control

- **There is ample plant and equipment to meet demand. Your contact at corporate headquarters argues that the plant can adjust production rapidly to changes in production schedules.**
- **Desired production (the factory production target) is determined by anticipated (forecasted) customer orders, modified by a correction to maintain inventory at the desired level.**
- **The firm continuously compares the desired inventory level to the actual level. They attempt to correct discrepancies between desired and actual inventory in eight weeks.**
- **Desired inventory is four weeks' worth of the expected order rate. This corresponds to two weeks to cover the minimum order processing delay plus two weeks for a safety stock. The total coverage goal of four weeks provides enough inventory on average to fill essentially all incoming orders.**

Model Structure: Production Rate



Formulation for Production

Production = MAX(0, Desired Production)

Desired Production =
Expected Order Rate + Adjustment for Inventory

Adjustment for Inventory = $\frac{\text{(Desired Inventory – Inventory)}}{\text{Inventory Adjustment Time}}$

Desired Inventory =
Expected Order Rate * Desired Inventory Coverage

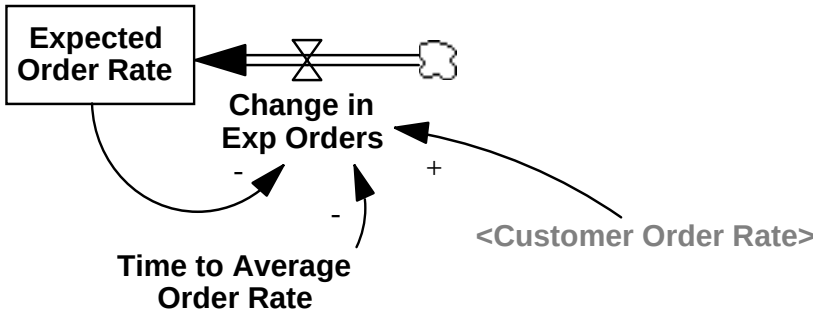
Desired Inventory Coverage =
Minimum Order Processing Time + Safety Stock Coverage

Modeling Demand Forecasting

Demand Forecasting

- **Expected Customer Orders are based on the history of actual orders.**
- **The firm forecasts customer orders by averaging past orders over an eight-week period as a way of smoothing out any noise or lumpiness in demand.**
- **As is common in many firms, they use exponential smoothing to forecast demand.**

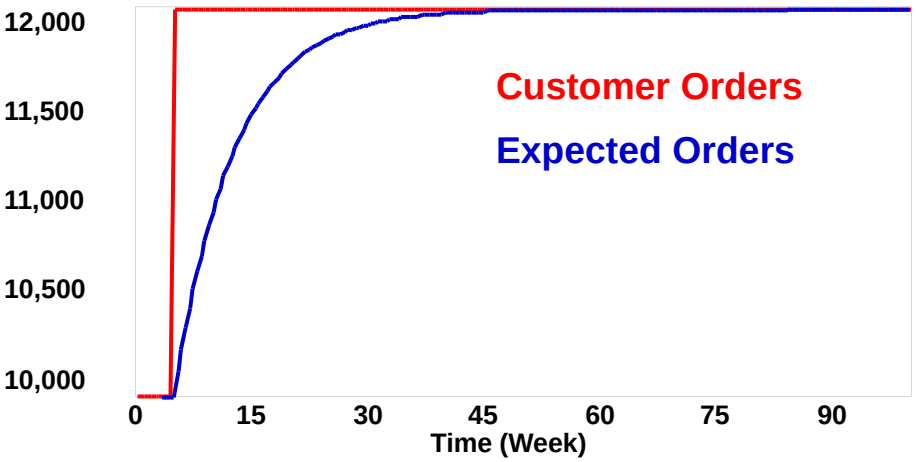
Model Structure: Demand Forecasting



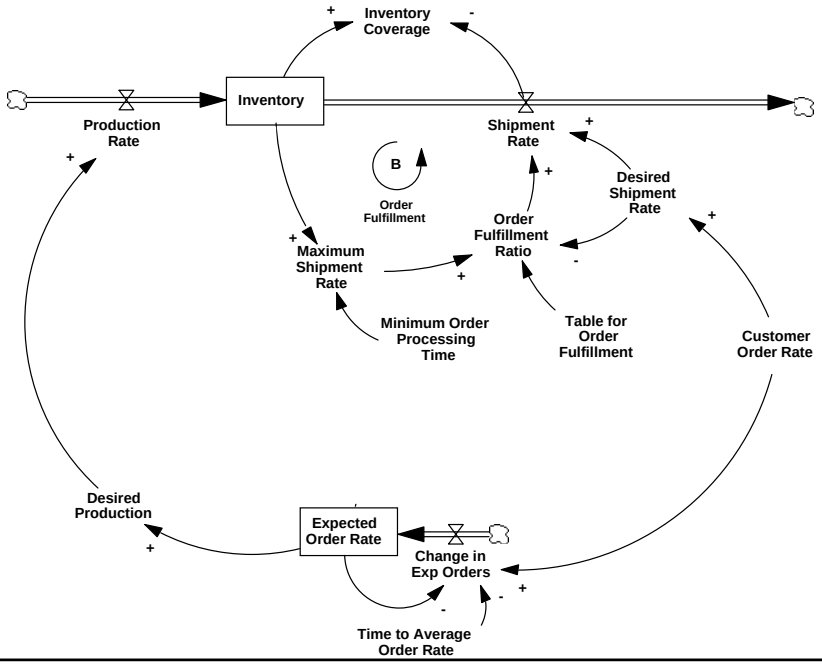
d/dt(Expected Order Rate) = Change in Exp Orders =

