Independent Demand Models

- **Non Linear** (Chemical Industry - take or pay)
- **Deterministic Simulation** (make to stock - lumpy demand)
- **Mathematical Programming** (family structure - near optimum)
- **Heuristic** (make to stock - sequence independent)
- **Heuristic** (Make to stock - sequence dependent)

Additional Models:

Capacitated MRP (finite planning for dependent demand)

Continuous Replenishment Systems (optimal truck loading)

Welch's has a large amount of **<u>forecast error and bias</u>**

As a result, Welch's has experienced a breakdown **<u>in finite capacity planning</u>**

Often SKEP shows we are out of capacity (red) in the locked period and beyond, when the real cause is a forecast with high variability or bias

Typical Forecast Errors at Welch's,

- Are often quite dramatic
- Seldom follow a normal distribution, even over extended periods of time
- Show extreme bias, with limited patterns of adaptation through time

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- Production planners deal with weekly variability
- We measure error by dividing the monthly forecast by the number of weeks in a month and comparing to actual shipments for the week

A Detailed Look at Welch's Forecast Error Data

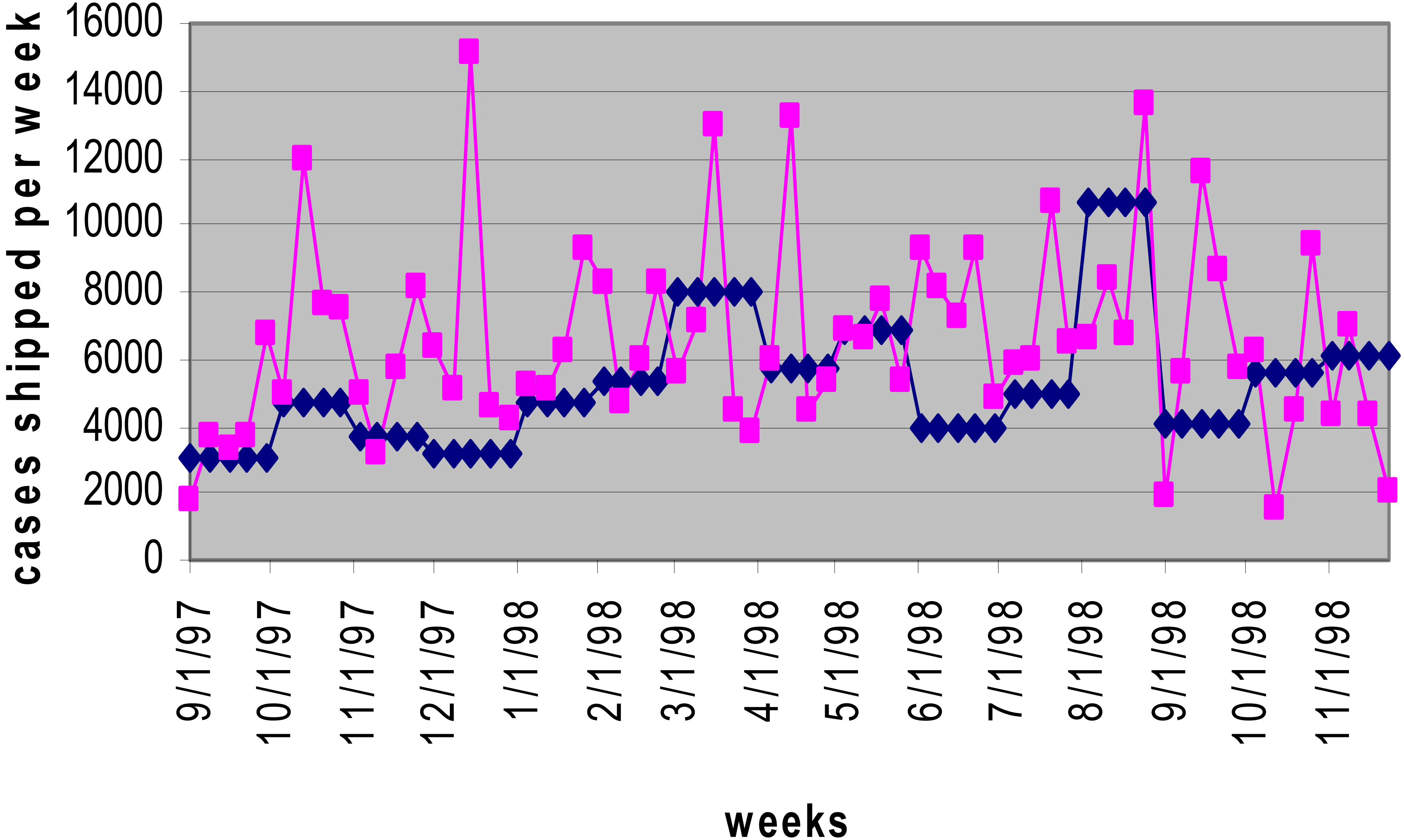
We calculate the forecast indicators and list:

a. Forecast error by product by manufacturing plant (three tables)
b. Forecast error for a single product manufactured at all plants in the Welch network (five tables)
c. No table lists forecast errors by manufacturing line
d. Some of Welch's forecast error results from improper plant splits rather than high level forecast error (product manager level)

Negative Bias in the Forecast

- FETS varies between 0 and 1
- Consistent oversell of the forecast
- <u>Implication:</u> 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**

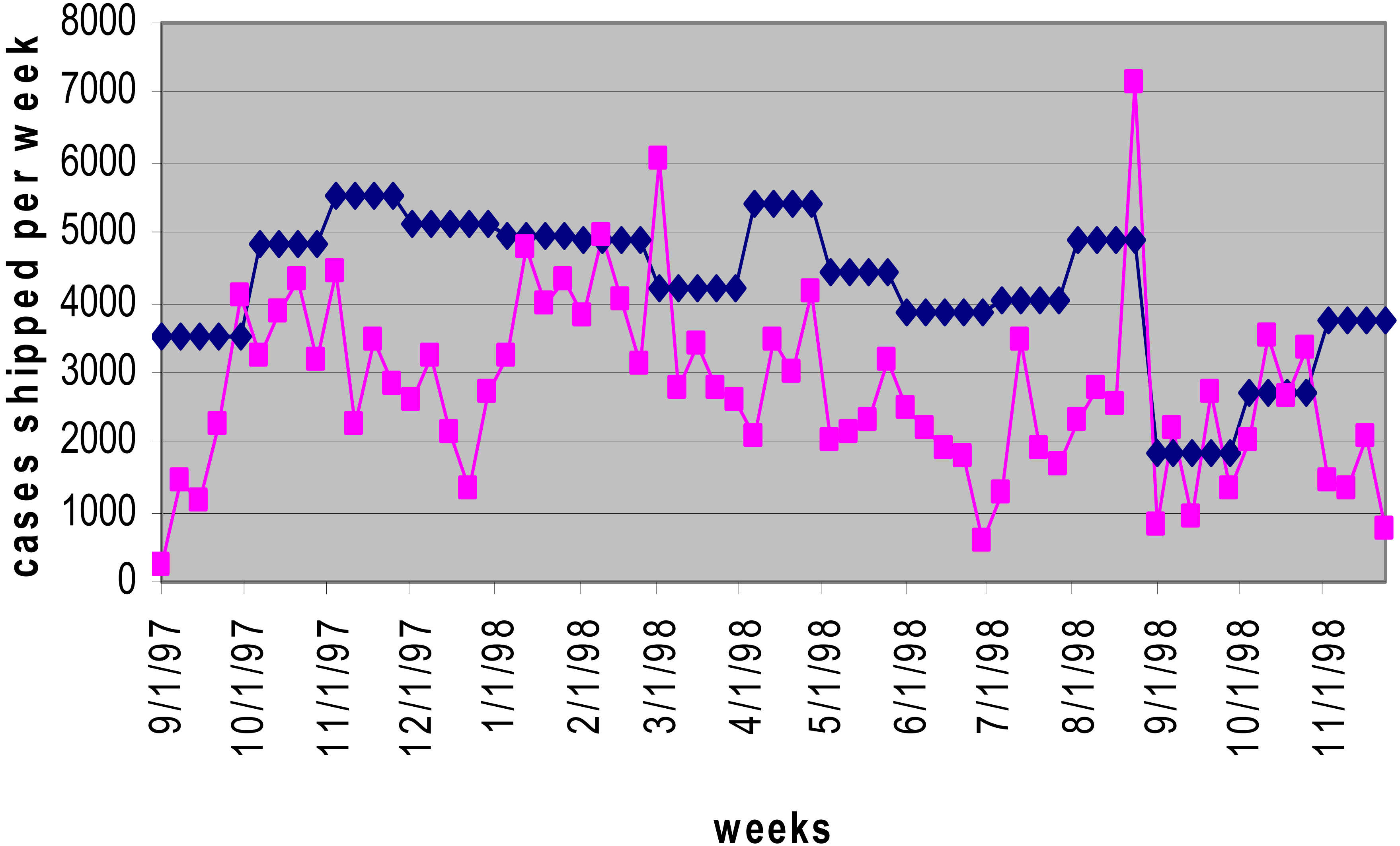
Example of Negative Bias (Oversell) WPD21100 at KW, FETS = -.65



