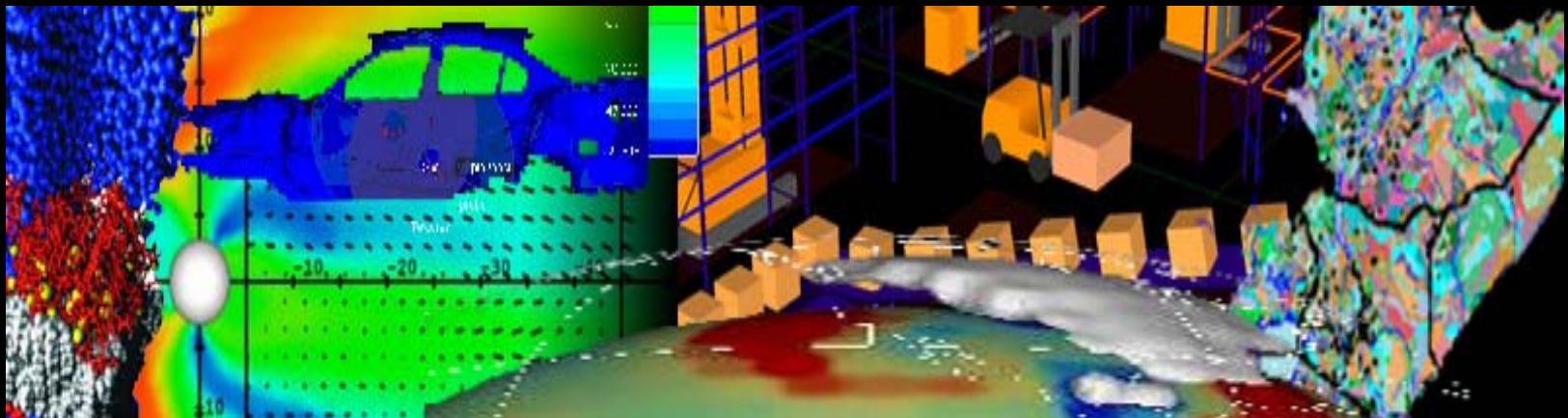


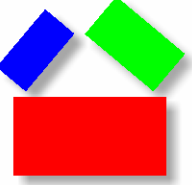
THE DATA CENTER

Master Production Schedule Stability Under Conditions of Finite Capacity



Edmund W. Schuster

Massachusetts Institute of Technology

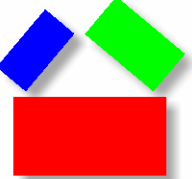


A Copy of the Paper Can be Found At:

<http://mitdatacenter.org/>

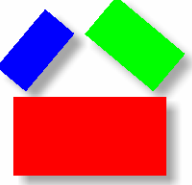
“Research”

Under Review for CSCMP



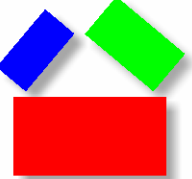
The Direction of the Internet

- The Web of Information
 - HTML and the World Wide Web
- The Web of Things
 - Linking physical objects together using Auto-ID
- The Web of Abstractions
 - Building a network of mathematical models
 - Link models together
 - Link data to models
 - Computer languages & protocols to create a free flow of models in a network (Internet or Intranet)