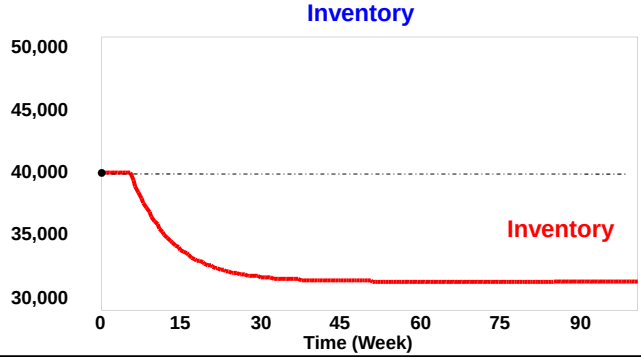
$$\frac{\text{(Customer Order Rate - Expected Order Rate)}}{\text{Time to Average Order Rate}}$$

Response to Unanticipated Demand Increase (20% step in Customer Orders in week 5)



Model Without Inventory Adjustment



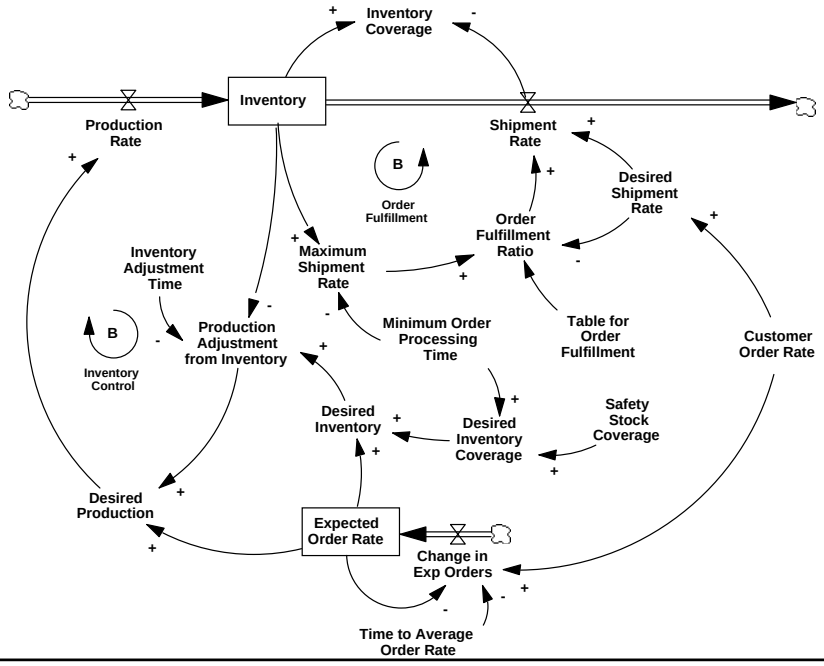


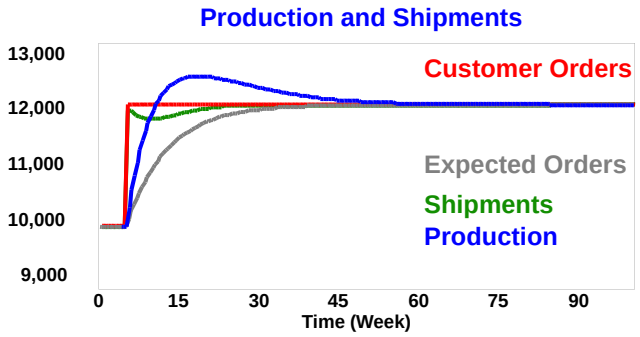
Model Behavior without Inventory Adjust.

