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Supply-Chain Analysis at Volkswagen of America

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In 1995, Volkswagen of America began a review of its vehicle-distribution system looking for opportunities to improve customer responsiveness and simultaneously reduce system costs. An analytical tool was required to evaluate alternative designs in terms of cost and customer service level, both of which are functions of probabilistic and dynamic elements. These elements include inventory policies, demand seasonality and volume, customer-choice patterns, and transportation delays. By using an innovative combination of simulation and discrete optimization models, we addressed the problem of analyzing a large number of alternatives efficiently. Our analysis indicated opportunities for significant savings in estimated annual transportation costs, and it provided insights on how to implement the proposed system.

Volkswagen of America (VoA), a wholly owned subsidiary of Volkswagen AG (Germany), imports, markets, and distributes Volkswagen and Audi vehicles in the United States. The Volkswagen vehicles are assembled in Mexico or Germany and distributed to a network of

Volkswagen dealers across the United States. In 1995, Volkswagen appointed a project team to review the vehicle distribution process and develop new concepts. This reengineering effort merged two initiatives; the first, a process of business renewal within Volkswagen begun in 1994,

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and the second, a Volkswagen AG initiative to improve responsiveness and reduce costs from customer to customer throughout the world. The study that is the subject of this paper was one part of the overall reengineering effort. Our team consisted of several members of the core Volkswagen project group and the first two authors of this paper as external consultants providing the analysis expertise.

The existing Volkswagen vehicle-distribution process had served the organization for years. Vehicle distribution in

Ford did not design the automobile franchise distribution system to maximize system level profit.

the United States has a single dominant form, in which the original equipment manufacturers (OEMs) inventory and sell new vehicles to franchised dealers. The franchised dealers inventory and sell new vehicles to the end users. The franchise system was introduced by Ford Motor Company early in the 20th century and was structurally intact in 1995. The current structure is so old that the original performance intentions around which it was built are rarely examined. However, it is as clear now as it was at the time of its origin that Ford did not design the automobile franchise distribution system to maximize system level (OEM and dealers together) profit but to realize cash flow for the OEM. The system that evolved has some distinctive operating assumptions. First, to maximize its cash flow, the OEM identified the dealer as its primary customer, and by default the dealer became

the exclusive supplier to the end user. Dealers and OEMs are only loosely coupled within the system. Each manages its own inventory costs and understands the balance of competitive relationships that exist between them. OEMs encourage dealers to carry as much inventory as possible but understand that excessive carrying costs could force a dealer out of business. Dealers recognize that the carrying costs of excessive inventory are threatening. They also recognize, however, that if they are individually reluctant to purchase inventory, the OEM may restrict supply or appoint additional, competing dealers. Second, the distribution logic was developed on the assumption that automobiles were configured as a standardized product line. This was a sound assumption when Ford originally produced one model in one color. The system architecture did not anticipate the proliferation of products that each OEM produced in the 1990s.

In the last decade, competitive advantage has been replacing cash flow as the primary focus for the franchise network; however, the structure of the distribution system has remained largely unchanged. Firms now recognize that the traditional system has performance limitations. For example, years of manufacturers and dealers focusing on their own costs and not attending to their combined system costs has created an unnecessary duplication of processes and inventory. Also, OEMs now offer thousands of model configurations (body, engine, transmission, optional equipment, and color combinations). In 1995, the average Volkswagen dealer in the United States sold fewer than 30 cars per month and stocked fewer than 100 in

inventory; the likelihood that any dealer might have the exact choice that each customer might have in mind was small. To compensate for not being able to offer customers their first choices, dealers would often offer purchase incentives to encourage the sale of the stock on hand.

The project team at Volkswagen sought a means to deal with these limitations, a new configuration that could achieve the following goals:

- (1) To maximize the percentage of customers who received their first choice of vehicles;
- (2) To deliver customers' first choice of vehicle configurations within 48 hours, either from dealer inventory or from Volkswagen inventory; and
- (3) To reduce the total system (dealers and Volkswagen) costs for transportation, financing, and storage, primarily by reducing inventory.

One concept that appeared to have potential was to pool vehicles in regional depots and reduce the local dealers' inventories. By aggregating the inventories of a number of dealers, Volkswagen would enhance the likelihood of satisfying customers' first choices. Rapid release from the pool and transportation to the selling dealer within 48 hours for delivery to the customer would complete the transaction. The system could increase first-choice sales, be timely, and reduce inventory costs.