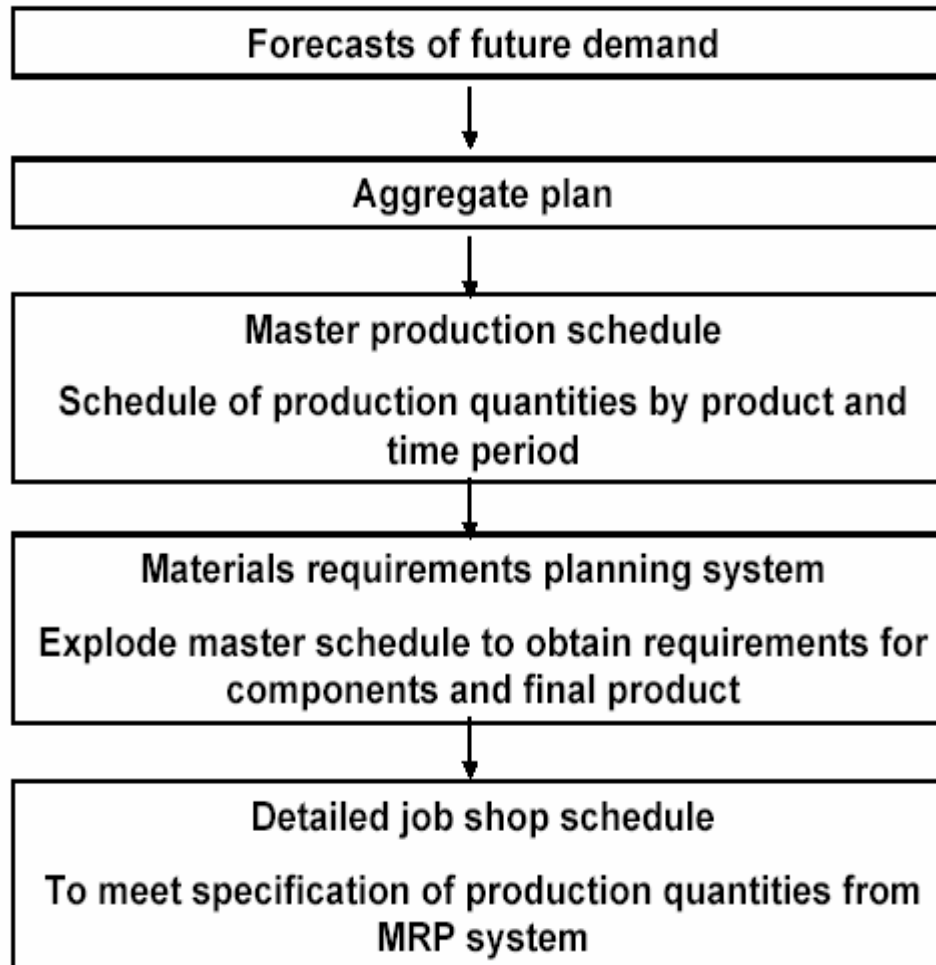


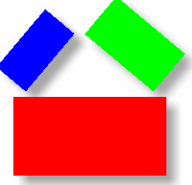
The Process Industries

- Have manufacturing operations that include:
 - Mixing
 - Separating
 - Forming
 - Chemical reactions
- Major Industries:
 - Food
 - Chemical
 - Pharmaceutical
 - Paper
 - Biotechnology



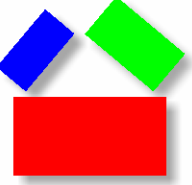
HIERARCHY OF PRODUCTION DECISIONS





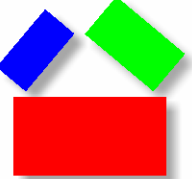
Traits of Process Manufacturing

- **Wide range of environments**
 - continuous vs batch process
- **No universal solutions**
 - wide differences between different segments
- **High customer service expectations**
 - 99% percent cases ordered vs cases shipped
- **Dynamic demand**
 - sudden changes in demand



Solution Methods (Models) for Planning and Scheduling

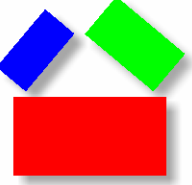
- Mathematical Programming
- Mathematical simulation
- Heuristics
- Process Flow Scheduling
- Theory of Constraints
- System dynamics
- Genetic algorithms
- Neural networks



Comparison of Different Scheduling Approaches

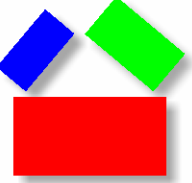
Attribute	Math Programming	Simulation	Heuristic
Hold Time		X	X
Queue Time		X	X
Customer Service		X	
Forecast Bias		X	
Set-up Cost	X		X
Holding Cost	X		X
Overtime Cost	X		X
Capacity	X		X
Production Lot Size	X		X
Production Sequence	X		X
Customer Due Date	X	X	X
Family Structure	X		

X = Functional



Safety Stock Planning and Forecast Bias

- Forecast error seldom is normally distributed
- There are few finite planning models that include safety stock
- Some mathematical models account for forecast bias

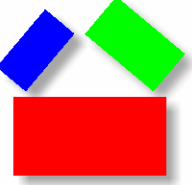


Semantic Modeling

Take the output of one model and use as the input of another model

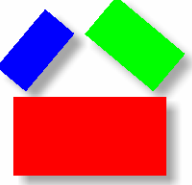
Find the models that need to be linked together

Bias adjusted safety stock model + Finite production planning Model



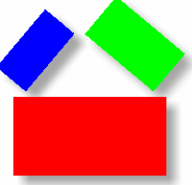
Safety Stock in Finite Planning Systems

- User input, “days of supply,” no direct link to customer service levels
- Calculation of safety stock based on forecast
- A “lumpy” forecast produces a dynamic safety stock through time
- Production planners have a hard time determining safety stock levels for the 200-300 sku’s
- Improper safety stock levels negatively impacts a) production timing, b) production lot size and c) production sequencing



Archetypal Finite Planning Systems

- Do not integrate statistical safety stock planning into algorithms or heuristics
- Make no provision for type 1 or type 2 customer service levels (ability to meet demand \forall s total percentage of cases shipped)
- Do not account for forecast bias
- Assume independent demand is “deterministic”
- Accept forecast at face value
- Can not find optimal solutions for sequencing and lot sizing problems under situations with dynamic safety stock



Safety Stock is Defined as:

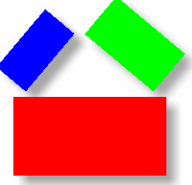
Demand through lead time depending on:

1. Length of lead-time
2. Forecast error
3. Forecast bias
4. Level of customer service

The nature of forecast error has a great impact on safety stock

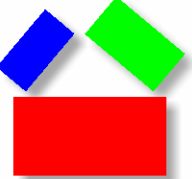
Each forecast has its own “fingerprint,” not every forecast is bad.