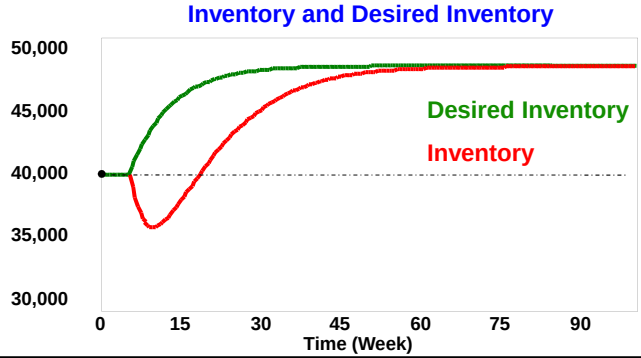
Equilibrium Conditions:

1. **Customer Orders = Expected Orders**
2. **Shipments = Production**

Model With Inventory Adjustment







Model Behavior with Inventory Adjust.

Equilibrium Conditions:

1. **Customer Orders = Expected Orders**
2. **Shipments = Production**
3. **Inventory = Desired Inventory**

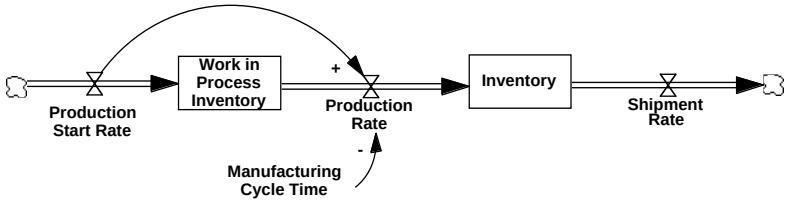
Modeling Manufacturing Delays

Including Manufacturing Delays

Noting that your model does not fluctuate, you suspect that you have omitted some significant delays in your representation of the system. You go back to the plant and investigate production in more detail. You find that:

- **The production process involves a significant delay due to the complexity of the fabrication and assembly process.**
- **The average manufacturing cycle time (the time between the start of the production process and its completion) is four weeks.**
- **Some items in the product line can be made faster than four weeks, and some take longer.**
- **The delay means there is a significant stock of WIP inventory.**

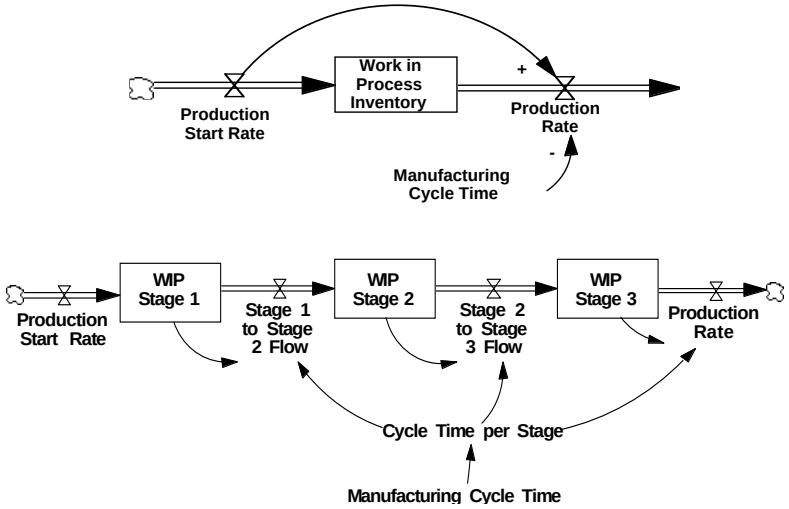
Revised Stock and Flow Structure



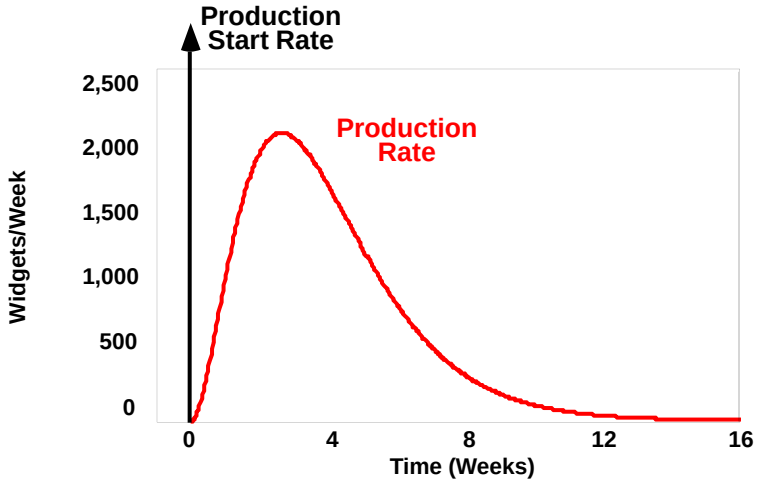
Production Rate =

DELAY3(Production Start Rate, Manufacturing Cycle Time)