However, Volkswagen had no effective way to test the concept for viability. The team was particularly concerned about integrating such a system with the existing seaport-based distribution centers. The complexity and scope of the system made

static analysis of limited value. We identified simulation as a potentially effective means of testing the concept and various scenarios of implementation.

Problem Description

Vehicles for sale in the US are first shipped to one of the five US ports that act like distribution centers. These five ports have processing centers that conduct various handling and quality-control checks on all vehicles. They would then transport the vehicles to dealers using a combination of rail and truck. We focused on simulating the flow of vehicles from plants to dealers and assessing the impact of modifications to the existing structure. The basic idea was to establish more distribution centers close to metropolitan markets to test the hypotheses that they might effect two performance criteria, customer responsiveness and system cost,

—By increasing the chance of supplying customers' first-choice vehicles by combining dealer and distribution-center inventory;

—By delivering first-choice vehicles with shorter lead-times;

—By replacing part of the current expensive truck routes with cheaper rail routes; and

—By reducing the dealers' burden of carrying high inventory by pooling various popular vehicles at nearby distribution centers and thus reducing total system costs.

We sought to explore potential new locations for distribution centers and their opening sequence for opportunities leading towards system-level optimization of vehicle distribution.

System Description

The system consists of two cycles: (1) a customer-flow cycle that defines customer-service measures, and (2) a vehicle-flow cycle that defines distribution-cost measures.

In the customer-flow cycle, customers arrive at dealers and ask for vehicles with certain features, such as interior and exterior colors, automatic or manual transmission, and leather or fabric seat covers. If

Pilot dealers in midwestern metropolitan markets experienced enhanced service and reduced costs.

such a vehicle is available in inventory, it is a strong first-choice hit from the customer-service perspective. Otherwise, the dealer attempts to locate the desired vehicle by checking the distribution center inventory or by going to another dealer for a trade. Although the latter two actions incur extra costs, they still satisfy the customers' first choices. If the dealer cannot deliver first-choice vehicles, customers have three choices: (1) issuing a direct factory order for the first-choice vehicle, (2) agreeing to buy a second-choice vehicle, or (3) leaving the dealer. Consequently, we measure customer service using the following counts over a year:

- (1) First-choice hits at dealers, distribution centers, and through dealer trades;
- (2) Second-choice hits;
- (3) Direct factory orders; and
- (4) Lost customers.

The vehicle-flow cycle starts when dealers order vehicles from distribution centers to replenish their inventories. Distri-

bution centers, in turn, order from the plants to maintain their pool inventory. Currently, all vehicles shipped from a plant must go through a processing center before reaching a distribution center unless, like ports, the distribution center also has a processing center. Therefore, there may be one or two intermediate points on the route between plants and dealerships. The vehicle-distribution cost and transportation delays depend on the mode of transportation (highway, rail, or sea) and the mileage between the two points. For our purposes, we break the total distribution cost into three components:

- (1) The cost from plant to processing center;
- (2) The cost from processing center to distribution center; and
- (3) The cost from distribution center to market area.

In addition, we added inventory holding costs as finance charges to the total distribution cost at four levels: market inventory, distribution-center inventory, processing-center delay, and transportation delay.

Clearly, the number and locations of processing centers and distribution centers are major factors that affect both customer service and distribution costs. Moreover, VoA considered two types of facilities for installation at distribution-center locations. Type 1 facilities are smaller in capacity and cheaper. Type 2 facilities are larger, but the increase in operating expenses is nonlinear, so that they offer economies of scale.

Modeling Approach

We developed location scenarios (or policies) to specify the number and loca-

tion of distribution centers and processing centers as well as the set of market areas covered by each distribution center and the set of distribution centers covered by each processing center. Given a location scenario, realistic computation of the performance measures requires explicit consideration of the dynamic and stochastic elements in the system. Dynamic elements include the inventory-control policies (both quantity and mix) at dealers and distribution centers and demand seasonality over the year. Stochastic elements include customer demand, customer choice, and transportation delays. We used a simulation model to consider both elements.

The simulation model included the customer and vehicle cycles to calculate performance measures. We made several assumptions to keep the model size manageable. First, we consolidated the large number of dealers into 52 major demand areas. Then, we defined 50 products, each representing a family of vehicles with similar physical characteristics, such as color, transmission, and engine, as well as similar sales and inventory histories. Finally, we analyzed past sales data to calculate probability distributions for demand fluctuations within a year. VoA estimated the probabilities for alternative customer actions.

