Blending OR/MS, Judgment, and GIS: Restructuring P&G's Supply Chain

JEFFREY D. CAMM — Department of Quantitative Analysis and Operations Management, University of Cincinnati, Cincinnati, Ohio 45221-0130

THOMAS E. CHORMAN — The Procter & Gamble Company, Cincinnati, Ohio 45224

FRANZ A. DILL — The Procter & Gamble Company, Cincinnati, Ohio 45224

JAMES R. EVANS — Department of Quantitative Analysis and Operations Management, University of Cincinnati

DENNIS J. SWEENEY — Department of Quantitative Analysis and Operations Management, University of Cincinnati

GLENN W. WEGRYN — The Procter & Gamble Company, 2 Procter & Gamble Plaza, PNC-12, Cincinnati, Ohio 45201-5559

In 1993, Procter & Gamble (P&G) began an effort entitled strengthening global effectiveness (SGE) to streamline work processes, drive out nonvalue-added costs, and eliminate duplication. A principal component of SGE was the North American product supply study, designed to reexamine and reengineer P&G's product-sourcing and distribution system for its North American operations. The methodology developed to solve this problem drew on OR/MS and information technology, merging integer programming, network optimization models, and a geographical information system (GIS). As a result of this study, P&G is reducing the number of North American plants by almost 20 percent, saving over $200 million in pretax costs per year and renewing its focus on OR/MS approaches.

Procter & Gamble (P&G) makes and markets over 300 brands of consumer goods (Table 1) worldwide in over 140 countries and has operating units (plants, divisions, facilities) in 58 locations around the world. The company is the worldwide market leader in seven categories: laundry detergents, diapers, feminine protection pads, shampoos, facial moisturizers, acne teen skin care products, and fabric soften-

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INDUSTRIES—PHARMACEUTICAL
DECISION ANALYSIS—APPLICATIONS

—Acne Care: Clearasil, Noxzema
—Analgesics: Aleve, Percogesic
—Baby Diapers: Luvs, Pampers
—Baking Mixes: Duncan Hines
—Bar Soaps: Camay, Coast, Ivory, Oil of Olay, Safeguard, Zest
—Beverages: Folgers, Millstone Coffee
—Bleach & Prewash Additives: Biz, Tide
—Cosmetics: Cover Girl, Max Factor
—Deodorants/Anti-Perspirants: Old Spice, Secret, Sure
—Dish Care: Cascade, Dawn, Ivory Dish, Joy
—Fabric Conditioners: Bounce, Downy
—Feminine Protection: Always
—Fragrances: Giorgio, Hugo Boss, Laura Biagiotti-Roma, Old Spice, Red, Venezia, Wings
—Gastrointestinal: Metamucil, Pepto-Bismol
—Hair Care Product Lines: Head & Shoulders, Ivory, Pantene, Pert Plus, Prell, Vidal Sassoon
—Hard Surface Cleaners: Comet, Mr. Clean, Lestoil, Spic and Span
—Incontinence: Attends
—Juice: Hawaiian Punch, Sunny Delight
—Laundry: Bold, Cheer, Dash, Dreft, Era, Gain, Ivory Snow, Oxydol, Tide
—Oral Care: Crest, Crest Complete, Fixodent, Gleem, Scope
—Tissue/Towel: Banner, Bounty (Towel), Charmin, Puffs, Royale (Tissue and Towel), Summit 1100's
—Peanut Butter: Jif
—Prescription Drugs & Physician-Selected Products
—Commercial Services
—Global Oleochemicals Group

Table 1: P&G North America product groups and brands.

ers. P&G had worldwide sales of $33.5 billion in fiscal year 1995 and earnings of $2.64 billion.

The company has grown continuously over the past 159 years. To maintain and accelerate that growth, P&G recently undertook a major restructuring called SGE (strengthening global effectiveness) to streamline work processes, drive out non-value-added costs, eliminate duplication, *and rationalize manufacturing* and distribution. This program was major in terms of cost, impact, and savings—P&G wrote off over $1 billion of assets and transition costs. The program affected over 6,000 people, and it saved $200 million annually before tax. It involved hundreds of suppliers, over 50 product lines, 60 plants, 10 distribution centers, and hundreds of customer zones. In fact, when we asked the Booz Allen-Hamilton consultants if anyone had developed a model appropriate for this complex study, they said they didn't know of anyone with the possible exception of the US military.

A major component of the SGE initiative was a fundamental reexamination of P&G's North American product supply chain (which comprises the United States, Canada, and Mexico) with an emphasis on plant consolidation. Prior to the study, the North American supply chain consisted of hundreds of suppliers, over 50 product categories, over 60 plants, 15 distribution centers (DCs), and over 1,000 customers. As it has moved to global brands and common formulas and packages wherever possible, P&G has realized economies of scale and needs fewer operations. It needed to consolidate plants to reduce manufacturing expense and working capital, to improve speed to market, and to help it to avoid capital investment (fewer production-line conversions because of new reformulations). In addition, P&G's ongoing efforts to deliver better consumer value by eliminating nonvalue-added costs required it to develop more efficient linkages with trade customers, reducing the inventory customers manage, and eliminating the least productive sizes.

