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OPERATIONS RESEARCH AT ARTHUR D. LITTLE, INC.: THE EARLY YEARS

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THE BEGINNING

One afternoon in the fall of 1949, I was sitting at my desk in the Manville, New Jersey, building products plant of the Johns Manville Corporation, where I worked as a financial analyst studying the financial and business aspects of various manufacturing operations at the plant, when the phone rang. It was a person named Harry B. Wissman calling from Arthur D. Little, Inc., in Cambridge, Massachusetts. Despite having spent nearly two years across the river at the Harvard Business School, I had never heard of Arthur D. Little. Harry Wissman asked me to meet him for dinner to learn about a new activity Arthur D. Little was about to launch and to discuss a possible mutual interest in coming to work in it. Harry Wissman had come across my resume at the Harvard Business School and thought I might fit in usefully as a junior staff member.

Several members of the Arthur D. Little staff had taken leave for government service during World War II and some had worked in, or had become acquainted with, the military operations research groups. They felt there might be a role for a counterpart activity at Little, as an element of its young and growing management consulting practice. (Until shortly before WWII, Arthur D. Little, Inc. was primarily a technical contract research, development, and engineering firm, although its technical skills were being drawn on increasingly to advise governments, investors, and business firms on the economic development and business implications of new technology.) They convinced Raymond Stevens, a senior officer of Arthur D. Little, to support an experiment to test the possibilities of operations research in industry. He, in turn, asked Harry Wissman, as part of his work, to take on the task of building an operations research activity, and persuaded Theodore Houser, the top merchandising officer of Sears, Roebuck & Co., for whom Little had done some superb technical work, to become a client to test the new activity.

I met with some of the Little staff, read a recently declassified Navy publication, which Harry Wissman lent me, *Methods of Operations Research* by Philip Morse and George Kimball, and spent a day in Cambridge being interviewed by Mr. Stevens and others. At the end of the day I

was offered a job, with the assurance that they would keep me at least a year even if the experiment failed. I accepted, as the first full-time member of the Operations Research Group at Arthur D. Little, Inc. I eventually retired from the company forty-eight years later; the commitment of the company to keep me "at least a year" having been met.

THE SEARS PROJECT

Sears, Roebuck in the decades after WWII was the major company in what was then known as the "mail order" business; it was also building a large and growing retail chain. The mail order business was built on a customer list of about ten million names. Sears distributed two large and very expensive catalogs each year, spring and fall, to this customer list, along with other specialty, holiday, and sale books. The large catalogs, for which Sears was famous, were too expensive to mail to all ten million names; about five million of each were mailed at the beginning of each spring and fall season. The question was: Which names on the customer list should get the catalog in order to maximize revenue? Catalog costs were high enough that a small loss in the efficiency of catalog distribution would seriously affect mail order profits.

The essential information Sears had about a customer, besides name and location, was the customer's past ordering history. Each order was recorded on a customer record card as it was received and the customer record was maintained in a "customer index." When it was time to mail a new catalog edition, clerks who managed the index would study each card, one by one, and following a simple set of rules related to the number, size, and timing of the customer's orders, would decide whether to produce a mailing label for sending a catalog to that customer. A Sears staff department had studied the selection rules for decades, including the operation of test customer indices made up of all the customers in certain cities and towns in selected parts of the country. The amount of test analyses and data that had been accumulated was enormous. Mr. Houser, thinking that this function had been the most thoroughly and analytically studied in the company, posed the improvement of the catalog mailing rules as the test case for the infant Arthur D. Little operations research activity.

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The customer records for customers in the test towns were maintained on punched cards. We were able to get copies for analysis of several thousand of the records spanning a few years. The question we studied was how did these customers behave as revealed by their purchasing records. We sought to find out in what way the past records might be predictive of future activity.

We were able to discover some regularities in the data. For example, it turned out to be far more important how frequently a customer ordered than the size of his order. Also, George Kimball, who at the time was working with us as a consultant, surmised that there should be some orderly pattern of decay in the value of the order information over time, and the most sensible form of decay would be exponential. We were able to demonstrate by analysis of the data at hand that this indeed was the case; this implied how the structure of the selection rules should be set up. We were able to characterize the form of the distribution of customer ordering rates in the customer population, which was the key customer characteristic, and demonstrate that the receipt of one of the main catalogs effectively doubled the observed order rate for the season. With these and other observations gleaned from the data, we were able to design a new set of rules for selection of customers to receive catalogs that promised a modest improvement over the existing system that had been refined over several years. Although the gain was modest, it represented millions in added revenue each year at no additional advertising cost.