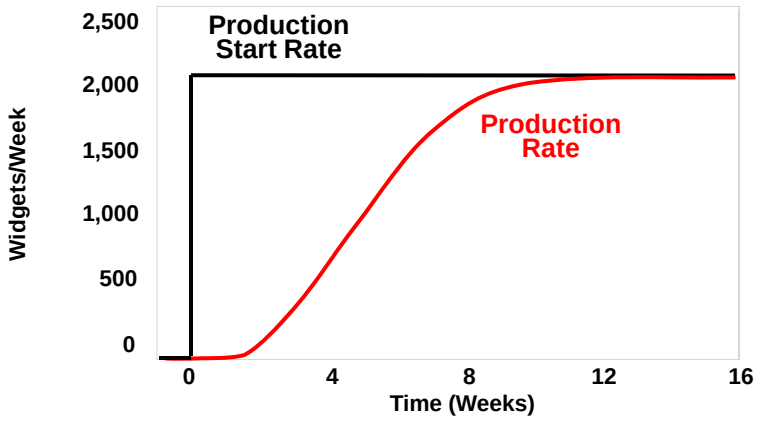
Unpacking the DELAY3 Function



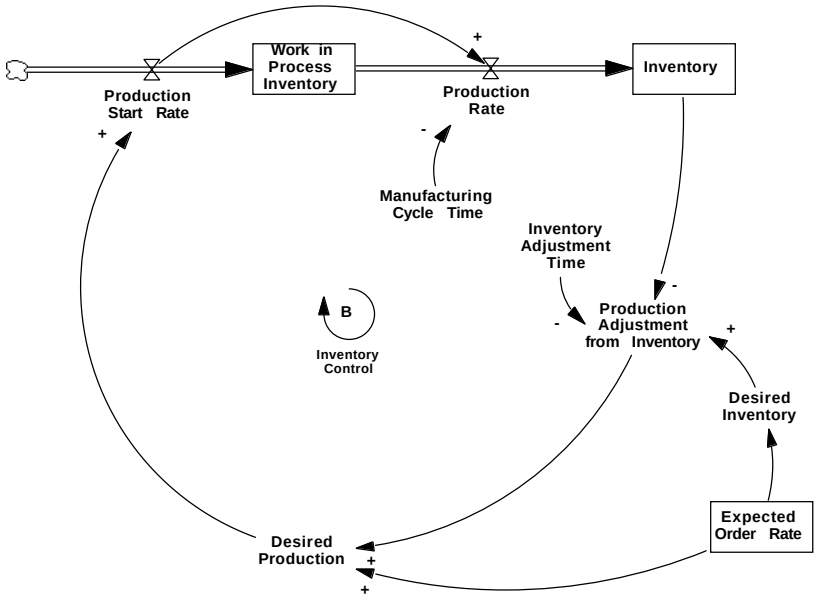
Response of Third Order Material Delay: Pulse Input of 10,000 units; Delay Time = 4 weeks



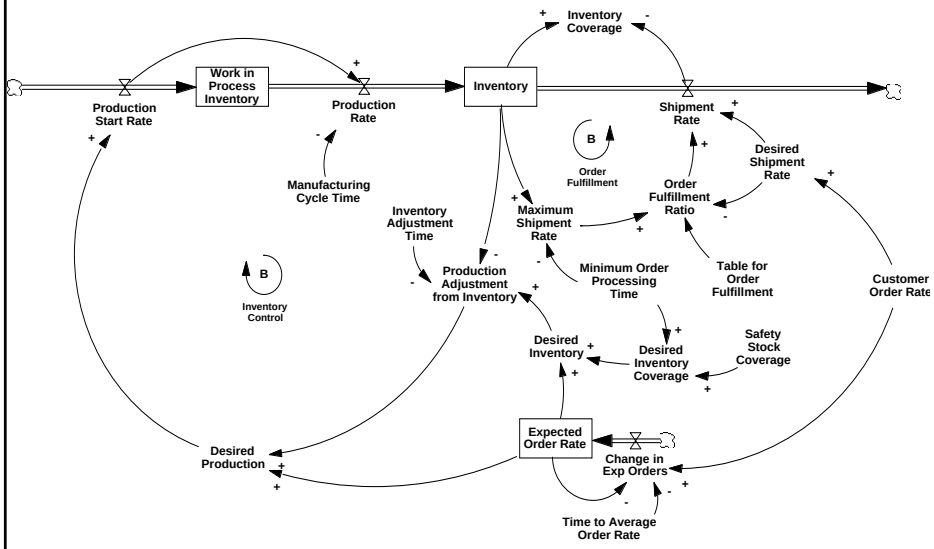
Response of Third Order Material Delay: Step Input of 2,000 units; Delay Time = 4 weeks