The only practical way to deal with safety stock and forecast error in finite capacity planning is through “layering” of models.

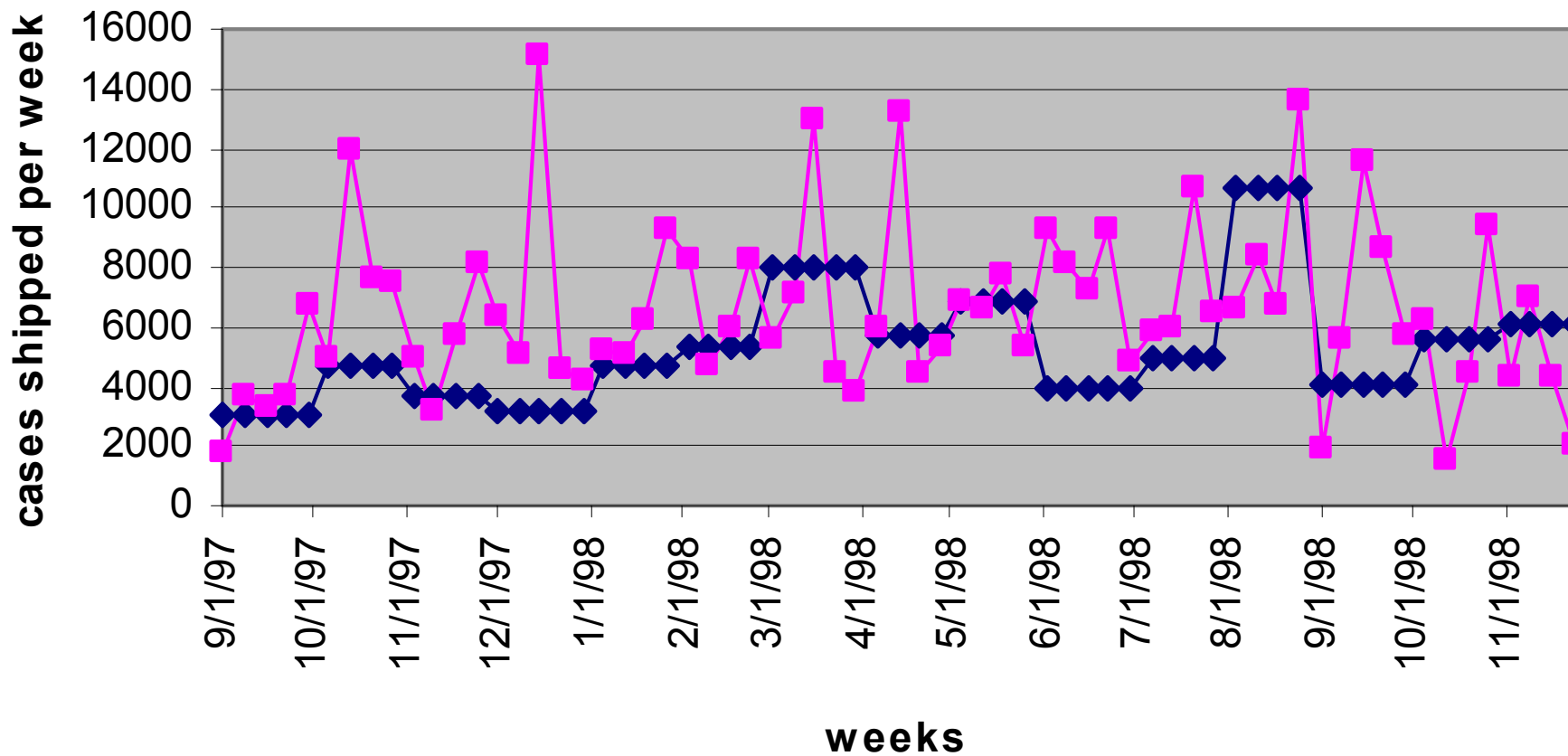


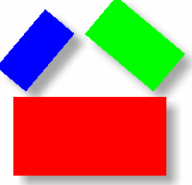
Negative Bias in the Forecast

- FETS varies between 0 and 1
- Consistent oversell of the forecast
- Implication: out of stock before next scheduled production run, *forced break in production sequence to maintain customer service*
- **A deadly situation in cases where capacity utilization is high**