The proposed new system was tested in a large field test, simple in concept but effective. A large sample of customers was chosen at random from the customer file. Both the new and the old selection rules were applied to each customer; the result was the grouping of customers into four groups:

| | | Existing Rules | |
|-----------|----------|-------------------------------------|-------------------------------------|
| | | Selected | Rejected |
| New Rules | Selected | A: selected by both | B: selected by new, rejected by old |
| | Rejected | C: selected by old, rejected by new | D: rejected by both |

Most customers were selected or rejected by both systems (Groups A and D). The difference between the two systems would be demonstrated in the comparison of the two blocks of customers (B and C) classified differently between the two systems. The customers in these two blocks were divided at random for treatment (i.e., to receive a catalog or not), under the old rules or the new. Sales from the two groups were tallied over a period of several months; it became clearly evident that the customers in B were substantially superior in response to receiving a catalog than those in C. Thus, the new rules were overall superior to the traditional ones in generating revenue.

The knowledge about the customer population and the confidence built by the initial success led to a long-term relationship that lasted essentially as long as Sears remained in the catalog business. In another study, for example, it was shown that the behavior of the customer population over time could be characterized as a Markov process with the transition probabilities of the individual customer affected by the receipt of catalogs or not. This led to a very different view of the function of the catalogs, as an investment in customer maintenance rather than short-term sales promotion, and as a consequence, a more aggressive catalog program. Other major investigations included the issue of the effect of catalog distribution around retail stores on sales in the stores themselves, and promotional strategies to exploit unused logistics capacity during off-peak business periods.

The success of the Sears program was built significantly on a focus on investigating data and carefully designed and analyzed field experiments, rather than preconceived "models." At one point in the work, a colleague, Jerome Herniter, and I submitted a paper to the *Journal of the Operations Research Society*, describing the customer population model's construction and its use; it was rejected on the grounds of "being too pragmatic." I think that was the last time I tried to submit a manuscript to the *Journal*.

THE PEOPLE IN THE OPERATIONS RESEARCH GROUP

Harry Wissman assembled an interesting group of professionals, including veterans of the military activity together with freshly minted PhDs from the physical sciences. Philip Morse and George Wadsworth, both from MIT, served as active consultants. George Kimball moved in the early 1950s from his position in the Columbia chemistry department to the Little staff. John Lathrop, Sherman Kingsbury, and Arthur Brown came from the Navy OEG, followed later by Martin Ernst and David Boodman. The younger group included physicists like Frank Allen, Harry Wolf, and Jerome Herniter, and others such as chemical engineers like Richard Heitman. Charles McGee, an electrical engineer, joined the group after a tour teaching in India. James Hetrick and Norman Dreibeck joined the group from the petroleum industry. It was some time before the group began to recruit the products of formal operation research programs; Joel Jensen was one of the first, outstanding examples of a staff member with formal academic OR training. Over the course of its first decade under Harry Wissman's leadership, the group grew to over forty professional staff with additional support staff, and spawned a variety of activities within the company in such areas as engineering computation, statistics, and information technology.

On a historical note, our early experimental data analysis was done using punched card equipment or by hand, using batteries of Marchant calculators. Internally programmed computers were just on the horizon. Our first was a Datatron that was programmed in binary code. It was a different world.

WORK IN LOGISTICS

Over the course of the 1950s, work in logistics grew to be an important component of the group's activity.

The first project was undertaken for the Baby Products Division of Johnson & Johnson in 1951. The division produced a variety of products like baby oil, shampoo, and talcum powder, made on highly automated mixing and packaging lines in a plant operated by a skilled work force. Each line's hourly capacity was fixed by the highly automated nature of its facilities. Workers could be shifted among packaging lines and could work overtime, at premium rates. The normal work crew was not sufficient to operate all production lines at once, and adding temporary new workers to the skilled force was very expensive. The difficulties posed by these constraints on production, in the face of a highly seasonal demand, were exacerbated by a longstanding policy of closing the plant for vacation in the middle of the peak in sales. As a result, the plant had to build substantial inventories ahead of the peak demand while making judicious use of overtime. The issues: what products, when, and how much? We were asked to help. George Kimball was in charge of the project and I worked on it with him.