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**

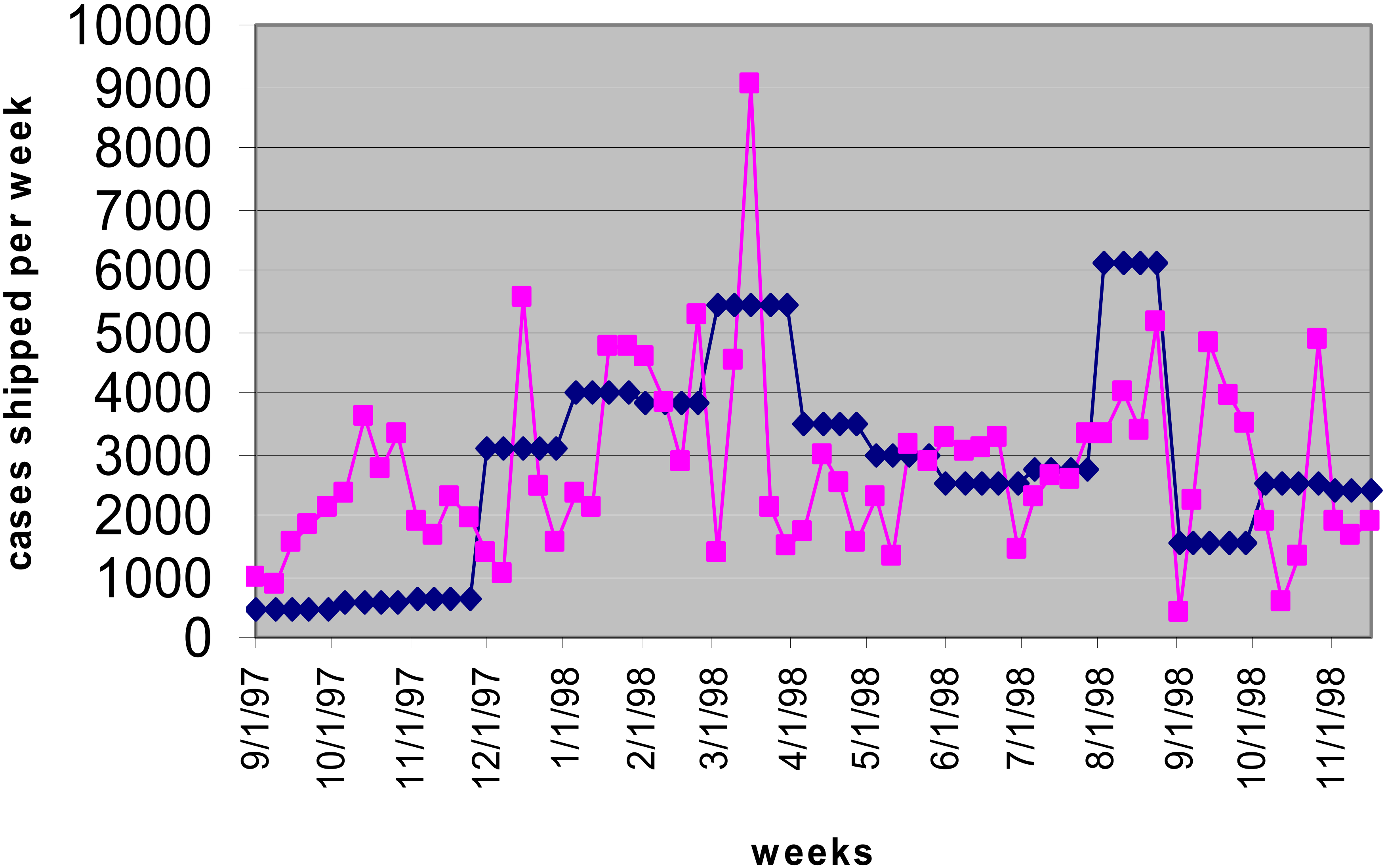
Example of Positive Bias (undersell) WPD19200 at LT, FETS = .83