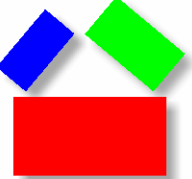
Example of Negative Bias (Oversell) WPD21100 at KW, FETS = $-.65$



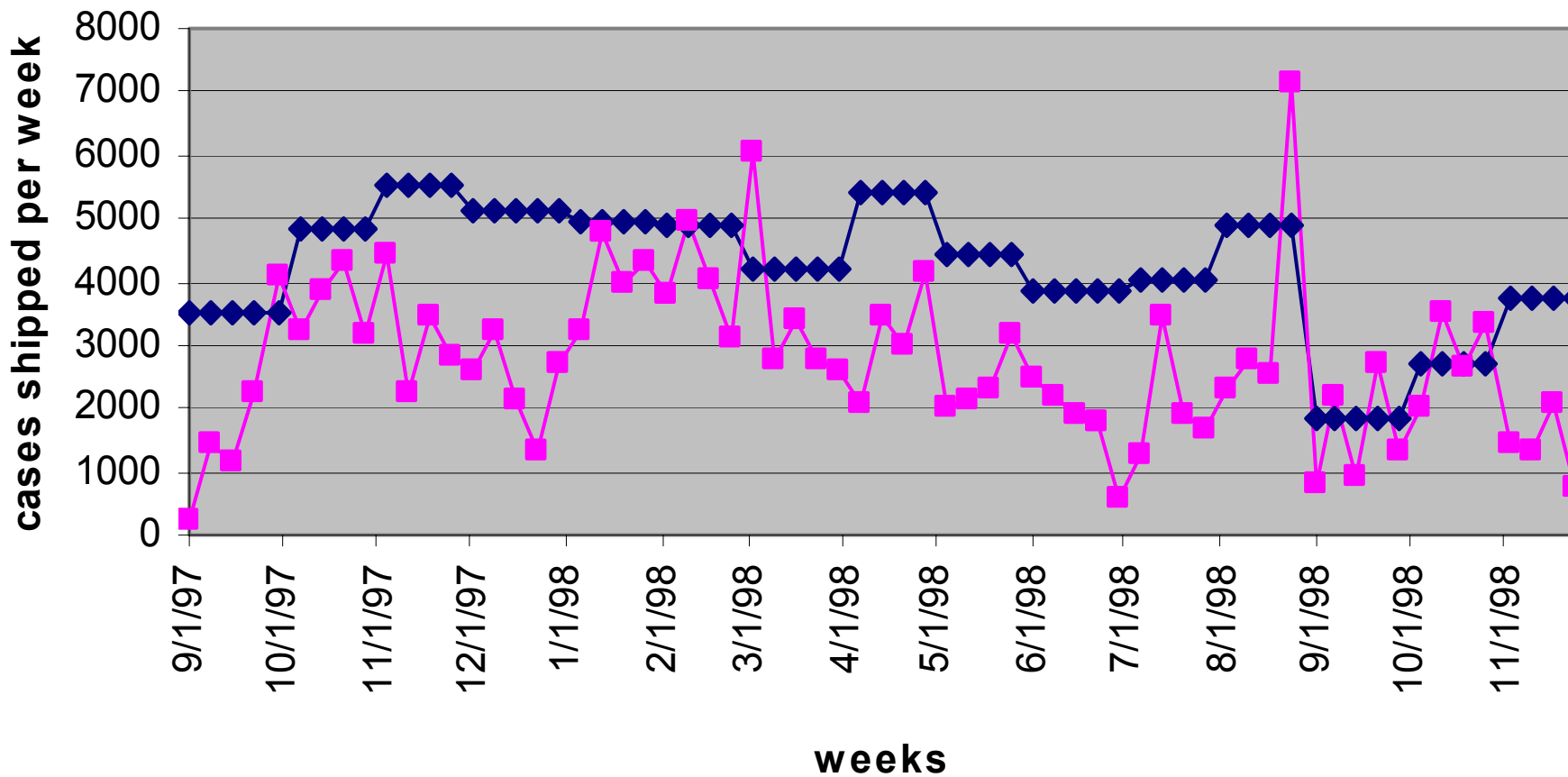


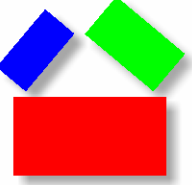
Positive Bias in the Forecast

- FETS varies between 0 -1
- Forecast is frequently higher than actual
- Implication - by planning production to the forecast, *we have too much inventory*
- **This situation is deadly when there are warehouse storage limits on products**