George Kimball's first request to me was to go to the library to find out what was in the literature concerning production control or inventory management. There was not much. There was some early work from Bell Labs concerning economic manufacturing order quantities and Thomas Whitin had recently published a book, based on his Ph.D. thesis, on the same topic. Otherwise, the literature consisted of advice and descriptions related to clerical systems, record keeping, and other procedural matters.

My function on the project was primarily to create a description of the plant and its operations and to collect data on product demand, costs, plant flexibility, and constraints. George Kimball considered various ways we could organize this information analytically to find an improved approach to scheduling the plant.

One day George sat down with me to discuss his latest idea, based on a concept he called "linear programming." (This was well before the publication of the Rand conference proceedings edited by George Dantzig, which I believe was the first generally available publication on linear programming.) I recall his use of the example of producing a can of mixed nuts at lowest cost, subject to constraints on the mix, to illustrate the concept. I made the mistake of asking if there was someplace else where I could learn more; he referred me to a monograph by Herman Weyl in the *Princeton Annals of Mathematics* concerning the mathematics of multidimensional linear spaces. It was heavy reading, but contained the basic optimization theorem underlying linear programming.

Based on the use of the linear programming "transportation" model, it was straightforward to develop a simple procedure to assign production time during the year to build up needed seasonal inventory to meet peak demand while minimizing inventory investment and carrying cost.

Other projects related to inventory management and production scheduling and control followed. Two important ones from the perspective of learning were the development of a production assignment procedure for the American Thread Company, whose production facility was operated essentially as a job shop, and for the Lamp Division of the General Electric Company, in the management of finished product stocks at the plant and in the field, later extended to production planning and scheduling. These three cases, including the J&J seasonal planning project, permitted the group to get a full perspective on the role of inventories in the management of the supply-production-distribution system.

Inventories had traditionally been viewed in business as a "necessary evil," required to operate but to be kept to a minimum possible. The group was able to change this point of view, to articulate a theory for the management of inventory as a useful economic asset, to be managed for the optimal performance of the logistical system. The early results of this work were published, first, in a series of articles in the *Harvard Business Review* (Magee 1956) and later as a book, *Production Planning and Inventory Control* (Magee 1958), published in several languages.

One component of an efficient inventory management system was an effective forecasting procedure to permit the system to adapt to the uncertainty of demand within the lead time for supply. A forecasting technique based on a statistical projection would be convenient, but as early computers came on the scene, the technique had to be economical in the use of memory and simple to compute, given the typically large number of items being controlled. The answer was another application of the Kimball principle of information decay, to formulate the statistical forecasting (projection) technique as an exponential formula; in its simplest form:

$$\text{Forecast}(\text{period } 2) = A(\text{actual, period } 1) \\ + (1 - A)(\text{forecast, period } 1).$$

Exponential forecasting, as this general technique came to be known, turned out to be a very useful tool in applications, and was the subject of another book, *Statistical Forecasting for Inventory Control* by Robert G. Brown.

A wide variety of production and distribution projects were undertaken over the ensuing years, including plant allocation and location studies. The group was able to draw on and organize the lessons learned, and methods developed, from these projects to build a coherent view of industrial logistics. It remained always necessary, however, to look at the real facts in each case to understand the nature of the issues in question.

For example, in the case of a large multi-plant manufacturer of newsprint, the home office staff used an elaborate linear-programming model to assign sales to the various plants for fulfillment in order to reduce "trim loss," the amount of newsprint lost to scrap when a reel of production from a paper machine was cut into rolls for shipment to

customers. Each customer, typically a newspaper, required its own width of roll; effectively fitting these onto a reel to minimize loss in cutting was a major determinant in the efficiency of the plant. The home office staff took each month's expected sales by roll size, and assigned these to sets to make up reels of the lengths available in the various plants. The staff gave credit to the linear program model for the fact that the firm had one of the lowest trim-loss rates in the industry. The company also asserted it operated from production machine straight to shipping, with no finished inventory since everything was made to order. Investigation revealed that life at the plants was very different, and much more chaotic, than described in the home office. Orders were constantly subject to cancellation or change; shipping instructions changed daily as ships arrived early or railcars were not available as expected. There was, in fact, a small inventory of finished rolls in the shipping area of each plant that had accumulated from past order changes. Each evening before going home, the shipping room superintendent at each plant set out the next 24-hour schedule for cutting rolls from reels to be produced, taking into account the materials on hand, last-minute shipping instructions, and expected reel production. Investigation indicated the superintendents made up their cutting instructions essentially without regard to the sets recommended from headquarters. The outstanding trim-loss record of the company was much more due to the ingenuity of the shipping room superintendents in making use of available production and the flexibility provided by the small actual inventory available to them than to the elaborate model run under idealized assumptions quite different from reality.

