Supply Chain Optimization Tools Improve the Vehicle Distribution System at Volkswagen of America*

Nejat Karabakal  Production Modeling Corporation
Ali Gunal  Three Parklane Blvd., 910 West
Dearborn, MI 48126
Warren Ritchie  Volkswagen of America, Inc.
3800 Hamlin Road
Auburn Hills, MI 48326

ABSTRACT
In designing a tool to aid Volkswagen of America in its vehicle distribution system reengineering effort, it was necessary to compute performance measures in terms of both transportation cost and customer service that are functions of probabilistic and dynamic elements. These elements include inventory control policies, demand seasonality, customer demand, customer choice, and transportation delays. To consider all, a simulation approach appears appropriate, but the potential number of alternative designs that need to be evaluated is excessive. Discrete optimization models, on the other hand, help reduce the alternatives; however, it is difficult to incorporate those probabilistic and dynamic elements while keeping the model size manageable. With an innovative use of both types of models iteratively, we were able to solve the real problem that faced Volkswagen in analyzing vehicle distribution system alternatives.

Introduction
Volkswagen of America (VoA), a wholly owned subsidiary of Volkswagen AG, imports, markets and distributes Volkswagen and Audi vehicles in the United States. The vehicles are assembled in Mexico or Germany and distributed to a network of approximately 750 dealer sites across the United States. In 1995, VoA management appointed a project team with the mandate to review vehicle distribution process and develop new concepts to serve into the next century. This effort was part of an enterprise wide process of renewal that had begun in early 1994.

The existing vehicle distribution process had served the organization over a number of years but was in need of review in light of changes occurring in automotive retailing. The existing system had been developed around two implicit assumptions. The first is that the dealer (retail operator) is the "customer" of the VoA distribution process, not the end user. The logic was that Volkswagen of America distributes to the dealer and the dealer distributes to the end user. The second assumption was that, significant vehicle inventory (60-90 days of sales) carried by the dealer operator creates an incentive (financing cost avoidance) to increase the rate of sales. Thus the distribution system operated as a "push" system. Efficiency was the key performance criteria. Neither of these assumptions were unique to the VoA distribution system, in fact they reflect the dominant logic of vehicle distribution the U.S. auto industry.

The push system does have significant limitations. One is that not all customers are able to purchase their first choice configuration of vehicle color and optional equipment. Many manufacturers offer many more vehicle configurations than individual dealers are able to inventory (even carrying 60-90 days of sales). Dealers, who are interested in completing sales transactions as quickly as possible, generally offer customers the selection vehicles from their current inventory. If the current inventory does not contain the customer's first choice configuration the dealer may offer a price discount as an

* This is a working paper.
incentive for the customer to accept a non first choice vehicle. Although this process often does result in a consumer purchasing a vehicle, the transaction is inefficient. Both parties have compromised to accommodate an inventory shortfall. The end user has not received his first choice of vehicle and the dealer has unnecessarily discounted the price.

Another limitation of the push system are the high system (importer + dealer) costs of transportation, financing and storage. Vehicles are inventoried at point of sale, the most expensive location in the entire distribution chain. In short, the push system is only coincidentally responsive to customer choices and it maintains large inventories at point of sale.

The project team at VoA was searching for a means to deal with these limitations. As a design principle for the new distribution system, the project team had rejected both of the above mentioned assumptions. The new system had to serve the end user's requirements as its key performance measure. In doing so, the new system would be designed to support a "pull" type of distribution strategy. The new system would have to be, first and foremost, responsive to end user choices and simultaneously more efficient than the current system. From these new principles the following performance criteria were established that the reengineered process would have to meet;

1. Maximize the percentage of customers who received their first choice of vehicles.
2. If a customer's first choice was not in a dealer's inventory, a first choice vehicle would be delivered to the dealer from VoA inventory within 48 hours.
3. Significantly reduce the total system (dealers and VoA) costs associated with transportation, financing and storage. Primarily through inventory reduction.

The project team developed a number of logistics concepts that alternatively managed where inventory might be aggregated and how it might be transported. However, they did not have an effective means of testing the concepts. The complexity and scope of the system made static analysis of limited value. Simulation was identified as a potentially effective means of testing the concept and various scenarios of implementation.

Problem Description

Vehicles for sale in the U.S. are first shipped to one of the five U.S. ports that act like distribution centers. These five ports also have facilities, called processing centers, which all vehicles go through for various handling and quality control checks. They are then shipped to the dealers at major market areas by a combination of rail and truck transportation.

We focused on improving the flow of vehicles from plants to dealers in terms of cost and customer service. The basic idea was the establishment of more distribution centers closer to metro markets so that the following benefits could be realized:

- the chance of meeting a customer's first choice vehicle increases with a combined dealer and distribution center inventory,
- first choice vehicles are delivered with shorter lead times,
- part of the current expensive truck routes could be replaced by cheaper rail routes, and
- the burden of carrying high inventory for multiple dealers is reduced through pooling various popular vehicles at a single nearby distribution center,

The main issues that need to be addressed were the determination of new distribution center locations, and an opening sequence so that the greatest benefits could be realized earlier.
System Description

A convenient way to describe the system is to introduce two cycles: 1) customer flow cycle that defines customer service measures, and 2) vehicle flow cycle that defines distribution cost measures.