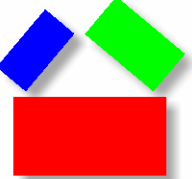
Example of Positive Bias (undersell) WPD19200 at LT, FETS = .83



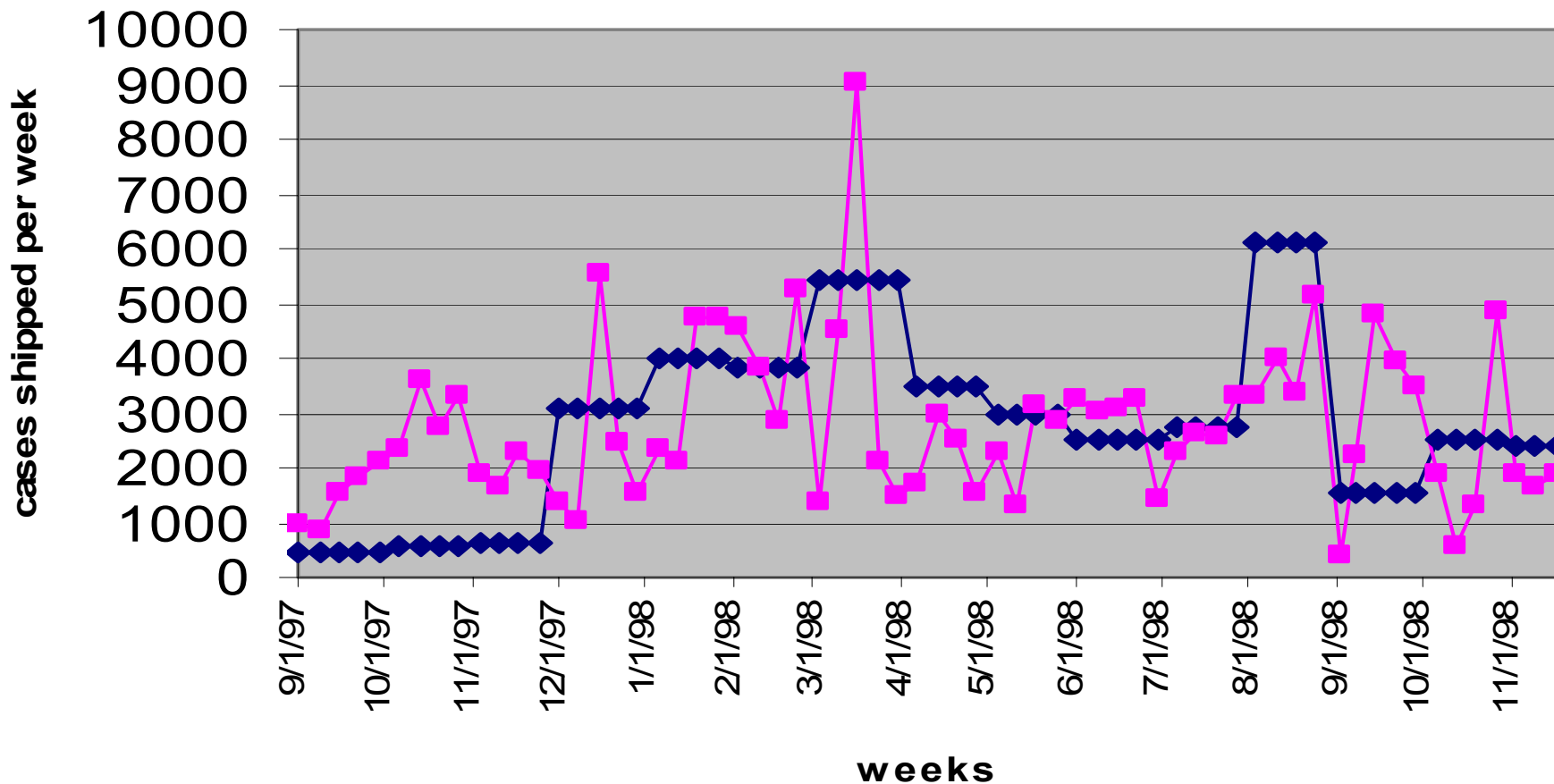


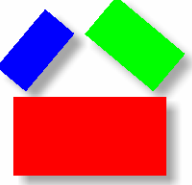
High Variability Between Forecast and Actual

- Demand in relation to the forecast means almost nothing
- Implication - the need for high safety stocks
- It is hard to put a limit on how much safety stock is needed
- Creates substantial uncertainty when several products on a production line (with finite capacity) experience high variability
- More inventory required!!!!