Five factors led P&G to believe that it could save money by restructuring the supply chain. First, since our last internal study of this type in the early 1980s, deregulation of the trucking industry had lowered transportation costs; products can be shipped more cheaply than before. Second, a trend toward product compaction (for example, detergents in concentrated form, compact packaging of diapers) allowed P&G to ship more product per truckload. Because of these transportation economies, P&G saw reducing the number of plants and DCs and thus eliminating overhead as an attractive possibility. Third, P&G's focus on total quality in recent years had led to higher levels of reliability and increased throughput at every plant. This also meant that P&G might need fewer plants. Fourth, the decrease in product life cycles from three to five years a few decades ago to approximately 18 to 24 months today required plants to change equipment more frequently. Fewer plants would be more cost-effective. Finally, because of several corporate acquisitions, P&G had excess capacity; consolidation would lower product costs.

P&G had worldwide sales of $33.5 billion in 1995.

For these reasons, P&G executives decided to focus on product sourcing, that is, choosing the best location and scale of operation for making each product. The scope of production at any particular site is limited to products that rely on similar technologies. Producing too many products at a site increases the complexity of operations. However, operating large, single-product plants also exposes the firm to risk. In addition, because plant locations affect the costs of supplying raw materials and distributing finished products, P&G could not make product sourcing decisions without considering the design of the distribution system. These issues defined the scope of the study.

Project Planning and Organization

P&G executives assigned responsibility for developing product sourcing options to 30 major product-strategy teams. These multifunctional teams were aligned with P&G's major business categories and consisted of individuals from various functions, such as finance, manufacturing, distribution, purchasing, R&D, and plant operations. They were organized around product category groups that shared similar technology and could therefore be produced at the same manufacturing site. Management also formed a separate distribution and customer service team charged with developing options for DC locations, assigning customers to DCs, and making transportation decisions.

P&G recognized that it needed sound analytical support for a project of this nature. There were potentially millions of feasible options to consider, whereas the product-strategy teams could study only a select few hundred scenarios in depth. The choices of which options to study further had to be well justified. The teams would spend months collecting and analyzing data to generate a detailed risk-adjusted cash flow. A second and more important reason for sound analysis was the potential impact of the project on people. Any decision to close a plant had to be objective and based on sound business logic. Without this kind of grounding, leadership credibility would be jeopardized and the trust necessary for a high quality transition would be eroded.

P&G had developed a close relationship with the University of Cincinnati, particularly between the company's OR/MS personnel and the quantitative analysis and operations management faculty, and it asked them for assistance in this project. P&G considered the use of external consultants important for analytical support and objective input to the decision-making process.

The primary analytic strategy team included three managers from P&G and three members of the University of Cincinnati's

Fewer plants would be more cost-effective.

Center for Productivity Improvement (the authors). Our objective was to develop a decision support system for the product-strategy and distribution teams to use to find the best options to consider for more detailed analysis.

A number of organizational and problem-specific factors influenced how we approached the task. One important factor was the way in which P&G executives had structured the strategic study. Its formation of 30 product-strategy teams and a separate distribution team was consistent with P&G's brand-management philosophy. Because each product-strategy team was familiar with its product category, it could ensure that we considered all reasonable options concerning technology, scale of operation, and plant location. This structure suggested a natural decomposition approach in which the distribution team could rationalize DC choices based on its knowledge of the consolidations being considered by each of the product-strategy teams. Once the product-strategy teams had completed their consolidation plans, the distribution team analyzed changes needed in the DC network to support the complete consolidation plans across all product groups.

We recognized, however, that by using this approach we might suboptimize across product categories. We could address the issue of suboptimization with a comprehensive logistics optimization model [Arntzen et al. 1995; Geoffrion and Graves 1974; Geoffrion and Powers 1995]. Many comprehensive OR/MS models for managing supply chains and designing distribution systems incorporate complex models and take a long time to develop (often several years) [Arntzen et al. 1995; Geoffrion and Graves 1974]. The SGE initiative was under a rigorous and tight time schedule. The project took about one year in total. It took about three months to develop the software required. We developed software incrementally, adding new features as the teams required them. When we started the modeling project in early 1993, the teams had already begun collecting data, and we needed to have the system available when they were ready to evaluate options. It was virtually impossible to develop a comprehensive, global model that would optimize over all aspects of the supply chain. Even if we could have done so, such a model would have been inconsistent with the alternative-generation approach the product-strategy teams used.