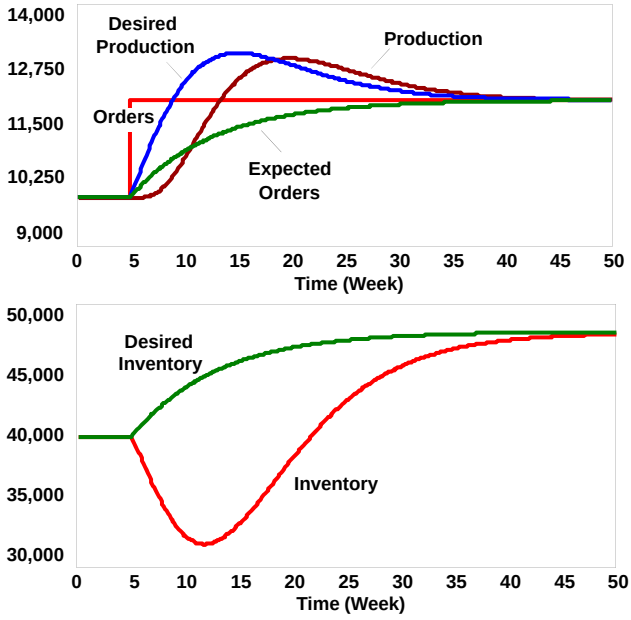
Production Start Rate = MAX(0,Desired Production)



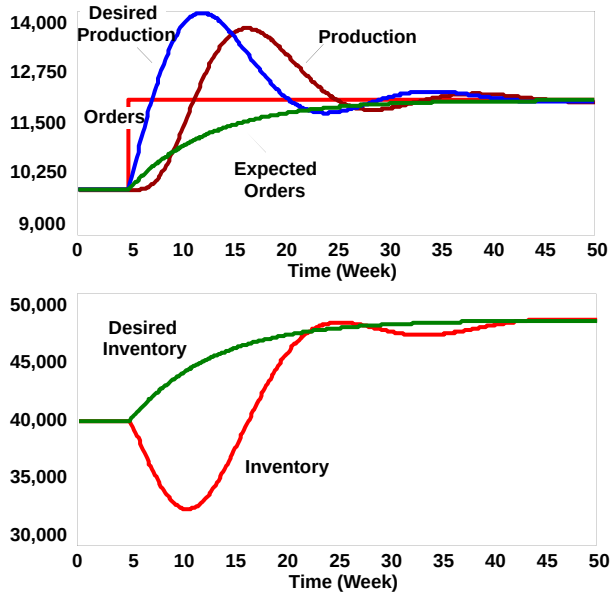
Revised Model With WIP



Response to 20% Step



Response to 20% Step: Short Inventory Adjustment Time



Explaining the Dynamics

- The model now oscillates, and you excitedly show it to managers at Widgets.
- The client asks you to explain the causes for the oscillation.
- The model oscillates because you have assumed that production is initiated without regard for the quantity of work in process.
- Your client is offended that you believe they are so foolish as to ignore the supply line of work in process…

Modeling Work In Process Manufacturing

Critiquing the model

- After observation and discussion with operators, shift supervisors and managers, you learn that:
  - Production starts depend on the **desired rate of production** *AND* on the **quantity of work in process**.
  - When WIP is low compared to the level needed to meet the desired production rate, additional units are started. If WIP is high relative to the desired level, production starts are reduced.
  - Desired WIP is the level required to complete production at the desired rate, given the manufacturing cycle time.
  - The firm seeks to eliminate any discrepancy between desired and actual WIP over a 2 week period.

Revised Formulation: Production Starts

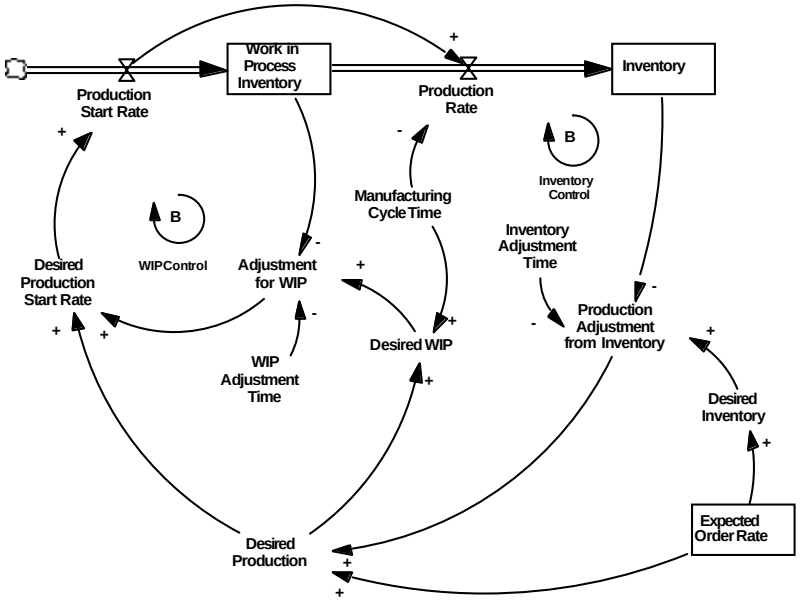
Production Start Rate =
MAX(0, Desired Production Start Rate)

