Dealer-Specific Vehicle Inventory Replenishment Optimization

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Drive Into the Future

Your car knows a lot about you. And it’s talking.

By IAN SHER and MIKE RAMSEY

Ford Motor Co. wants to read car buyers’ minds.

A fantasy? Maybe. But by mashing together large databases and analytical algorithms, the Dearborn, Mich.-based auto maker may have achieved the next best thing.

About three years ago, Ford began offering a system to dealerships that reads the dealer’s inventory, checks national and local supplies of vehicles, interprets buying trends and makes recommendations about what vehicles the dealer should stock—for example, three Ford Fusions with blue paint and specific types of engines.

The result has been significant. Ford vehicles are sitting on lots for fewer weeks, and the prices consumers are paying are rising. The increase in "net pricing," or the price a consumer pays minus a subsidy from the manufacturer, has been a driving force behind Ford’s big surge in profitability.

"Making sure the inventory matches what the customer is looking for is really critical," says John Ginder, manager of system analytics and environmental sciences in Ford's research and advanced engineering division. "The dealer makes a major investment every time he or she orders a vehicle—there is a long lead time in getting a vehicle, and if the vehicle is ordered in a fashion not popular with customers, it can sit on the lot for months."
The Inventory Manager at a Dealership Has a Difficult Job

Suppose that I am a dealership’s inventory manager and I am contractually obligated to order 10 Escapes from Ford this week. My problem: What specific configurations should I order today to replenish inventory? I should consider

- What series, features, options and colors appear to be popular (fast-turning, profitable)?
- How should these features be combined into specific configurations?
- How diverse should my orders be?
- What does my current inventory look like and what is in the pipeline?
- What do I expect to sell until the units I am ordering arrive at the dealership?
- It would be nice to know what’s selling effectively at competing dealers in my market area.
- Do I have any biases in my ordering decisions (I personally don’t like the running boards)?
- How did recent incentive programs impact what sold?
- Are we expecting incentive program changes in the near future?

And, I have to consider these factors for all vehicle lines for which I am placing orders, including F150 and Super Duty? I need help!!!
Operational Principles

- Personalized dealer orders
  - each dealer is unique

- Dealer-specific market areas
  - surrounding dealers’ inventory and sales performance guides target dealer ordering

- Balanced inventory
  - stock inventory in proportion to what is selling

- *Turn-and-earn* Commodity Allocation
  - allocate constrained commodities to those regions and dealers where they are most needed

- High inventory turn rates
  - choose configurations that have high probability of sale

- Diversity promotion
  - dealers desire diversity of exterior paint color
  - diversity at configuration level, by choosing unique configurations, subject to feature allocation and product definition constraints
Process Roadmap for Order Generation

Setup Process

1. Map Names Between Data Sources, Define Features and Families; Report Format
2. Encode Product Definition and Generate a List of Possible Configurations
3. Generate Product Definition Relationship Constraints

Weekly Process

1. Count Inventories
2. Create Weighted Time Series
3. Count Sales
4. Project Inventories and Set Targets
5. Train Neural-Network to Predict Rate-of-Sale
6. Run Rate-of-Sale Calculator
7. Optimize Feature Allocation
8. Optimize Order Selection
9. Generate Reports
10. End Process
Overlap of Dealership Locations and Customer Addresses

• Image to the right shows locations of Ford dealerships in the Boston area
  ▪ Circle encloses dealership locations within a 25 mile radius

• Image to the left shows locations (red balloons) of zip codes of addresses of customers who purchased a particular vehicle model from the center-most dealer
  ▪ This dealer serves customers from over 50 miles away
Definition of Dealer Market Areas

- SIMS market areas provide a dealer-specific view of competing dealers
- Distance of a competing dealer from a target dealer determined the level at which the target dealer’s performance is influenced by the competing dealer
- Most dealer market areas will consist of 25 or more dealers
  - An exception would be dealerships in Alaska

Chicago, 25 mile radius

Montana, 200 mile radius
Analytical Techniques Employed

- Principal Components Analysis for Dimensionality Reduction
- Mixed Integer Quadratic Programming for Feature Allocation
- Neural Network Methods for Survival Analysis
- Set Theory and Computational Geometry for Product Definition Constraints
- Mixed Integer Quadratic Programming for Order Selection
- Configuration Rate of Sale Analysis
- Inventory Analysis & Balancing
- Order Generation / Recommendations

Sales, Inventory, & Production History
Product Definition for SIMS

- Representation of product definition is a critical component of the SIMS application
  - Compact representation for SIMS feature allocation
  - Source of configuration-level information for evaluating and recommending fully-configured orders
- Issue: No capability existed for generating configuration data for complex vehicle lines (e.g., F-150)
Key Variables and Concepts

- Let $I$ denote available vehicle inventory and $S$ denote vehicle sales within some weekly time period

- Rate of Sale (or Inventory Turn Rate):
  \[ r = \frac{S}{I} \] at total vehicle level
  \[ r_i = \frac{S_i}{I_i} \] at vehicle feature level

  For inventory to be balanced, all vehicles should sell at a common rate.