We identified 18 potential locations for distribution centers or processing centers in the US, including the current five ports. Initially, we ran simulations using a few alternative location scenarios that we generated based on intuition. We soon realized, however, that we needed a systematic way of generating location scenarios

because of the tremendous number of alternatives. To reduce the number of alternatives, we formulated a mixed integer program (MIP) that generates a reasonable number of good scenarios. The formulation is customized from the well-known fixed-charge problem [Taha 1992] (Appendix). The MIP minimizes a cost function that approximates the distribution cost of the actual system by ignoring the stochastic and dynamic aspects. The output of the MIP is a location policy (scenario).

The objective function consists of two components: (1) total transportation cost, which depends on the mileage between locations, modes of transportation, and

The learning from the simulation and pilot test has not been lost.

truck load factors; and (2) fixed facility installation costs and overhead costs at processing centers and distribution centers, which depend on the location and capacities. Truck load factors refer to the average number of vehicles that a truck carries in a typical shipment. A truck carries a maximum of 10 vehicles. Typically, truck load factors are proportional to the market demand. We used the load factors to determine the number of truck shipments to a major market. To simplify the calculation of the transportation cost, we assumed that each truck trip cost has a fixed component and a mileage-variable component. We ignored the inventory holding costs in the MIP.

We specified constraints to insure that

- (1) We satisfied market demands;
- (2) We did not violate capacity limitations

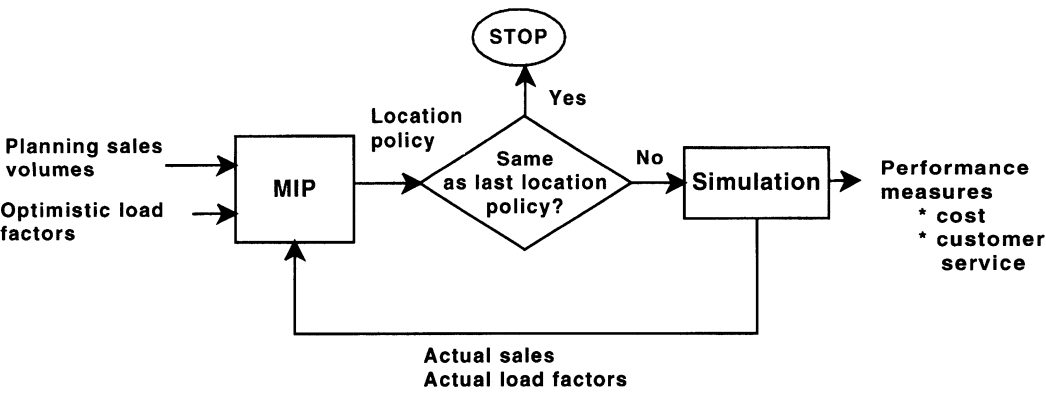


Figure 1: To reduce the number of alternative location scenarios to be evaluated, we used a mixed integer program (MIP) as a front end to the simulation. We developed a heuristic procedure that iterates between the MIP and simulation until both models agree on a particular location policy. We used text files and Excel macros to automate the communication between the MIP and simulation.

for facility types;
(3) We could ship vehicle orders within a specified time window; and
(4) We did not exceed the maximum number of distribution centers and processing centers to be installed.

Two major input parameters to the MIP are actual sales and truck load factors, which, in fact, are both functions of the location policy. To resolve this problem, we used a heuristic iterative procedure (Figure 1). We start solving the MIP by making optimistic assumptions such that sales in markets equal the planning sales volumes (based on demand forecasts), and all load factors are 10 (that is, fully-loaded trucks). We used the resulting location policy as input to the simulation model. Considering the dynamic and stochastic elements, the simulation run produced more accurate estimates of the sales and load factors as a result of implementing this particular location policy than what we assumed while solving the MIP. We used these more accurate estimates to update the input parameters of the MIP and

solved the MIP again. If the output location policy had changed, we ran the simulation using the new location policy as input. Otherwise, the most recent estimates were not different enough from the previous ones, and both the MIP and simulation agreed on a particular location policy. Although we could not guarantee convergence in general, this procedure resulted in fairly quick convergence in our computational experiments. Most of the time, we reached a final location policy between the MIP and the simulation in two to three iterations, and the total number of iterations never exceeded six.

Implementation

We implemented the simulation model using the PROMODEL software [PROMODEL Corporation 1995]. We coded the MIP using AMPL modeling language [Fourer, Gay, and Kernighan 1993] and used CPLEX as its solver. We made the two-way communication between the MIP and simulation software possible by creating text files from one software and importing these text files into a Microsoft Ex-

cel spreadsheet with a macro to create text files for the other software.