Desired Production Start Rate =
Desired Production + Adjustment for WIP

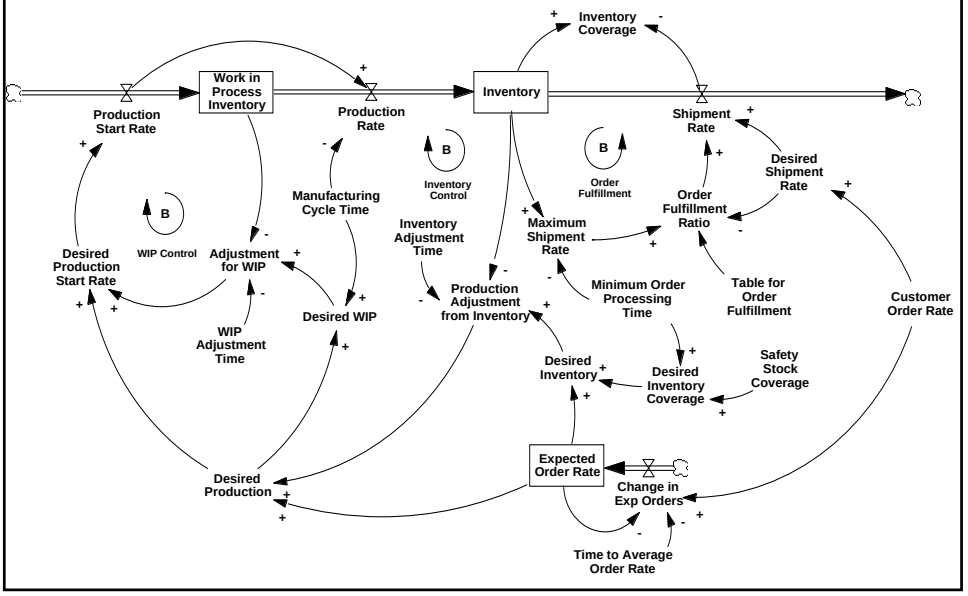
Adjustment for WIP = (Desired WIP – WIP) / WIP Adjustment Time