  Rate of sale at the configuration level should be a function of inventory mix rate at the feature level.

- Inventory Mix Rate:
  \[ a_i = \frac{I_i}{I} \]

  Assumption: Sales mix rates do not change substantially over short periods of time, everything else being equal.

- Sales Mix Rate:
  \[ f_i = \frac{S_i}{S} \]

Note: If inventory is balanced, then inventory and sales mix rates should be identical.
Example of Inventory Imbalance for 2009 MY Fusion Engines

- 15-day moving average window
- Absolute inventory turn rate can vary substantially over time
- Relative inventory turn rate is smoother
- Sales and inventory mix rate gaps have persisted since July, 2008
Example Output of Inventory Analysis

2008 Escape - Body & Array Mix

- Stock fewer
- Stock more

Dealer's Historical Sales Mix
Dealer's Projected Inventory Mix
Market Area's Historical Sales Mix
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Formulation for Feature Allocation Optimization

\[
\min \sum_{k=1}^{N_d} \sum_{j=1}^{N_f} \sum_{i=1}^{l_j} \alpha_j \left( g_{t,k}^{j,i} - a_{t,k}^{j,i} \right)^2
\]

\[
a_{t,k}^{j,i} = \frac{1}{I_{t,k}} \left( m_{t,k}^{j,i} + n_{t,k}^{j,i} \right)
\]

Optimization objective is to drive inventory mix rates towards historical sales mix rates, subject to total dealer vehicle allocation, production and product definition constraints. This is called inventory rebalancing.
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Neural Network Rate of Sale Models

- Using historical inventory and sales data, and applying principles of survival analysis with time-varying covariates, vehicle and region specific rate of sale models are developed with neural network methods
  - We use the most recent 8 weeks of inventory and sales data
  - Context is important
    - Dealer location via latitude and longitude
    - Retail/stock order type
    - Total dealer market area inventory
    - Fraction of market area inventory available at stocking dealer
    - Feature market area inventory mix rates
      - As feature inventory mix rate increases, the rate of sale of vehicles with that feature is expected to decrease, everything else being equal
  - 100 different models are trained for each vehicle-region combination
  - Configurations are evaluated separately for each dealer for order selection
    - Use results of feature allocation to restrict which configurations should be evaluated
Learnings From the Process of Delivering SIMS

- Heavily analytical business applications, involving optimization, statistics, machine learning, etc., require non-traditional approaches for institutionalization
  - Iterative development methods are essential
    - Use principles of DCOV (Design, Characterize, Optimize, Verify)
  - Small teams of on order 6 people
  - Blurred roles and responsibilities (better yet, shared R&R’s)
  - Analytically skilled technical specialists as members of the IT team
  - O.R. emphasis should be front-weighted
    - IT should have continuous involvement
    - O.R. team should actively participate in development all the way through launch, but with reduced involvement over time
Ford’s Smart Inventory System (SIMS): Summary

**Description:**
Use detailed knowledge of dealer-area vehicle sales and dealer inventory, together with forecasting and optimization algorithms, to generate customized dealer order recommendations that balance inventory and provide high-sales-rate vehicle configurations.

**Benefits:**
- Faster inventory turns & lower dealer trade volumes
- Allows Ford to align material requirements to customer demand, i.e., improve commodity availability

**Technologies:**
- Statistical Analysis and Neural Network modeling of large data sets
- Mathematical Programming to solve large optimization problems
- Model Predictive Control to satisfy conflicting requirements over time

**Details:**
- Supports all vehicle lines, all dealers
- Projects future inventory mix to identify gaps
- Combines
  - Balanced inventory approach
  - Fast-turn configuration analysis
  - Promotion of a diverse inventory
- Provides full-configuration order recommendations
- Initiatives impacted
  - Complexity Reduction in “real-time”
  - Vehicle and commodity allocation strategy
SIMS: Results

• SIMS orders are not traded as frequently
  • 25% SIMS orders vs. 45% of non-SIMS orders were traded
  • Lower aged inventory (25%), improved days-on-lot (10%) for SIMS orders
Acknowledgements

Ford Research & Advanced Engineering
Gint Puskorius
Yu-Ning Liu
Melinda Hunsaker
Yakov Fradkin
Barb Nance
Shigeru Sadakane

Ford Information Technology
Ravi Tappeta
Bob Dux
Shankar Subramanian
and countless others

Ford Marketing and Sales
Rob Aniol
Bill Fravel

Special thanks are extended to the collective efforts of these 3 Ford organizations plus the Ford-Lincoln Dealer Council
Thank You