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!!!!

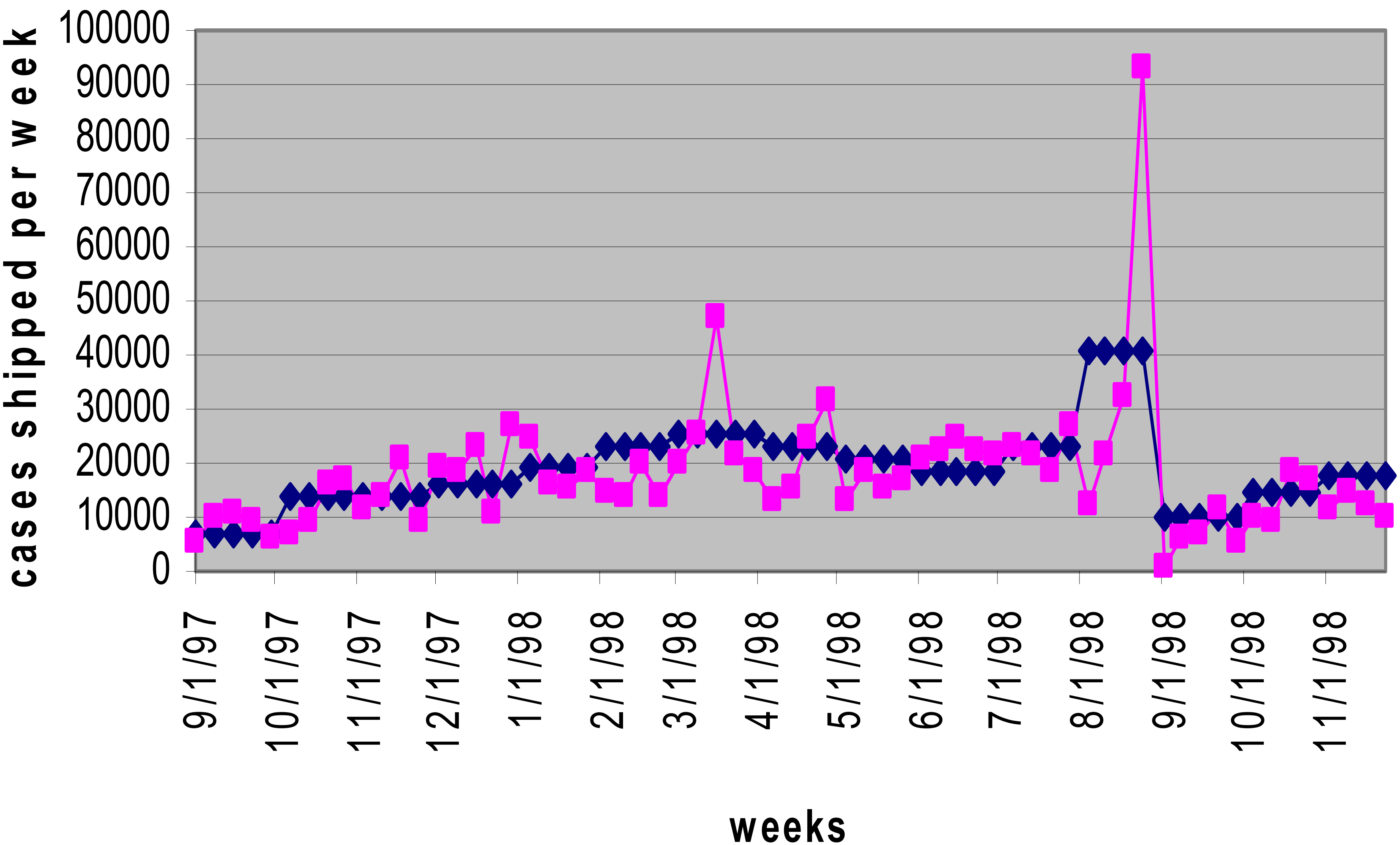
Example of High Variability WPD22900 at KW, TICF = .94