Thus, our objectives were

(1) To provide models and decision support for the product-strategy teams,

(2) To provide support to a team of experts in transportation and distribution who were concentrating on warehousing, distribution, and customer allocation problems, and

(3) To ensure that the composition of a complete-supply-chain solution across product-strategy and distribution teams was the best possible.

Modeling Approaches

At the beginning of the project, P&G had in place a comprehensive logistics optimization model to support its sourcing decisions for multiple product categories and multiple echelons. It had used this tool successfully for several years, but it had certain shortcomings. A mainframe-based tool, it required long turnaround times for each model run. Though a graphical interface had been developed for the system, it still required the long cycle of problem setup, submit, wait, solve, (fix a problem, resubmit, wait, solve) and finally, report the solution. The system reported the solutions on a map but did not provide interactive linkages that would permit it to quickly resolve a problem based on the outcome of a previous run. Nor did it allow interactive "drilling down" on data to determine why the model made a particular sourcing decision. Clearly, it was not the appropriate tool for the product-strategy teams; they needed quick turnaround and high interactivity to meet the project's deadline.

We needed a simple interactive tool that would allow product-strategy teams to quickly evaluate options (choices of plant locations and capacities), make revisions, evaluate the new options, and so on. If possible, we wanted a system that would guide users to better options in an evolutionary fashion. A quote attributed to Albert Einstein sums up our approach eloquently: "Things should be made as simple as possible but no simpler."

Our modeling strategy was to decompose the overall supply-chain problem into two easily solved subproblems: a distribution-location problem and a product-sourcing problem (one for each product category). We did this for several reasons. First, management's organization of the strategic-planning process into a distribution team and product-category teams implied a natural decomposition across echelons of the supply chain and across product categories. Second and more important, we found that manufacturing and raw-material costs dominated distribution costs by a very large margin, suggesting that product-sourcing decisions were not highly sensitive to the downstream distribution-system design. Third, direct plant-to-customer shipments accounted for the large majority of plant shipments, suggesting that sourcing decisions were more sensitive to customer locations than to DC locations.

Thus, it was reasonable to assume that for each customer zone, the proportion of demand satisfied by direct shipments as well as the proportion satisfied by shipments through the customer's DC could be treated as a constant for each product category. We viewed this proportion as primarily dependent on product characteristics and shipment quantities (for example, less-than-truckload versus full-truckload shipments); thus, we did not see it as significantly affecting the product-sourcing decisions. The product categories were formed in such a fashion that very little interdependence across categories existed.

We also assumed that the DC locations could be chosen independently of the plant locations. We justified this approach based on the relatively small volume (10 to 20 percent) shipped through DCs, the small number of DCs (five to eight) needed to support that volume, and the fact that manufacturing costs dwarfed distribution costs. Since distribution costs were not the major factor in locating the DCs, our primary concern was to ensure good customer service. We could separate the DC decision then from the plant-sourcing decision, and therefore, we decided to select locations for DCs first and treat them as fixed when developing the product-sourcing options.

Distribution Center Location Model

Top management imposed no constraints; our only real restriction in the entire supply-chain study was customer-demand locations (although strategic choices were limited because of the lack of data for any arbitrary location). We aggregated trade-customer demand into 150 customer zones; this gave us enough granularity to establish the correct location of five to 12 facilities (plants and DCs) in the supply chain. The major considerations influencing the choice of DC locations were customer location, customer services, and sole sourcing. We had to locate the DCs close enough to customer zones to maintain current levels of customer service.

We used an ordinary uncapacitated facility-location model to find optimal DC locations and to assign customers to DCs. For a fixed number of DCs, the model finds optimal locations, while ensuring that each customer zone is assigned to a single DC. The objective, discussed in more detail below, is to minimize the cost of all DC-customer zone assignments. We describe the mathematical model in the appendix.

In developing the cost coefficients for the model, we first determined the proportion of each customer's demand that was satisfied by direct shipments from the plants and the proportion that was shipped through a DC. We then took the cost of supplying a customer zone through a specific DC as the sum across all products of the DC costs (each DC would handle all products) plus transportation costs from the DC to the customer. The cost of supply to a customer zone includes both the inbound cost to the distribution center and a handling cost per case at the DC.

The cost factors we considered were material handling costs, inventory costs, transportation costs, duties associated with border crossings, and so forth. We did not model fixed costs for the DCs explicitly, because much of the company's warehouse space was rented and, compared to the costs of a plant and transportation, the fixed costs for a DC were less significant. Indeed, P&G ships much of its volume in full truckloads directly from the plants to the customer. Therefore, we decided how many DCs were needed subjectively by trading off the reduction in transportation cost and improvements in customer service provided by another warehouse against the increases in inventory costs and nonexplicitly modeled costs (fixed costs and organizational infrastructure) of another warehouse.