Desired WIP =
Desired Production * Manufacturing Cycle Time

Revised Production Starts Policy

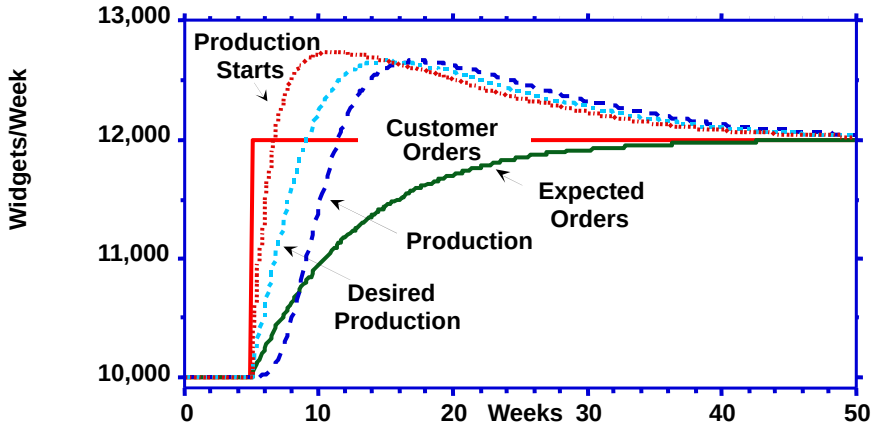


Revised Model

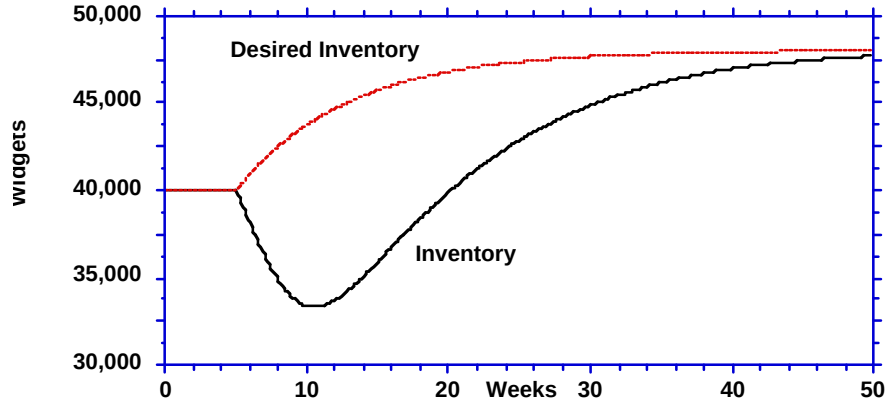


Response to 20% step increase in orders

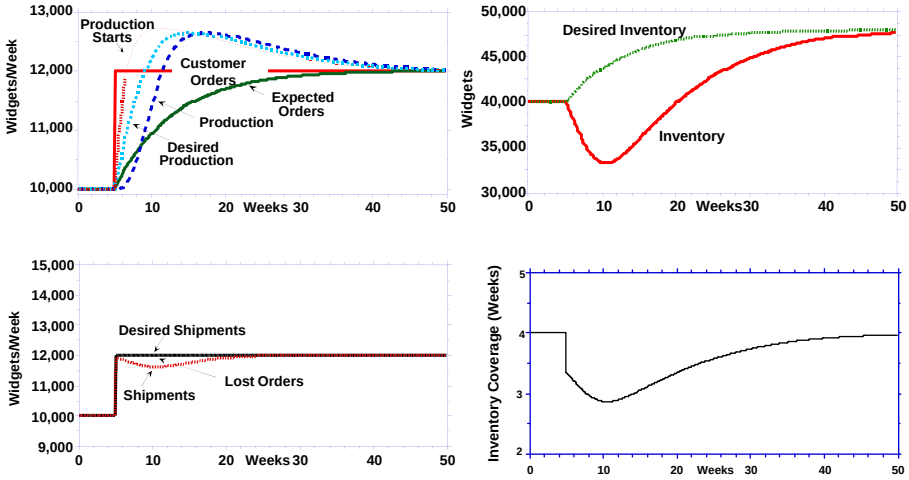
Response to a 20% step increase in orders



Response to a 20% step increase in orders



Response to a 20% step increase in orders



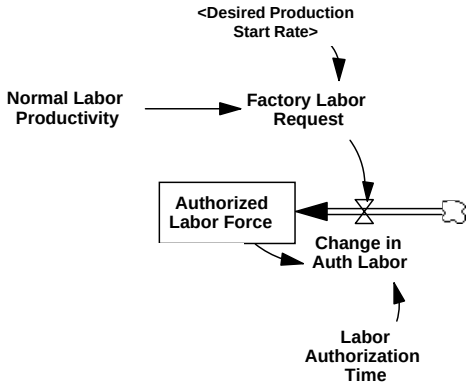
Modeling Workforce

Including Workforce to the Model

Further Discussions with management reveal that production often differs from the desired rate due to delays in adjusting the workforce to the appropriate level.

- While the firm has ample physical plant and equipment, labor cannot be hired and trained instantaneously. There is a two-stage process for changing the workforce.
- First, a target or desired workforce is determined from production targets developed by plant managers. The desired workforce is determined by desired production start rate and normal productivity.
- The desired workforce must then be reviewed and authorized by management, a process which requires an average of 4 weeks.

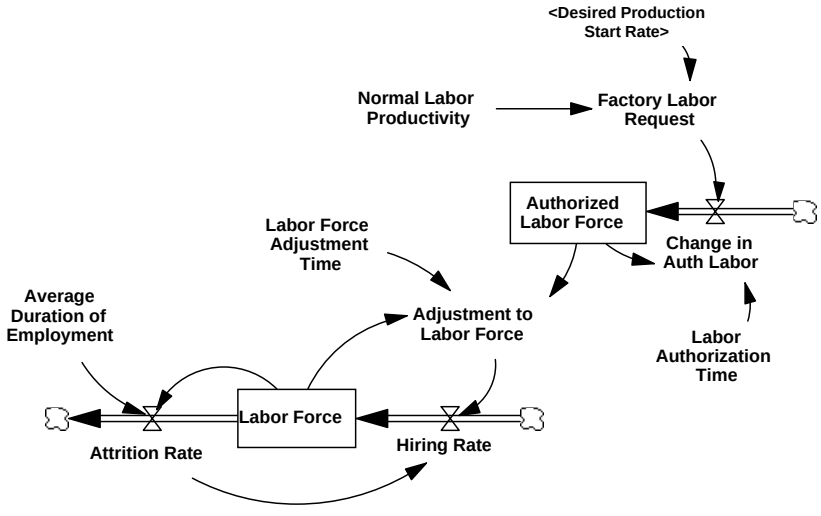
Labor Sector



Workforce Hiring Process

- Then, the workforce has to be hired.
- The hiring rate is determined first by replacement of workers who have left, adjusted up or down to bring the total labor force in line with the authorized level.
- It takes an average of eight weeks to adjust the labor force to authorized levels.
- The firm has a no layoff policy, so attrition is entirely voluntary.
- The average duration of employment is 100 weeks (2 years).