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)

Conclusion

- **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

Conclusion (continued)

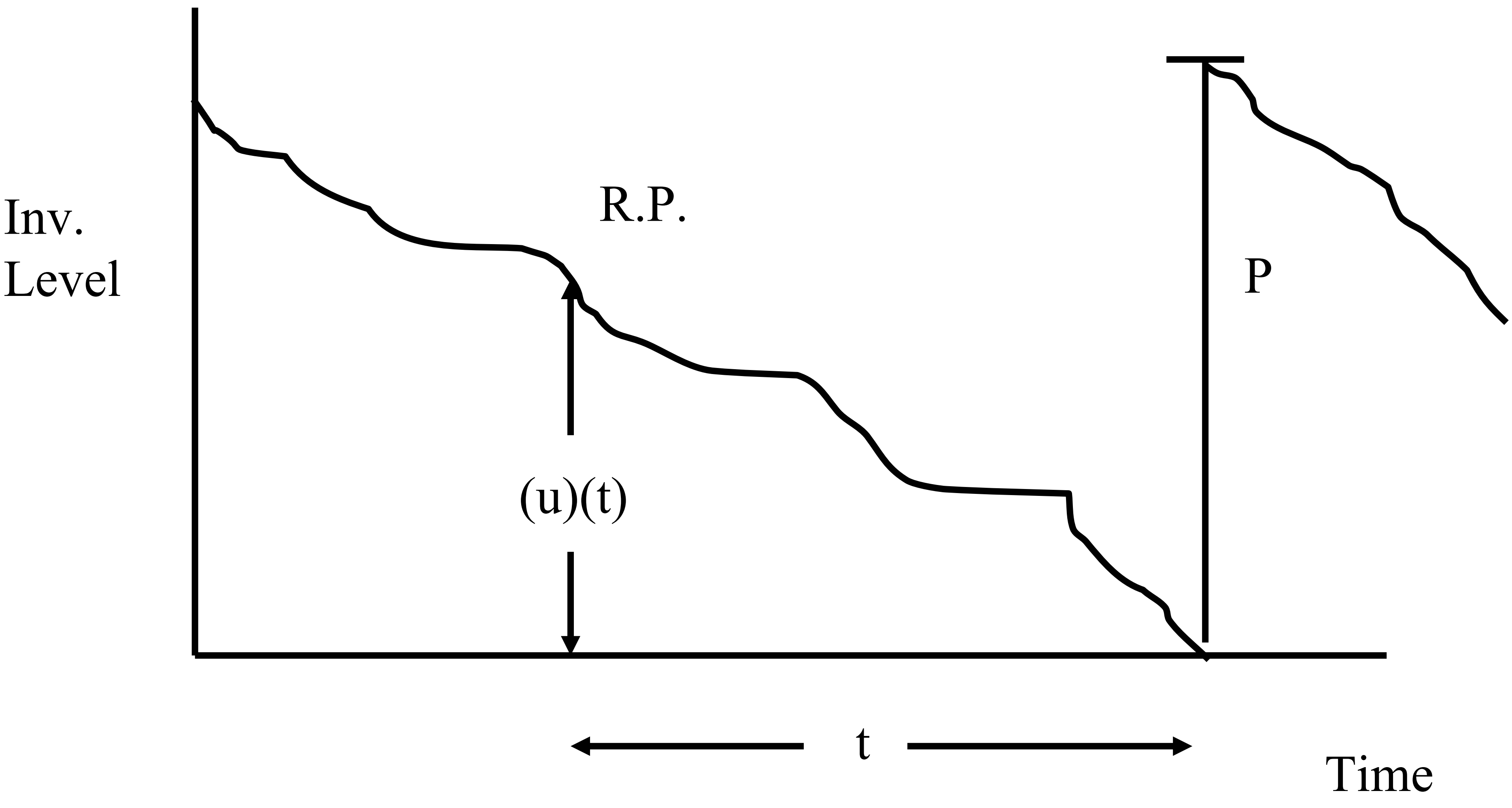
- With less need for safety stock, supplies and ingredients inventory also decreases:

  estimated decrease (conservative) = $0.2 MM
- Less safety stock also mean fewer "rapid sales" situations and less "obsolete" material in inventory

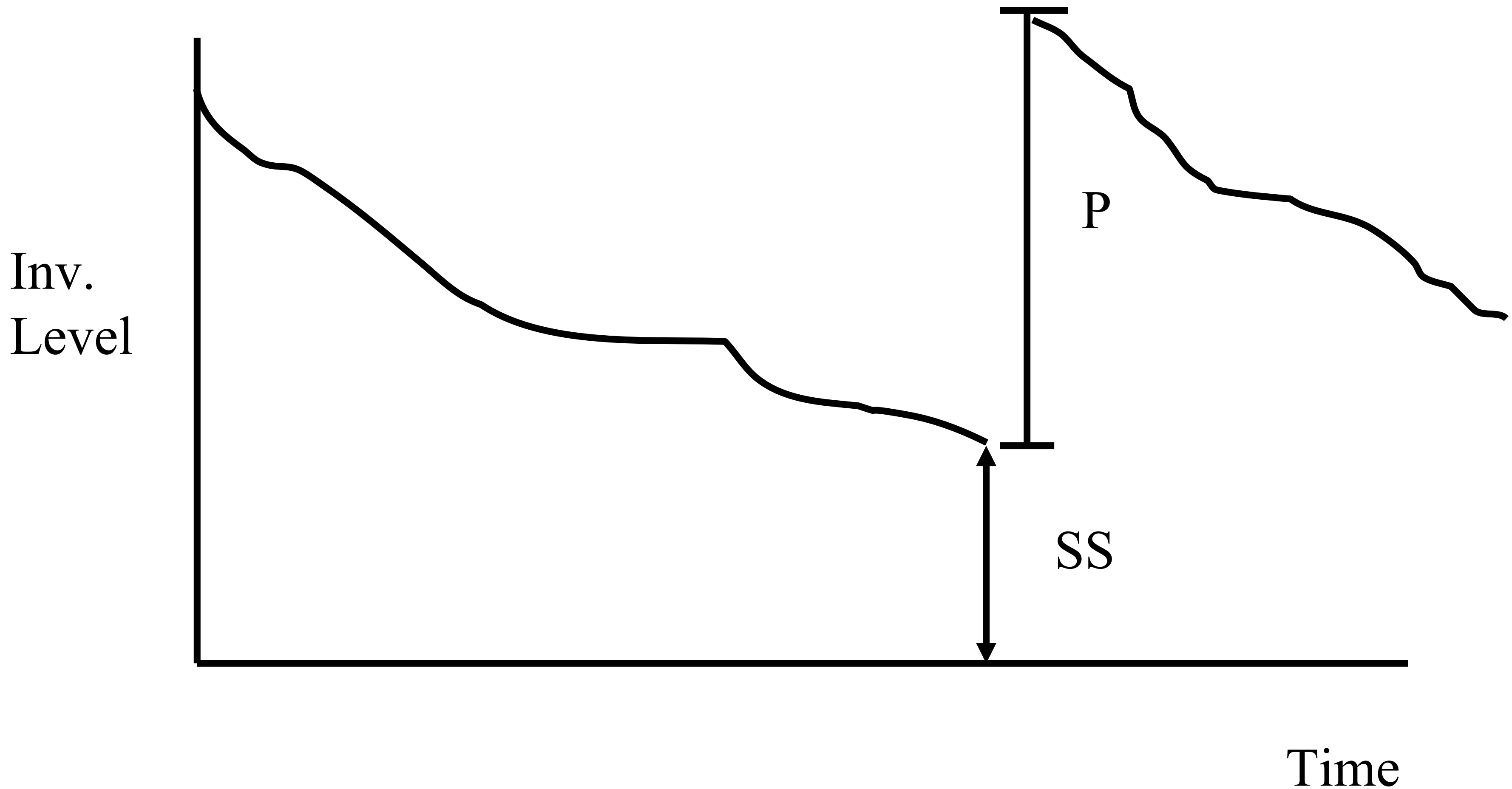
  estimated decrease (conservative) = $1.0 MM
- First cut at total decrease in cost:

  Savings of about $2.0 MM

R.P. Without Safety Stock



R.P. With Safety Stock



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 Vs 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.

TICF is a measure of variability

**larger means greater forecast error, positive and negative
**similar to a standard deviation

FETS is a measure of forecast bias

**0 to 1 the forecast is high compared to actual
**0 to -1 the forecast is low compared to actual
**0 the forecast is neutral, errors randomly distributed

S is a coefficient applied to safety stock

**FETS between 0 and 1 gives S is less than 1
**no adjustment for negative bias, we assume the forecast will be updated

The Calculation of Statistical Safety Stock

SS = (S) x (k) x (TICF) x (u) x (t)

Where:

u = forecast demand per day

t = lead time

k = service level multiplier

s = suppression factor (straight line) = 1 – FETS

$$TICF = \sum_{i=1}^{n} \left| u(i) - x(i) \right| / u(i) / /n$$

u(i) = past weekly demands
x(i) = past actual weekly sales
n = number of periods

$$FETS = \sum_{i=1}^{n} (u(i) - x(i) / u(i) / /TICF$$

If the forecast improves, the model calculates less safety stock.
Do we need to smooth the bias in SS calculations?

The Formula for Statistical Safety Stocks With Bias Adjustment*

$$SS = (u)(t) \times TICF \times (k) \times (s)$$

*Krupp, J.A.G. "Effective Safety Stock Planning," *Production Inventory Management Journal*, Third Quarter, 1982.

Trigg Indicator

- Used to identify a “strange” forecast
- Spread of forecast errors is non-random
- Smoothing factor of .1 (β in the equations) used for calculation of the indicator (significant weight given to past observations)
- A calculated value of T greater than .51 shows a forecast with peculiar bias

The Formula for a *Tracking Signal* Developed by Trigg*

$$E(t) = \beta e(t) + (1 - \beta) E(t - 1)$$

$$M(t) = \beta \left| e(t) \right| + (1 - \beta) M(t - 1)$$

$$T(t) = \left| E(t) / M(t) \right|$$

If forecasts are unbiased, the smoothed error E(t) should be small compared to the smoothed absolute error M(t).

*Trigg, D.W. "Monitoring a Forecasting System." *Operational Research Quarterly* 15, 1964, pp. 271-74.