We considered 17 possible locations for DCs, either existing locations or logical alternatives selected by company distribution experts on the basis of prior studies and analyses. We considered alternatives having a minimum of five to a maximum of 13 DCs for the 123 customer zones. This required models of the order of 2,000 variables and 2,200 constraints. As discussed in the appendix, we had to flag only 17 of the variables explicitly as binary.

In addition to generating an optimal solution, we also generated a family of near optimal solutions (for example, the 10 best configurations of five DCs) for each alternative using cuts to the unit hypercube as described by Balas and Jeroslow [1972]. We discuss the procedure in more detail in the appendix. We placed the families of solutions in a database that could be accessed by the product-sourcing model.

Because we chose the DC locations independently of the plant locations, the near-optimal solutions helped us to minimize the potential for suboptimizing when we coupled the product-sourcing options with the DC choices. The near-optimal solutions provided alternatives for coupling (composing) the product-sourcing options with downstream echelons of the supply chain. The risk of obtaining a poor overall solution is minimized if the product-sourcing option is optimal over a variety of near optimal solutions for the DC locations.

The Product Sourcing Model

We solved the second subproblem in the overall optimization effort using the product-sourcing model (PSM). Because of the decomposition used, this model is a simple transportation model for each product category (summarized in the appendix). The product-strategy teams specify the plant location and capacity options to be evaluated, so that for purposes of a computer run with the model, plant locations and capacities and their related costs are given. In the product-sourcing model, we treated each DC as just another customer with demand equal to the total demand assigned to that DC in the solution to the uncapacitated facility-location model. The demand for each "real" customer zone is the amount of demand by product category satisfied by direct shipments from plants.

In the transportation model, the arc costs are the sum of manufacturing, warehousing at the plant, and transportation costs. We found that manufacturing costs were the most important consideration in the product-sourcing decision, so we took great care in developing good estimates. We formed a team to develop a precise methodology to construct the costs based on its dozen or so components, including key raw materials, the technology employed, the scale of operation, and labor rates in the area. We needed only one to three key raw-material costs for each product.

Warehousing (DC) costs were composed of actual per-unit storage and handling costs at each of the company's existing DCs. We estimated the costs for new DC locations from these base costs, adjusting them for known differences in local storage and labor costs.

We employed two methods to estimate transportation cost. One was to use, where possible, actual negotiated rates the company was already paying for shipments between locations coupled with rates obtained from rate tables. For some runs, where reliable rates were not available, we used a simple model to generate the cost to ship between two points: a fixed cost plus a linear function of distance. We approximated actual road distance from an algorithm P&G had previously developed. We validated the transportation costs of the model by comparing its costs to the costs of the existing distribution system. This validation indicated that the model was accurate.

We solved the transportation models using an out-of-kilter algorithm [Bazaraa, Jarvis, and Sherali 1990], primarily because the computer code was readily available.

The success of the project has led to a renaissance of OR/MS at P&G.

Again, this was important because of the tight time schedule for the project. While more efficient algorithms exist for this problem, the out-of-kilter algorithm worked well for the size problems we were solving with PSM. It allowed the strategy teams to evaluate options in real time.

We integrated the product-sourcing model with a geographic information system (GIS) to provide a powerful and flexible decision support system for the product-strategy teams. We chose the GIS system Mapinfo because we could readily customize its user interface using the MAPBASIC programming language. A GIS uses a map to display and manipulate data. GIS systems are typically used to produce complex maps based on static data. We used a GIS to display and manipulate the results of a sourcing optimization. With this customization, the user could alter dozens of different aspects of the supply system with only a few keystrokes and then quickly compare the cost of the option to others under consideration.

The architecture of the system consists of a MapBasic program that uses Mapinfo to display the associated map. Behind the scenes is a C program that performs the actual optimization. Data is passed to and from the optimization using files. The entire system runs on a typically configured laptop running Windows 3.1. A typical optimization takes a few seconds.

The entire user interface of the system consists of a map of North America (Figure 1). The user chooses product type, potential plant locations, transportation mode, cost modes, and so forth, and tells the system to optimize the scenario. The system then displays the result of the optimization by drawing colored lines on the map to display the optimal sourcing solution (Figure 2). A window showing the data in tabular form also appears. A separate file is created for later reference.

The visual system with graphical interface is an ideal workbench for analyzing distribution scenarios. All users find it easy to understand, from distribution analysts to managers. It also allows users to query various aspects of the problem by simply pointing at the plant, distribution lane, or location and clicking. The system is object oriented and each object contains a list of its features, for example a distribution lane will contain its cost per mile, transportation mode, and assumed mileage.