Labor Sector



Workforce Formulation

Production Rate = Normal Production

Normal Production = Labor Force * Normal Labor Productivity

d/dt(Labor Force) = Hiring Rate – Attrition Rate

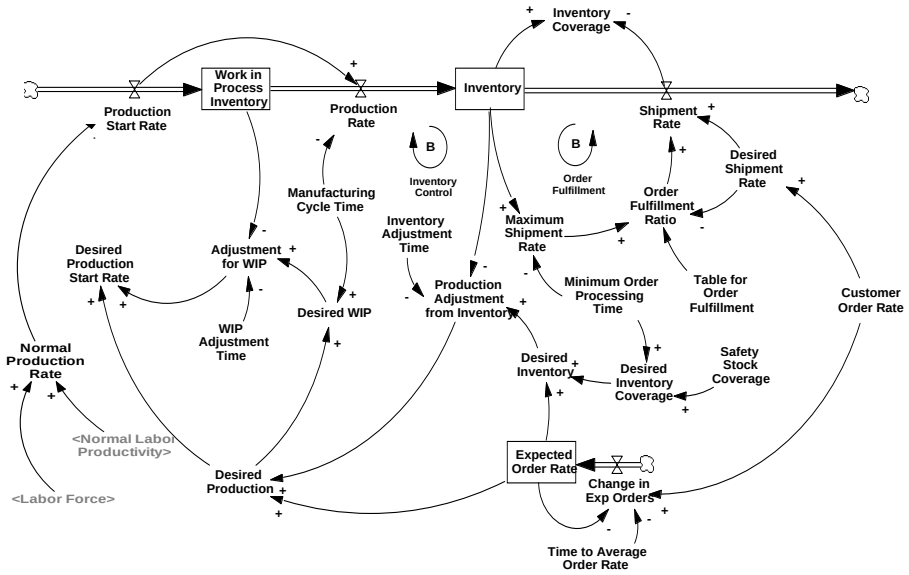
Hiring Rate = MAX(0, Attrition Rate + Adjustment to Labor Force)

Attrition Rate = Labor Force/Average Duration of Employment

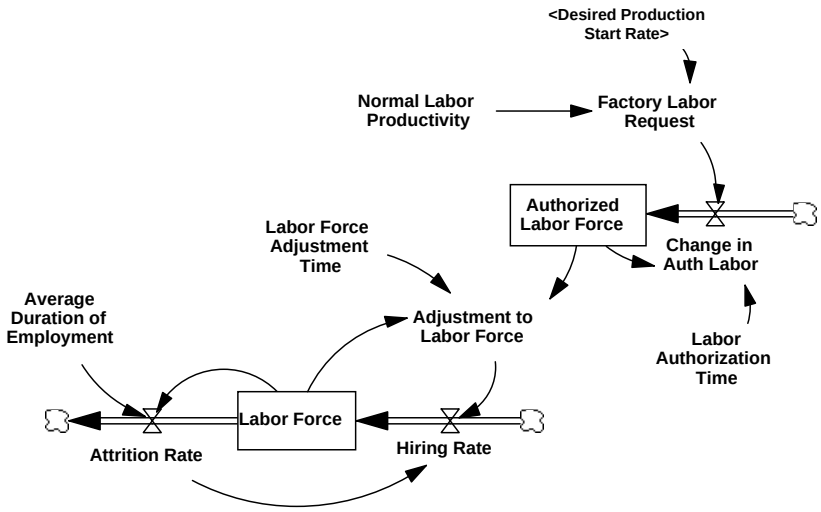
Change Auth Labor = $\frac{\text{(Factory Labor Request – Auth Labor Force)}}{\text{Labor Authorization Time}}$

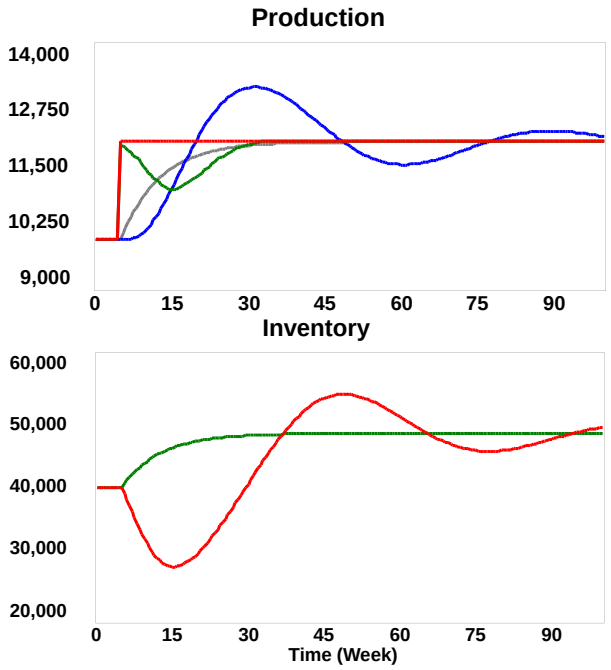
Factory Labor Request = $\frac{\text{Desired Production Start Rate}}{\text{Normal Labor Productivity}}$

Revised Production & Inventory Sector



Labor Sector





Response to Random Order Rate (5% Std. Dev.)