Customers come to dealers, which were strategically aggregated into 52 major markets, with a certain vehicle choice in mind. If that vehicle is available at the dealer inventory, it is counted as a strong first choice hit. If not, the dealer attempts to satisfy the customer's choice from a distribution centers inventory. If it is not there, another dealer nearby is asked for a trade. Although the latter two options incur extra costs, they still satisfy the customer's first choice. If none of these options works, the customer, with certain probabilities, a) issues a direct factory order for the first choice vehicle, b) considers a second choice, or c) just leaves the dealership. Consequently, we measure the 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. Factory orders.
4. Lost customers.

Vehicle flow cycle starts when dealers issue vehicle orders from distribution centers to replenish their inventories. Distribution 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 except for the possibility that the distribution center also has a processing center. Therefore, there may be up to two transshipment visits 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. plant to processing center cost
2. processing center to distribution center cost
3. distribution center to market area cost

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

Clearly, the number and locations of processing centers and distribution centers are major factors that affect both customer service and distribution cost measures. Moreover, there is choice for the type of facility to be installed at each distribution center location. Type I facilities are smaller in capacity and cheaper. Type II facilities are larger, but the increase in operating expenses is nonlinear and allows us to consider economies of scale in locating distribution centers in certain high-demand areas.

Modeling Approach

Let a location scenario (or policy) specify the number and location 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 felt that a simulation model was appropriate for the consideration of both elements.
We developed a simulation model, and implemented the customer and vehicle cycles to calculate performance measures. We also identified a list of 18 potential distribution center and/or processing center locations in the U.S., including the current five ports, and generated a few location scenarios "by eye" as input to simulation. It became quickly apparent, however, that a systematic way of generating location scenarios was needed because of the tremendous number of alternatives.

In an attempt 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 (e.g., see Taha 1992) and its details are described in 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 depend on the mileage between locations, modes of transportation, and truck load factors (explained below) and 2) fixed facility installation 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 ten 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. Inventory holding costs are ignored in the MIR.

Constraints are specified to assure that

a) market demands are satisfied,

b) capacity limitations for facility types are not violated,

c) market orders can be shipped within a specified time window, and

d) maximum number of distribution centers and processing centers to install are not exceeded.

Two major input parameters to the MIP are market demands and truck load factors, which, in fact, are both functions of the location policy. To resolve this problem, we used a heuristic iterative procedure that is depicted in Figure 1. We start with solving the MIP by making optimistic assumptions such that 1) all market demands equal the planning sales volumes, and 2) all load factors are ten (i.e., full-load trucks). The resulting location policy is given as input to the simulation model. Considering the dynamic and stochastic elements, the simulation run produces better estimates of the sales and load factors as a result of implementing this particular location policy. Now, we give these better estimates back to the MIP, and solve it. If the output location policy is changed, we proceed with running the simulation using the new location policy as input. Otherwise, the most recent estimates are not different enough than the previous ones, and both the MIP and simulation agrees on a particular location policy. Although there is no guarantee of convergence, this procedure proved satisfactory in our experiments.

**Implementation**

We implemented the simulation model using PROMODEL software (PROMODEL Corporation 1995). The MIP was coded using AMPL modeling language (Fourer, Gay, and Kernighan 1993) with CPLEX as its solver. Two way communications between the MIP and simulation software was made possible by creating text files from one software, and importing these text files into a Microsoft Excel spreadsheet with a macro to create text files for the other software. This process is depicted in Figure 2.
Figure 1: The procedure iterates between the Mixed Integer Program (MIP) and simulation until both models agree on a particular location policy.

Figure 2: Implementation of the iterative procedure in Figure 1. Communication between the Mixed Integer Program (MIP) and simulation are facilitated by the use of text files and Excel macros.
Scenario Analysis

We started with modeling the current system with five distribution and processing centers to be used as a benchmark for subsequent scenarios. We used simulation to generate all cost and customer service measures. Second, we made two assumptions to generate ideal, possibly unrealistic, conditions: 1) as many as all 18 distribution centers could be opened, and 2) the vehicles do not need to go through processing centers after they are imported. Iterative use of the MIP and simulation generated the measures for this ideal scenario, another benchmark. Next, we generated a number of interim scenarios that defined a path to go from the current scenario to the ideal scenario, as discussed below.