The use of a GIS as the medium for user

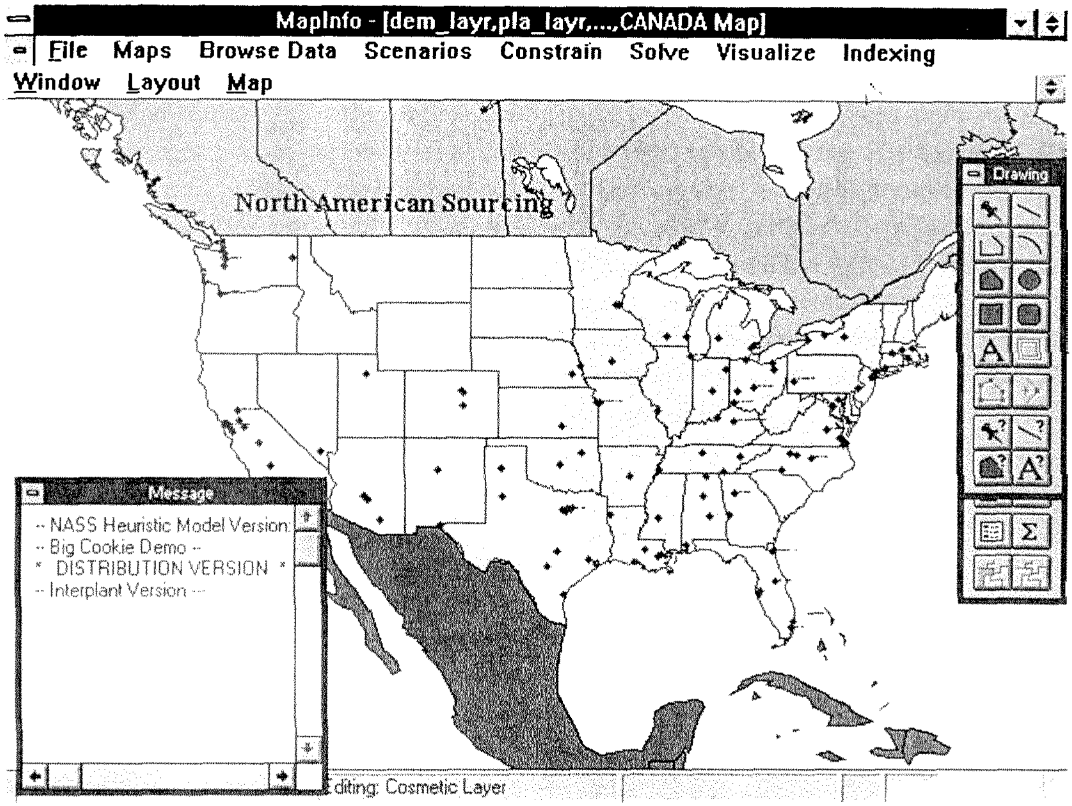

Figure 1: The GIS interface for the sourcing model.

interaction greatly facilitated user (the product-strategy teams) acceptance of the analytical techniques. The solution algorithm was totally transparent to the users. All they saw were maps on a computer screen emphasizing the spatial relationships among plants, DCs, and customers that are so important in problems of this type. This spatial visualization was very popular with the product-strategy teams. It helped them better understand the relationships among manufacturing costs, capacity, and the distribution-system design. Often insights provided by the spatial visualization led to new and better options. The model provided a laboratory in which the product-strategy teams could test ideas and develop insights.

Integrating a GSI into the models developed had a surprising byproduct: the spatial visualization it provided highlighted database errors that might otherwise have gone undetected. The arcs connecting each DC chosen with the customers it served made visible assignments that did not immediately make sense (such as, a customer in the Atlantic Ocean). When this happened, a check of the database usually turned up an error.

The optimal and near-optimal locations provided by the DC model were inputs to the product-sourcing model. The product-