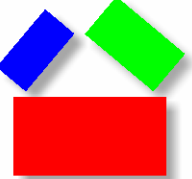
Example of High Variability WPD22900 at KW, TICF = .94



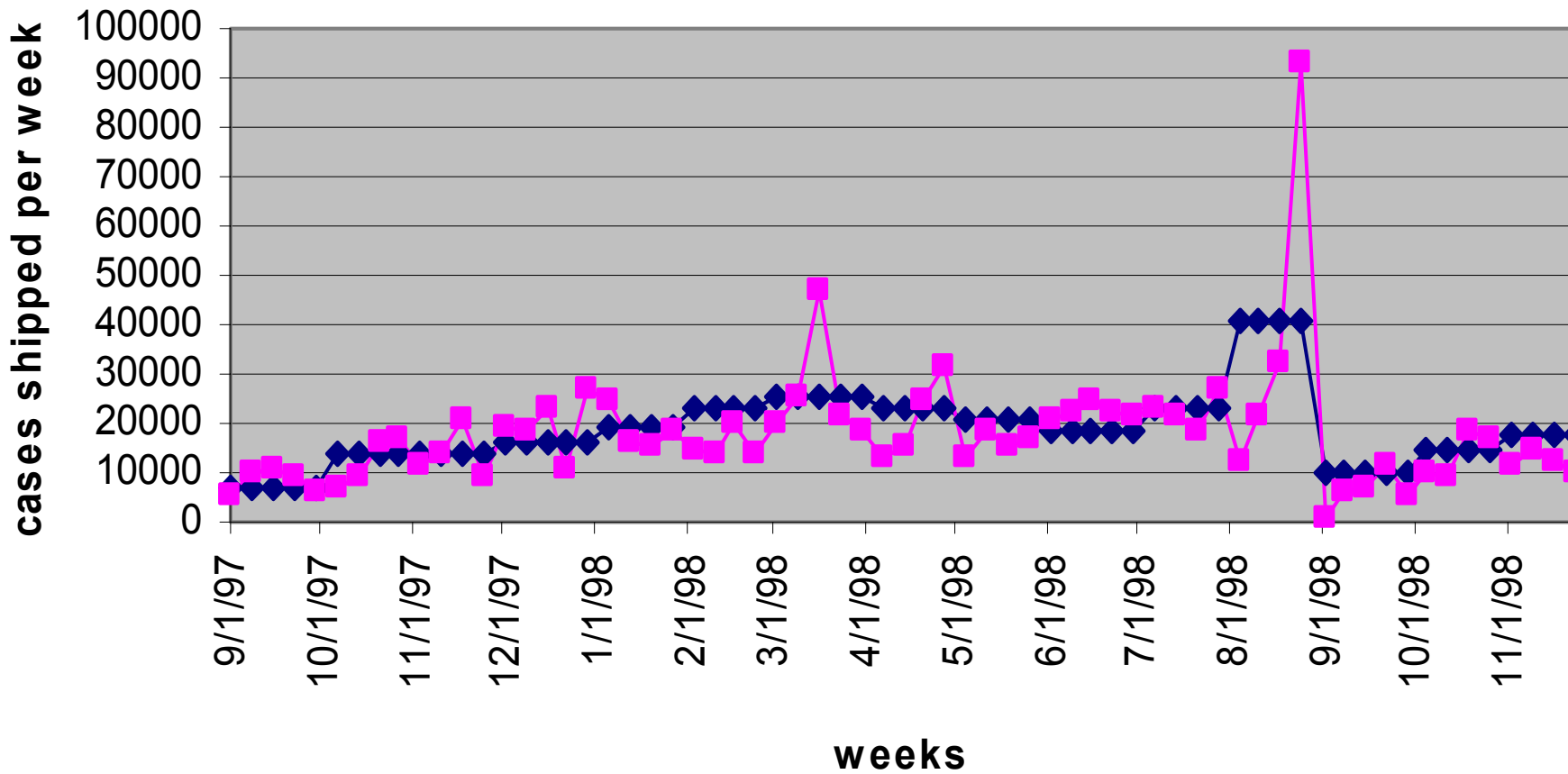


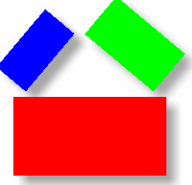
Low Variability Between Forecast and Actual

- A stable situation
- Finite capacity calculations are believable
- Occasional statistical “blip” seldom, if ever, is maintained through to the next period
- “Blips” are sometimes predictable (end of the year push)
- **LOW INVENTORY REQUIRED**



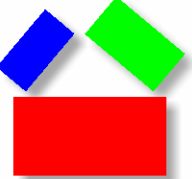
Example of Low Variability WPD21100 at NE, TICF = .3