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 gives the highest benefit. We then increased the parameter for the maximum number of distribution centers one at a time, until opening a new distribution center is no longer profitable, and obtained the curve shown in Figure 3. As one would expect, this curve reflects diminishing returns as more distribution centers are opened. We then repeated the above analysis under the condition that vehicles do not have to go through processing centers, but can be directly shipped to the distribution center, and produced a curve similar to that in Figure 3. Finally, we investigated the effects of decreasing the number of processing centers as well as the effects of letting other distribution centers act like processing centers by simply imposing additional constraints in the MIP (see Appendix for details).

![Total Cost Graph](image)

*Figure 3: Total cost graph of an analysis that adds a distribution center to the current system scenario one at a time. Adding more than six new distribution centers was not profitable.*

*Dollar figures are scaled arbitrarily for confidentiality reasons.*
Conclusions

Major findings of our quantitative analysis based on the optimization and simulation results included the following:

- Since railroad transportation is cheaper than trucks, a cost-optimal policy includes far more distribution centers than the current one. An optimal solution estimates over $20 million annual savings in transportation related costs.
- Distance to existing processing centers adds about $6 million per year to an optimal solution.
- Fixed costs of installing and operating pool facilities are insignificant as compared to savings in transportation costs.

The simulation outcomes demonstrated that a decentralized distribution center concept could achieve the new performance criteria. This concept was complemented with other revised distribution subsystems (forecasting, ordering, invoicing, etc.) and recommended by the project team for implementation. The recommendation was approved by VoA management and the implementation phase began in mid 1996. By the end of 1997 approximately one half of the distribution centers are anticipated to be operational.

References


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)
- \( f_i \) fixed annual operating and real estate cost of installing a Type \( t \) facility in distribution center location \( i \)
- \( g_k \) fixed annual operating and real estate cost of installing a facility in processing center location \( k \)
- \( C_i \) annual shipment capacity of a Type I facility at distribution center location \( i \)
- \( x1_{skv} \) annual shipment of type \( v \) vehicles from source \( s \) to processing center location \( k \)
- \( x2_{ki} \) annual shipment of type \( v \) vehicles from processing center location \( k \) to distribution center location \( i \)
\[ x_{3_{ij}} = \text{annual shipment of type } v \text{ vehicles from distribution center location } i \text{ to market } j \]
\[ y_{it} = \begin{cases} 
1 & \text{if a Type } t \text{ facility is installed at DC location } i \\
0 & \text{otherwise} 
\end{cases} \]
\[ z_k = \begin{cases} 
1 & \text{if a FPC is installed at location } k \\
0 & \text{otherwise} 
\end{cases} \]

Minimize the total combined costs of transportation and fixed facility installation, i.e.,
\[ \sum_{i} \sum_{j} z_k \left( \frac{x_{3_{ij}}}{\bar{L}} \right) \left( T_i + T_j m_q \right) + \sum_{k} \sum_{i} c_{2_{ki}} x_{2_{ki}} + \sum_{k} \sum_{i} c_{1_{ai}} x_{1_{ai}} + \sum_{i} f_{y_i} y_{i_n} + \sum_{k} g_{k} z_k \]
subject to the following constraints:

- Demand at each market area for each vehicle type must be met.
  \[ \sum_{i} x_{3_{ij}} = d_{ij}, \quad \forall j, v \]

- Vehicle flows between plants to processing centers and between processing centers and distribution centers must be conserved.
  \[ \sum_{k} x_{2_{ki}} = \sum_{i} x_{3_{ij}}, \quad \forall i, v \]
  \[ \sum_{i} x_{1_{ai}} = \sum_{i} x_{2_{ij}}, \quad \forall k, v \]

- 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.
  \[ C_i y_{i2} \leq \sum_{i} \sum_{v} x_{3_{ij}} \leq C_i y_{i1} = \left( \sum_{i} \sum_{v} d_{ij} \right) y_{i2}, \quad \forall i \]

- Similarly, no shipment is allowed to a processing center location if no facility is installed there.
  \[ \sum_{v} x_{2_{ki}} \leq \left( \sum_{i} \sum_{v} d_{ij} \right) y_{i2}, \quad \forall k \]

- Shipment quantities must be nonnegative: \( x_{1_{ai}}, x_{2_{ki}}, x_{3_{ij}} \geq 0 \)

The following constraints are scenario dependent, and enforced only a specific scenario calls for it:

- The distribution centers must be selected so that all market areas can be reached within \( r \) days. Suppose a truck travels, on the average, 300 miles a day.
  \[ \sum_{i} x_{3_{ij}} = 0 \quad \left\{ (i, j) \left| \frac{m_q}{300} > r \right. \right\} \]

- There may be at most \( Y \) distribution centers and/or \( Z \) processing centers to be selected.
  \[ \sum_{i} y_{i} \leq Y \]
\[ \sum z_k \leq Z \]

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

\[ z_i = \sum_j y_{ij} \quad \forall i \]

or, a processing center cannot be installed at location \( i \) unless a distribution center is installed at location \( i \).

\[ z_i \leq \sum_j y_{ij} \quad \forall i \]