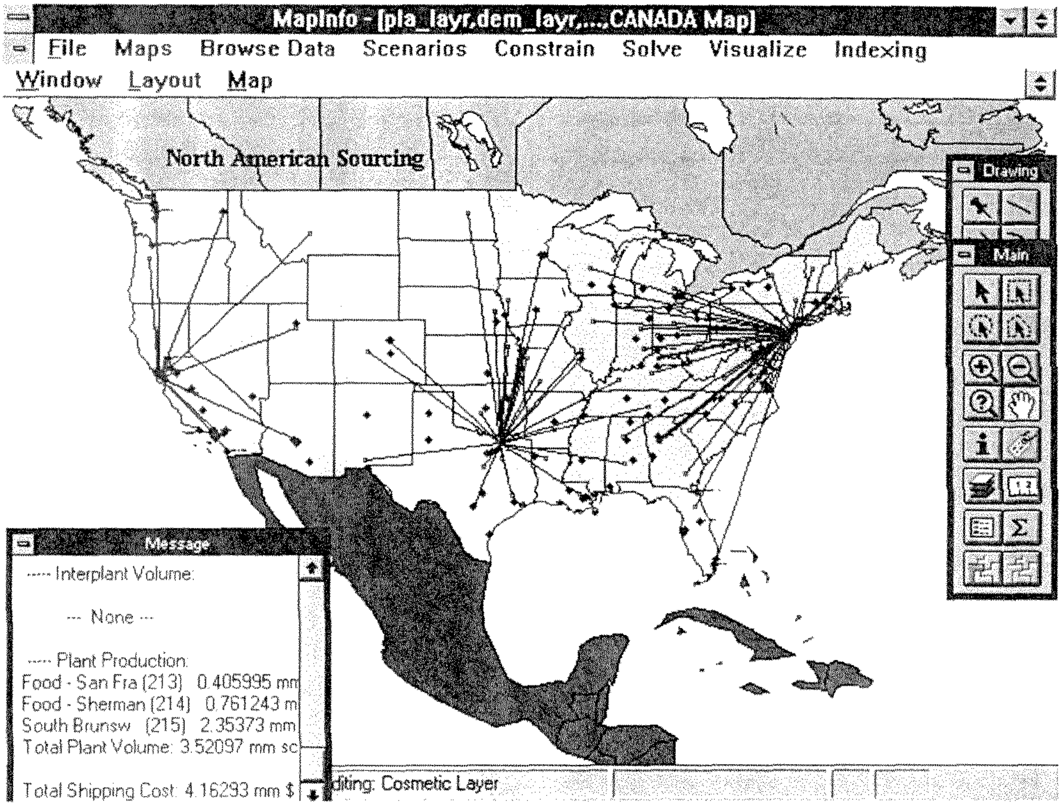

Figure 2: The sourcing model with solution displayed. Black lines indicate direct shipments to customers, red lines indicate shipments to RDCs, and blue lines indicate interplant shipments.

strategy teams then chose the potential plant locations, capacities, and manufacturing costs that were consistent with all the work they had done in evaluating technology and other factors affecting the product category. Once they chose these parameters, the product-sourcing model, installed on a laptop computer found the optimal manufacturing-and-distribution plan. After reviewing the output, the product-strategy teams would select new options, re-solve the model, and continue until they were satisfied with the options.

The product-sourcing model permitted rapid evaluation of many alternatives. The product-strategy teams conducted over 1,000 sessions to evaluate alternatives. The model could, in a matter of minutes, provide ballpark estimates for an alternative. A good ballpark estimate of the accuracy of the model is plus or minus 10 percent. Most of the inaccuracy of the model derived from the fact that it relied on forecast demand and costs. Also, in some geographical areas, where we have inadequate shipping experience, we had to use estimated transportation costs. When we verified the model using current data and current sourcing approaches, the results were plus or minus two percent. It should be remembered that most of the data in the model is meant to represent the year 2000 and is

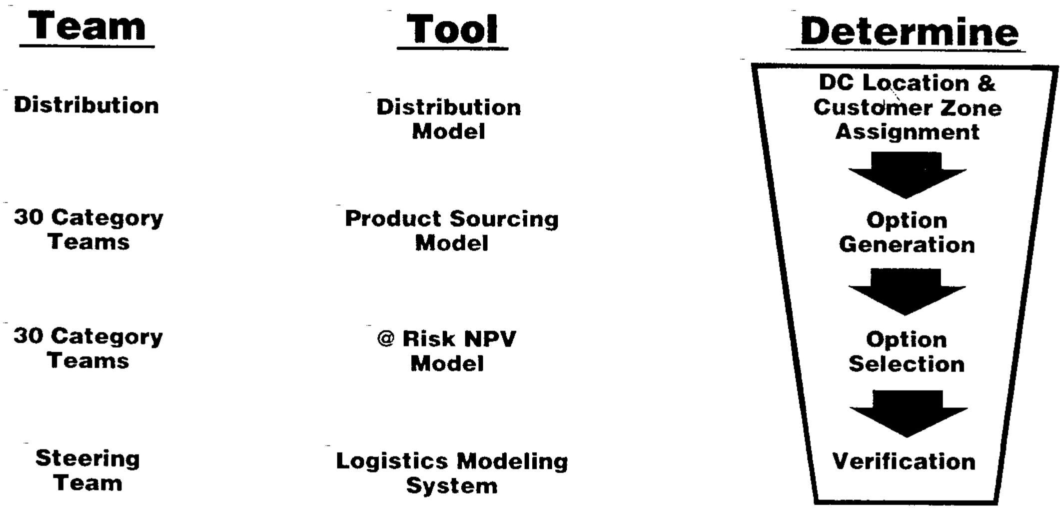

Figure 3: Sourcing model system architecture.

thus only as good as the forecast used.

The teams could use the estimates to bracket various alternatives. In all cases, they understood that the model could not provide the exact cost of an alternative, but rather a relative cost with regard to other options. In addition, the model could evaluate off-the-wall alternatives, like having only one plant, or having a plant in each region. Once they had established promising alternatives, the teams focused on collecting the data they needed to select an optimal long-term solution based on risk-adjusted net-present-value analysis.