One lesson taught by the more experienced staff and learned by all was: It was much more useful to search for simple methods to interpret real facts than to fit the facts to preconceived elaborate models.

OTHER EXAMPLES OF WORK UNDERTAKEN

The group undertook a wide variety of investigations for clients of Arthur D. Little, Inc. Many of the most interesting of these involved a multidisciplinary team from several parts of Little's professional staff. It was not unusual, for example, for such a team to undertake the investigation of a troubled manufacturing facility. Some members of the team might examine the quality of the technology or physical plant while others studied quality control processes, and still others looked into management methods including logistics issues. The multidisciplinary approach was often particularly powerful when parts of the operation interacted to exacerbate the difficulties. It was not uncommon, for example, for scheduling practices to create serious difficulties for the manufacturing processes, and at the same time, for the unreliability of manufacturing output to create scheduling emergencies, resulting in the need for expediting and similar crisis actions. In other cases, we found that a plant would be managed and scheduled as if it were a job shop operation, basically a facility that had

no established flow of product through operations. In most cases, in fact, there is a basic direction of flow from raw materials and purchased components through manufacturing and assembly. When a process flow can be established and exploited, manufacturing management can be strengthened, scheduling simplified, and lead times and in-process inventories significantly reduced.

In another example of teamwork, the operations research and electronics groups worked together to help American Airlines reach a decision to install a radically new approach to reservations using an integrated system employing advanced information technology, later known as the SABRE System. The basic technology proposed by IBM was drawn from the DEW Line defense system; it was novel and untested in commercial applications, including the one planned. The investment involved would be enormous and the impact on the airline would be profound. (No one at the time imagined the ultimate power of the system in marketing.) The team was able to assure the American Airlines management that the system was technically feasible and reliable. As designed, however, it was extremely costly and economically hard to justify, but the team demonstrated that the modification of a key very expensive component from single-server to multiplex mode was both technically feasible and would bring the investment into economic range. The analysis made use of queuing theory to demonstrate how redesigning the part of the system in question to operate in a multiplex mode would create delays that would be below any noticeable threshold. As a result and with the team's continuing assistance, the SABRE system was successfully installed as an operational and economic success.

Other work was done in sales and marketing, on such issues as the effects of advertising and promotion on sales and market penetration or the effective role and use of time of a sales force. This work always meant the analysis of field data on customers and sales, and almost always required the design and execution of field experiments, a difficult and time-consuming task. In one case, for example, the group studied the deployment and effectiveness of the sales force of a transportation company. At the time, the sales force members were assigned territories, and their typical day was spent patrolling the shipping docks of potential customers looking for shipments on which they might bid. Preliminary investigation with successful salesmen and with transportation managers of potential customers suggested the hypothesis that salesmen would be more effective if they spent less time chasing shipments and used their time to become personally acquainted with transportation managers and their interests. An experiment was set up to test the effect of having some of the salesmen use their time differently for a period of several months. The results supported the hypothesis, leading to a major shift in the training program for salesmen.

This work in marketing was another illustration of the group's focus on studying real data and designing field experiments to test hypotheses.

ARTHUR D. LITTLE, INC. AND THE OPERATIONS RESEARCH SOCIETY OF AMERICA

ORSA was born at Arden House, the old Harriman estate on the Hudson owned by Columbia University; it was possibly conceived, and certainly later incubated until it gained strength, at the offices of the Arthur D. Little Operations Research Group. Consultants Philip Morse and George Kimball (later full-time staff) were prime movers behind the effort to form the Society. John Lathrop served as secretary of the organizing committee and later as the Society's first Secretary. The company subsidized the work of organization and later provided the early home for the Society's administrative activities. Harry Wissman, Arthur Brown, John Lathrop, and I joined Morse and Kimball at the Arden House meeting and were founding members of the Society.

During the first several years of the Society, staff members from Arthur D. Little served the Society in a variety of capacities, including four of the twenty presidents in the Society's first two decades.

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