Scenario Analysis

We started modeling the current system with five distribution-and-processing centers as a benchmark for subsequent scenarios. We used simulation to generate all cost and customer-service measures. We also devised a best-case scenario with two ideal, possibly unrealistic, conditions that as many as all 18 distribution centers could be opened, and that the vehicles would not have to go through processing centers after they were imported. Iterative use of the MIP and simulation generated the measures for this ideal scenario, another benchmark. Then, we generated a number of interim scenarios that defined a path to follow from the current scenario to the ideal scenario.

First, we assumed that all vehicles have to go through processing centers, which is currently the case. We fixed the existing five distribution-and-processing centers in the model and set the parameter for the maximum number of distribution centers to six. This scenario yielded the distribution center that gave the highest benefit. We then increased the parameter for the maximum number of distribution centers allowed by one at a time, fixing only the existing five distribution centers each time. We continued until opening a new distribution center was no longer profitable, obtaining a curve that reflects diminishing returns as more distribution centers were opened (Figure 2). We then repeated this analysis under the assumption that vehicles did not have to go through processing centers but could be shipped directly to a distribution center, obtaining a similar

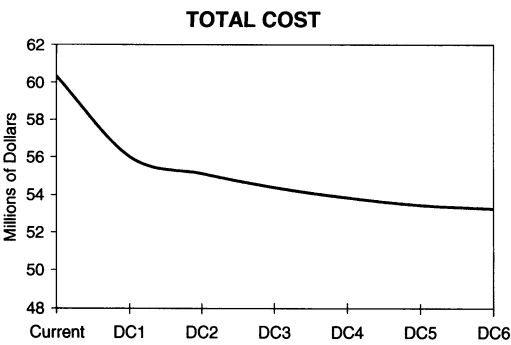


Figure 2: Our analysis of adding distribution centers to the current system scenario one at a time showed that adding more than six new distribution centers would not be profitable. Dollar figures are scaled arbitrarily for confidentiality reasons.

curve of diminishing returns. Finally, we investigated the effects of decreasing the number of processing centers and the effects of letting other distribution centers act as processing centers by simply imposing additional constraints in the MIP (Appendix).

In our computational experiments, we observed an interesting property. When we increased the parameter for the maximum number of distribution centers allowed by one to, say n , and solved the problem using the iterative heuristic procedure, the new optimal location policy always kept the optimal location policy of the previous scenario where this parameter was set to $n - 1$. In general, this property is not guaranteed, and it can be attributed to the specific data we used in our study.

Conclusions

The major findings of our quantitative analysis based on the optimization and simulation results included the following:—Since railroad transportation is cheaper than truck transportation, a cost-optimal

policy includes far more distribution centers than the current one. An optimal solution yields significant savings in estimated annual transportation-related costs.

—The requirement that all vehicles be routed through the existing processing centers reduces the potential savings by about 35 percent.

—The fixed costs of installing and operating pool facilities are insignificant compared to the savings in transportation costs.

By combining discrete optimization modeling and simulation, we evaluated modifications to the existing vehicle distribution system. The results suggest that, under conditions of 1995, certain modifications to the distribution structure might result in more customers receiving their first choice of vehicle configuration and simultaneously reduce total system costs.

Volkswagen opened a number of pilot distribution centers to test the implementation of these findings and realized varying degrees of success. Pilot dealers in midwestern metropolitan markets experienced enhanced service and reduced costs. Dealers in the southeast realized less benefit for two possible reasons. First, the southeastern dealers were in close proximity to the existing ports of entry. The pilot distribution centers represented some improvement over the existing ports in terms of delivery time and cost but less than that experienced in the midwest. Second, the pilot project represented a significant change in both distribution strategy and processes. The distribution-center strategy and the resulting reduction in dealer stock on the ground was not embraced univer-

sally by southeastern Volkswagen dealers. A number of larger dealers perceived the reduction in ground stock as a potential loss in competitive advantage over smaller dealers who typically were unable to carry large inventories. Process and information-technology start-up problems also made it difficult for some southeastern dealers to build confidence in the pilot test.

In 1997 and 1998, in the midst of the pilot distribution center program, Volkswagen introduced a number of new and next-generation models to the US market. These vehicles were very well received by the market and experienced high initial demand and low inventory availability. The low availability meant that most of the pilot distribution centers were unable to maintain the threshold level of stock to make them viable. In 1999, the pilot program was discontinued.