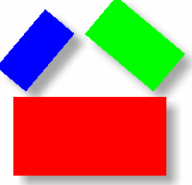


Cost of Forecast Error

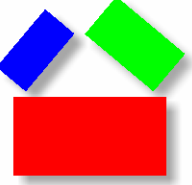
- Less forecast error means less safety stock
- Sample 4-5 major products produced at all manufacturing plants
- Compare safety stock (SS) calculation with current forecast error to SS calculation with min error (30% absolute error)



- **Total safety** stock is 47,074 cases for current forecast error
- **Total safety** stock is 35,137 cases for “ideal” forecast error
- Ideal forecast error results in 1 / 3 less packed product (PP) inventory
- Assume Average PP inventory = \$24 MM
- A 1 / 3 reduction = \$8 MM @ 10% carrying cost = \$800,000

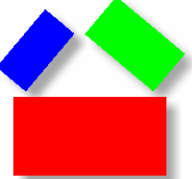


- With less need for safety stock, supplies and ingredients inventory also decreases:
 - estimated decrease (conservative) = \$0.2 MM
- Less safety stock also mean fewer “rapid sales” situations and less “obsolete” material in inventory
 - estimated decrease (conservative) = \$1.0 MM
- First cut at total decrease in cost:
 - **Savings of about \$2.0 MM**



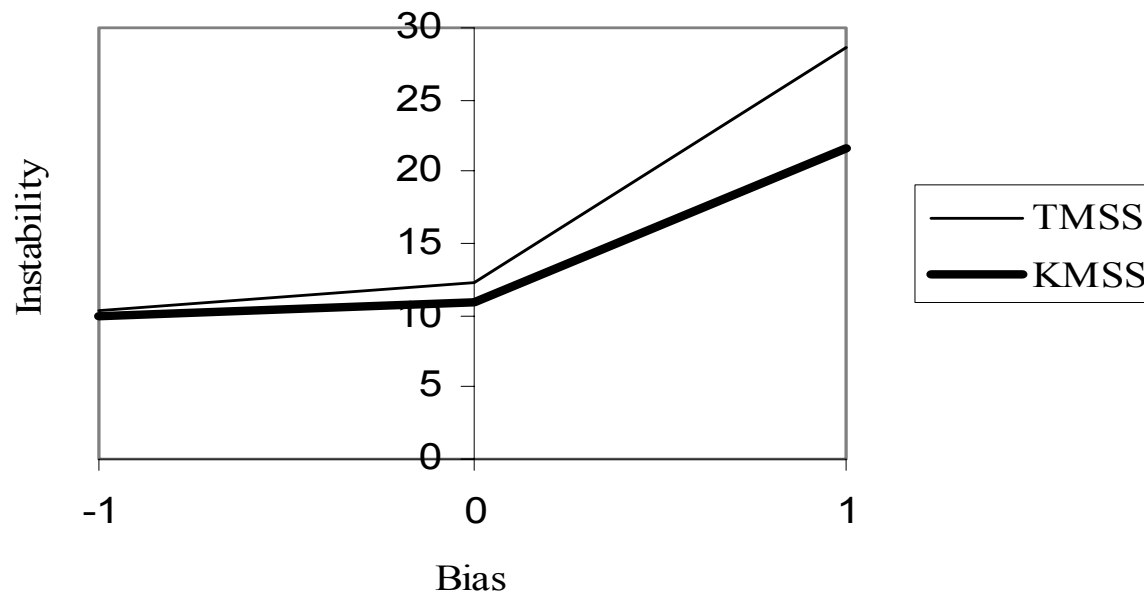
Conduct Experimental Design (Box, Hunter, and Hunter)

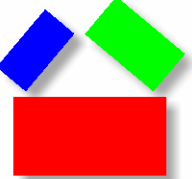
- Forecast Bias
- Capacity
- Demand Variability
- Customer Service Level
- Safety Stock Method
- FORM A NEW MODEL, Krupp + Allen, Martin, Schuster