This modeling tool can be viewed as a way to effectively link optimization methods, which are good for determining quantifiable best solutions, with human decision-making processes, which are good for understanding and integrating nonquantifiable issues. This approach differs from the usual applications of OR models, where analysts construct a model, solve it, and then present the results to management. In this case, the model was an integral part of the decision process, with the speed and accuracy needed to support the decision at hand. In the course of evaluating options, we discovered that the best product-sourcing options were indeed independent of DC locations. Manufacturing costs were the primary consideration; the magnitude and variability of manufacturing costs tended to dominate transportation costs in choices of product-sourcing options. In other words, given the near optimal solutions available, we typically found that one product-sourcing solution was optimal across all of the choices for DC locations.

Solution Composition and Verification

Figure 3 shows how we integrated and organized the models. The first two rows highlight the roles of the distribution and product sourcing models that we have described. Using the models, each category team developed a number of potential sourcing options, varying from as few as two to as many as 12. In generating these options, the teams generated and evaluated many more scenarios, rejecting some. During this process, they included many subjective considerations, such as the minimum number of plants to consider, which DCs to consider, and whether to use cross-border sourcing.

They used the product-sourcing model to find the top options for each product category and then subjected these options to a more thorough financial and risk analysis. The financial analysis took into account such costs as taxes, interest rates, labor rates, and utilities over a number of years into the future. The risk analysis considered the possibility of earth quakes, hurricanes, and so forth. Finally, political considerations played a role in some of the site selections.

The major insight we gained from this effort is that a hybrid approach is needed to solve difficult problems of this type, an approach that closely links expert human judgment and mathematical optimization. We found that the GIS was an ideal way to present the data to the group of experts, while the optimization supported their work by providing ideal solutions to selected subproblems. We do not feel that the solution could have been as good or as well supported by management if we had used a single large optimization model.

We employed a verification step to ensure that the solutions provided by the product-strategy and distribution teams together formed an overall optimal solution. Using the plant locations picked by the product-strategy teams as fixed, we ran a mixed-integer linear programming application (Insight's SAILS) to optimize the rest of the supply chain: to choose locations for distribution centers and to optimize the product flows throughout the three-echelon system. The solution it produced and its value did not differ significantly from that obtained using the decision support system. Management, therefore, concluded that our approach was valid.

We took a final step to establish the economic boundaries of the supply-chain restructuring. P&G commissioned a clean sheet study to determine the ideal locations for P&G plants and distribution centers without regard for the locations of existing facilities. The operating cost of this ideal solution provided a lower bound on the annual operating costs of the P&G supply chain (ignoring the transition costs of closing existing plants and opening new plants). We used the operating cost of the supply chain in existence before this restructuring as an upper bound. P&G was then able to assess how much progress it had made toward the ideal.

The total cost of the solution the product-strategy teams recommended was actually lower than the cost of the ideal solution when we included the capital costs it would require. Based on a financial analysis using net present values, we found that we could not justify the extra costs of closing and opening facilities to get to the ideal solution based on operating costs.

Project Benefits

We completed the study in 1994. By mid-1996, the recommendations P&G had implemented had resulted in its closing 12 sites and writing off over a billion dollars worth of assets and people-transition costs. This redesign of P&G's North American manufacturing-and-distribution system is saving well over $250 million (before tax) per year. Most of these savings come from lower manufacturing expenses, which result from P&G's operating fewer plants with less staff and making the supply chain more efficient. It has also resulted in savings in packing materials and ingredients, but as expected with fewer sites, delivery expenses have increased. Because P&G had to establish a reserve to implement the changes, the Securities and Exchange Commission closely monitored and verified the savings.

It is difficult to measure the portion of the savings directly attributable to OR/MS. Even without using models of any kind, P&G would have closed plants and improved its North American operations. Internally, we credited OR/MS with contributing 10 percent of the total savings.

Beyond the monetary impact of this study was its impact on people. P&G implemented these changes with the utmost concern for its employees. Six thousand people were affected by the changes to the product-supply system. One third of those affected retired early, a third were relocated to other P&G facilities, and the remaining third were retrained and placed with other companies. P&G treated these people fairly and with the respect and dignity that they deserved. At a recent shareholders meeting, an employee commented that, although he wasn't happy that his plant closed, he thought that it was done with respect for the employees and as well as could be expected in a tough situation.

The task of selecting which plants and distribution centers to close was difficult. Although, one might ask, Were these site closings low hanging fruit, and if so why didn't P&G close them earlier? Some of the site closings were obvious, but no operating category would be motivated to close a site and take a large profit hit for doing so. P&G also had no way of knowing for sure the effect each particular closing would have on the total system without coordinating all the recommendations.