In summary, the optimization tools did highlight potential opportunities for enhanced supply-chain improvement by focusing on system-level, not local-level, optimization. We found evidence of these enhancements, in particular, in the midwestern metropolitan markets. Changes in the balance of supply and demand for new models ended the pilot test program. However, the learning from the simulation and pilot test has not been lost. Specifically Volkswagen managers recognize that supply-chain performance must ultimately be viewed from the system level, and using a cash-flow-based system can suboptimize total system profitability and customer-service levels. Finally, simulation and other tools can provide important insights into supply-chain system optimization.

APPENDIX: Mixed Integer Programming Formulation

Let

d_{jv} = annual demand for type v vehicles in market j ,

m_{ij} = mileage between distribution-center location i to market j ,

$c1_{sk}$ = cost of shipping a vehicle from source s to processing-center location k ,

$c2_{ki}$ = cost of shipping a vehicle from processing-center location k to distribution-center location i ,

L_j = load factor for market j ,

T_1 = fixed component for a truck's shipment cost (\$/truck),

T_2 = variable component for a truck's shipment cost (\$/truck/mile),

f_{it} = fixed annual-operating and real-estate cost of installing a type t facility in distribution-center location i ($t = 1$ for type 1 facility, $t = 2$ for type 2 facility),

g_k = fixed annual operating and real-estate cost of installing a facility in processing-center location k ,

C_i = annual shipment capacity of a type 1 facility at distribution-center location i ,

$x1_{skv}$ = annual shipment of type v vehicles from source s to processing-center location k ,

$x2_{kiv}$ = annual shipment of type v vehicles from processing-center location k to distribution-center location i ,

$x3_{ijv}$ = annual shipment of type v vehicles from distribution-center location i to market j ,

$y_{it} = \begin{cases} 1 & \text{if type } t \text{ facility is installed at distribution-center location } i, \\ 0 & \text{otherwise,} \end{cases}$

$z_k = \begin{cases} 1 & \text{if a processing center is installed at location } k, \\ 0 & \text{otherwise.} \end{cases}$

Minimize the total combined costs of transportation and fixed-facility installation, i.e.,

$$\begin{aligned} & \sum_i \sum_j \sum_v \left(\frac{x3_{ijv}}{L_j} \right) (T_1 + T_2 m_{ij}) \\ & + \sum_k \sum_i c2_{ki} \sum_v x2_{kiv} \\ & + \sum_s \sum_k c1_{sk} \sum_v x1_{skv} \\ & + \sum_i \sum_t f_{it} y_{it} + \sum_k g_k z_k \end{aligned}$$

subject to the following constraints:

—Demand at each market area for each vehicle type must be met.

$$\sum_i x3_{ijv} = d_{jv} \quad \forall j, v.$$

—Vehicle flows between plants to processing centers and between processing centers and distribution centers must be conserved.

$$\sum_k x2_{kiv} = \sum_j x3_{ijv} \quad \forall i, v,$$

$$\sum_s x1_{skv} = \sum_i x2_{kiv} \quad \forall k, v.$$

—Total vehicle flow to each distribution center must satisfy the minimum and maximum capacity requirements of the type of facility installed. Also, no shipment is allowed to a distribution-center location if no facility is installed there.

$$\begin{aligned} C_i y_{i2} & \leq \sum_j \sum_v x3_{ijv} \\ & \leq C_i y_{i1} + \left(\sum_j \sum_v d_{jv} \right) y_{i2} \quad \forall i. \end{aligned}$$

—Similarly, no shipment is allowed to a processing-center location if no facility is installed there.

$$\sum_i \sum_v x2_{kiv} \leq \left(\sum_j \sum_v d_{jv} \right) z_k \quad \forall k.$$

—Shipment quantities must be nonnegative: $x1_{skv}, x2_{kiv}, x3_{ijv} \geq 0$.

The following constraints are scenario dependent and enforced only if a specific scenario calls for them.

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—The distribution centers must be selected so that all market areas can be reached within r days. Suppose a truck travels on average 300 miles a day.

$$\sum_v x_{3ijv} = 0 \quad \left\{ (i, j) \mid \frac{m_{ij}}{300} > r \right\}.$$

—There may be at most Y distribution centers or Z processing centers or both to be selected.

$$\sum_i \sum_t y_{it} \leq Y, \quad \sum_k z_k \leq Z.$$

—Whenever a distribution-center facility is installed at a location, a processing center must also be installed at the same location,

$$z_i = \sum_t y_{it} \quad \forall i,$$

or a processing center cannot be installed at location i unless a distribution center is installed at location i .

$$z_i \leq \sum_t y_{it} \quad \forall i.$$

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