Results of Experimental Design

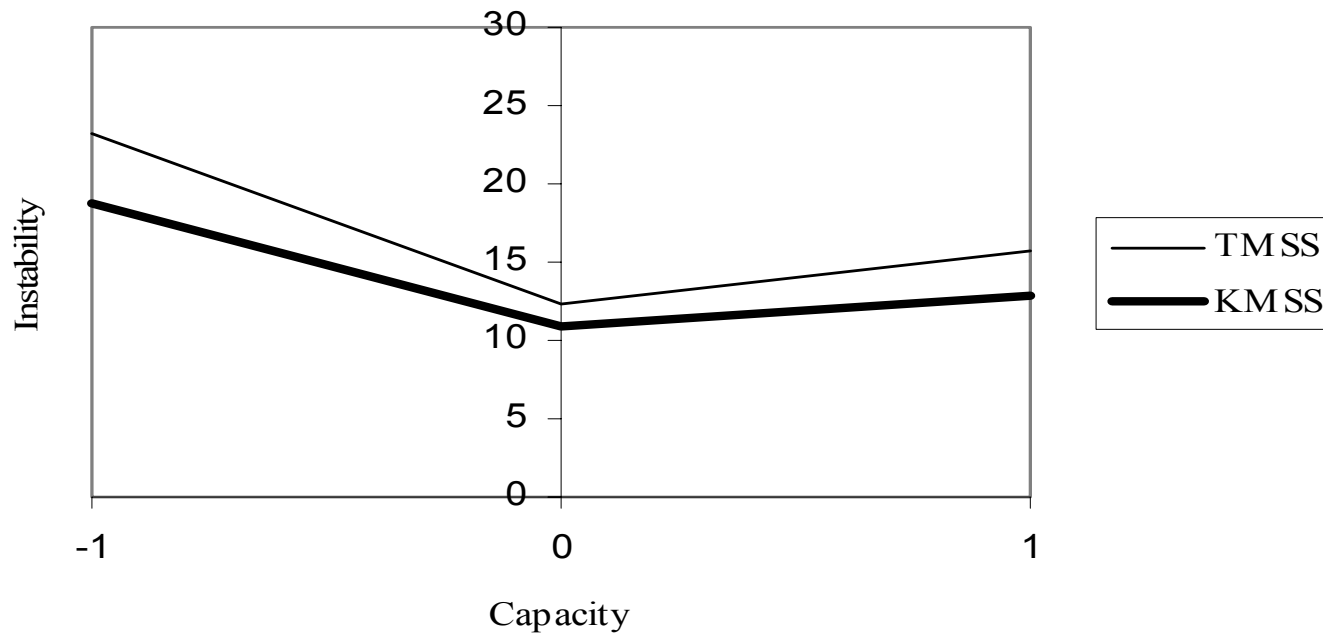
Instability vs Bias for Two Safety Stock Methods

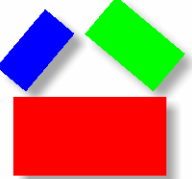




Results of Experimental Design

Instability vs Capacity for Two Safety Stock Methods

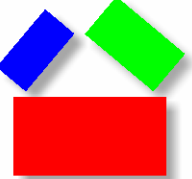




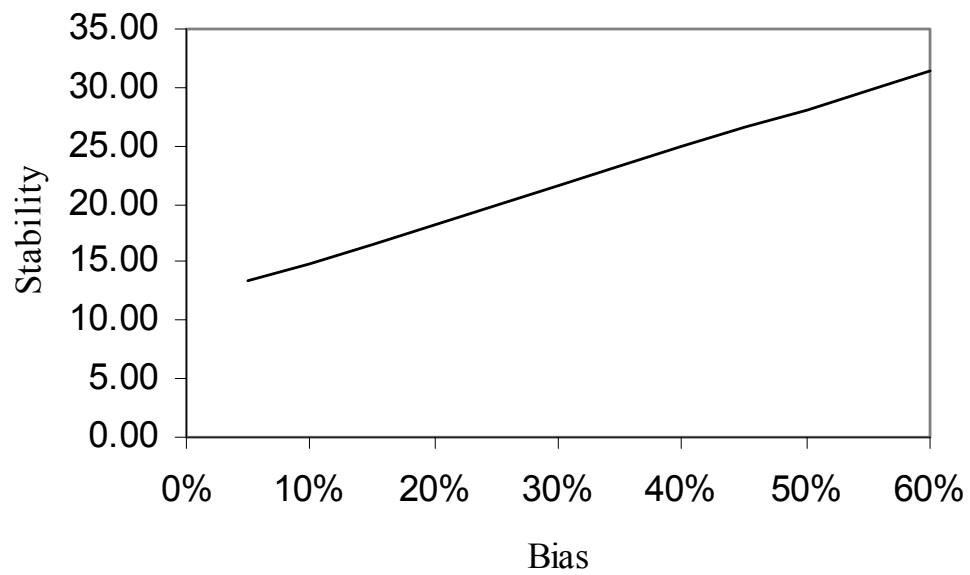
An Equation for Stability

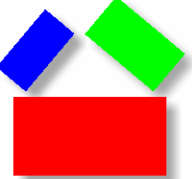
$$\text{Stability} = 17.29 + 7.44 (\text{Bias}) - 3.33 (\text{Capacity}) - 1.77 (\text{SS Method}) - 1.63 (\text{Bias} \times \text{SS Method})$$

Coded independent variables need to be translated



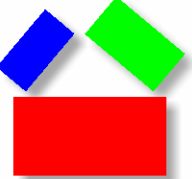
Stability vs Bias





CONCLUSION





New Research Area, IESL

“Improved Marketing Analytics Through Visualization of Spatial Diffusion”