This project was a unique opportunity for operations research and management science at Procter & Gamble. This study clearly demonstrated that OR/MS practitioners could model a very complex system and through data visualization help users and managers to understand the key changes P&G needed to make to improve the system. This study enabled P&G management to decide with certainty which plants and distribution centers to close. General management was impressed with the decision support system's ability to model complex sourcing-and-distribution scenarios and produce visual output that was easy to understand. The system provided an interactive laboratory in which P&G could test sensitivity of currency exchange rates, plant productivity, and cost.

The success of the project has led to a renaissance of OR/MS at P&G. The company now requires that all future sourcing decisions be based on analytic methods of this type. P&G has used the model to conduct competitive analyses. Tools similar to this model have gained widespread acceptance, with demand for their use in domestic, regional, and global sourcing studies. Since the study, the company has made a commitment to allocate resources to new technologies in management science. It has established a new Center for Expertise in Analytics for solving business problems within P&G.

Conclusion

The OR/MS models we used were simple but creative. The nature of the planning process and the resulting subproblems created the potential for suboptimization. We built ties between the models so that the composition of an overall solution would not cause significant suboptimization. The most complex mathematical models used were a simple transportation model and an uncapacitated facility-location problem. By aggregating products sharing the same technology, parameterizing across the proportion of demand going through DCs and over near-optimal solutions to the DC location problem helped us to guard against designing an overall suboptimal supply chain. The innovative synergy of OR/MS and GIS led to a very high level of acceptance by the product strategy teams and consequently to very usable decision support for P&G management. GIS coupled with OR techniques for decision support is still in its infancy, but it surely has great potential in logistical planning, routing, marketing applications, and location analysis.

Of course a project of this scope must involve many people. In this case, over 500 P&G employees worked together to complete the supply-chain restructuring for the company. It has been said before and it is still true–models do not make difficult decisions, managers do. In the face of time constraints and an overwhelming number of alternatives, OR models can be of great help.

APPENDIX: Mathematical Models
The Uncapacitated Facility Location Model (UFL):
Minimize

$$\sum_{i\in I}\sum_{j\in J} C_{ij}X_{ij}, \tag{1}$$

subject to

$$\sum_{i\in I} X_{ij} = 1 \quad j \in J, \tag{2}$$

$$X_{ij} \le Y_i \quad i \in I, j \in J, \tag{3}$$

$$\sum_{i\in I} Y_i = k, \tag{4}$$

$$X_{ij}, Y_i \in \{0, 1\} \quad i \in I, j \in J. \tag{5}$$

Decision Variables

X_{ij} = 1 if customer zone j is assigned to DC i, 0 if not, and
Y_i = 1if DC i is chosen, 0 if not.

Data

C_{ij} = total relevant cost of satisfying customer zone j demand from DC i,
k = number of DC's allowed,
I = index set of DC's, and
J = index set of customer zones.

Objective (1) minimizes the cost of assigning customer zones to DCs. Constraint set (2) ensures that each customer zone is assigned to exactly one DC. Constraint set (3) implies that customer zone j cannot be assigned to DC i unless DC i is chosen. Constraint (4) limits the number of DCs opened. Constraint set (5) requires that the decision variables all be binary in accordance with the above definition. We note that for fixed binary values of Y_i, the X_{ij} variables will automatically be binary because the resulting constraint matrix is totally unimodular. We therefore, branch first on the Y_i variables avoiding the need to declare the X_{ij} variables as binary. We solved the models on a 486 33 Mhz computer using LINDO with the DOS extender.

Generating Near Optimal Solutions

We use the following cuts to generate the N best solutions: Let $O_1 = \{i \mid Y_i^* = 1\}$ in the optimal solution to the UFL. We find a second best solution by adding the following constraint and resolving UFL:

$$\sum_{i \in O_1} Y_i \leq k - 1$$

The third best solution is found by adding another constraint of this type to the problem solved to find the second best solution, and so on. In general, we may find the N^{th} best solution by defining $O_{N-1} = \{i \mid Y_i^* = 1\}$ in the $N - 1^{st}$ best solution and adding the following to the model solved for the $N - 1^{st}$ best solution:

$$\sum_{i \in O_{N-1}} Y_i \leq k - 1.$$

The Transportation Model for a Product Category

Minimize

$$\sum_{p \in P} \sum_{k \in R \cup Z} C_{pk} S_{pk}, \tag{6}$$

subject to

$$\sum_{k \in R \cup Z} S_{pk} \leq Cap_p \quad p \in P, \tag{7}$$

$$\sum_{p \in P} S_{pk} = Dem_k \quad k \in R \cup Z, \tag{8}$$

$$S_{pk} \geq 0 \quad p \in P, k \in R \cup Z. \tag{9}$$

Decision Variables

S_{pk} = amount of demand at location k to satisfy from plant p.

Data

C_{pk} = per unit cost of satisfying customer zone k (or DC k) from plant p,
P = index set of plants,
R = index set of DCs chosen by UFL,
Z = index set of customer zones,
Cap_p = capacity at plant p (in units of production), and
Dem_k = demand at customer zone k (or DC k).

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