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Cybernetics and Agriculture¹

By Harry C. Trelogan

THE GREATEST BOON from cybernetics² has been the stimulus given to man to formulate new concepts of how things are done and can be done--new views of the interrelationships of parts to a whole system. The new concepts lead to new ideas for conceiving of, and arranging, communications and control among the parts, between a central control and the parts, between external stimuli and central control, and between external stimuli and particular parts.³ Cybernation opens opportunities for exploration of unconventional approaches to the achievement of given objectives, whether they be greater output, less costly operation, reduction of fatigue, speedier production, or combinations of these toward a primary objective judged as paramount, say the output of a new product or increased profitability.

Agriculture, bound with many long-established customs, is vulnerable to new approaches. In the not very distant past, farming was believed to be governed largely by nature. Farmers, work as hard as they might, simply had to work within the constraints of natural elements such as seasons, climates, weather, topographies, ecologies of undomesticated plants (weeds) and animals (insects) that were subject to little, if

any, effective control. Also, in numerous instances, there was little advance communication or notification of what was going to occur (farmers' almanacs excepted, of course), despite intense interest in the factor concerned ("everybody talked about the weather, but nobody did anything about it"). Uncertainty, risk and other impediments induced by lack of control were accepted as facts of life the farmers had to adjust to--not adjust.

The late John Brewster probed into the implications for farming at length in his philosophical-economical way. He noted how mechanized factories brought production into controlled environments to permit output expansion of tremendous proportions. Why not farming? His first explanation of why even partially mechanized farms could not do so focused on the spatial requirements of farming. A farmer as an overseer had severe limitations on his ability to supervise many workers. Even with the horse and later the truck he was unable to exercise close enough observation, communication, and control to expand his operations much without serious loss of efficiency.

In view of this circumstance, it was clearly advantageous to have small farms, individually owned to instill the incentives for industry and care to maximize output. Each farmer reaped the fruits of his own industry and initiative. This fitted in well with the attitudinal, philosophical, and value concepts of the American Dream incorporating the Enterprise Creed, the Democratic Beliefs and the Work Ethics that Brewster explained so well in his writings.⁴

¹ Extracted from a talk presented at Cornell University's Conference on Impact of Mechanization, Automation, and Cybernation on Modern Agriculture, Ithaca, N.Y., December 11, 1967.

² Norbert Wiener. *Cybernetics*. The MIT Press, Cambridge, Mass., 2d ed., 1961. (Webster's New International Dictionary defines cybernetics as the "comparative study of the control system formed by the nervous system and brain and mechano-electrical communication systems, such as computing machines.")

³ Leonard C. Silvern. *Systems Analysis and Synthesis in Training and Education*. Automated Education Handbook, Automated Education Center, Detroit, 1966.

⁴ John M. Brewster. Technological advance and the future of the family farm. *Jour. Farm Econ.*, Vol. 40, No. 5, Dec. 1958.

Later Brewster⁵ put greater emphasis on another circumstance limiting the ability of farming to adapt to the factory system. That was the requisite sequential nature of the productive functions dictated by the seasonality of weather. This requirement circumscribed the opportunity for farm laborers to specialize in the performance of specific functions. Since farm production had to be spread out over time, it was not possible to perform successive production steps simultaneously so that crews of specialized workers could work continuously on specific tasks and maximize the use of their skills, as was done within the confines of a factory where their work could be synchronized to contribute most efficiently to the production of an end product. Instead, each farmer had to organize his productive resources so that he would have sufficient labor to perform one job after the other as each season progressed. The necessary communications and controls were lodged, for the most part, in the farmer himself as the manager of all operations throughout all seasons. His management skill reflected his ability to move from one function to the other from beginning to end of the production process at minimum cost.

Advances in mechanization adapted to farming enabled the farmer to extend his labor resource with the use of more capital. At first this development used animal power and later the greater power of steam engines and automotive equipment. But the problems of communications and control remained essentially the same and limited the farmers' managerial power because of the greater dependence upon personal observation and decision-making.

In general, farming has taken some advantage of the innovations coming out of each of the eras cited by Wiener in the gradual evolution of power developments. (He referred to the 18th century as the age of the clock, the 19th century as the age of steam, and the present age as that of servo mechanisms.) Except for the era

of animal power, the adaptation of new power sources to farming has been tardy and less complete compared with commercial and industrial enterprises. The relative tardiness is particularly notable with respect to electronic power applied to communications and servo mechanisms in relatively small and continuous increments. Tremendously impressive and very frightening potentials for farm application remain for exploitation.

New Concepts Related to Farming

The impressive aspects pertain to the impact electronic power may have on men's concepts of farm production. Bringing cybernation to bear on the communication and control limitations of farm operations creates the potential for overcoming some of the space and time handicaps that Brewster saw so clearly. The great dependence upon relevant observations and judgments previously made by individual farm managers may now be replaced with precise measurements made by technicians that can be transposed into data, masses of which can now be transmitted, processed, and analyzed quickly at central points quite removed from the farming sites; so that specialized management skills need no longer be decentralized among millions of farm operators. Servo mechanisms may well be devised to use the feedback from even abrupt changes in weather to react promptly and flexibly to major contingencies. Mechanical and automotive power has already enhanced the ability to respond quickly to needed changes in resource inputs, particularly those previously requiring labor. Fatigue becomes far less limiting compared with animal and manual power.

Environmental controls likewise have been introduced to a remarkable degree and are subject to conscious and deliberate employment. Forewarnings of impending changes in the natural environment are now commonplace. They are not yet early enough or accurate enough to satisfy--they are unlikely ever to satisfy--but they are beyond past experiences, hopes, and dreams.

One example of a developing work closely akin to the responsibilities of the Statistical Reporting Service may serve to suggest cybernetic applications of the future.

⁵ John M. Brewster, Technological advance and the structure of American agriculture. *Jour. Farm Econ.*, Vol. 29, No. 4, Part I, Nov. 1947. Also, The machine process in agriculture and industry. *Jour. Farm Econ.*, Vol. 32, No. 1, Feb. 1950.

Crop and livestock estimating is fundamentally a communication and control function or mechanism. This is especially true as many businessmen and, to a lesser extent, farmers use the service. It can therefore be regarded as an example of cybernetics in a very crude, gross, and macro sense. The service can be conceived as an annual cycle of forecasts and estimates that begins with measurements and readings to alert a whole host of decision makers to agricultural supply portents in the season ahead. Reports of intentions to plant, intentions to breed, placements in poultry breeding flocks, hatcheries, and broiler chickenhouses, seed production and livestock inventories, are examples of such data. Subsequent data on actual acreages planted, cattle on feed, cows milked, and farm labor inputs provide information on the degree to which intentions or plans have been altered as a result of feedback within the system. Interim estimates of yields and production forecasts as the season progresses reflect the probable impact of contingencies related to weather, insects, diseases, and the like. Harvest estimates followed by stocks, utilization, and disappearance data and final revisions depict the realization of plans and give current supply indications. Crop and livestock estimating is one form of a communication and nervous system essential to the successful functioning of a capitalistic farming system characterized by numerous independent farmers served by numerous independent suppliers, handlers, and distributors.

Acquisition of data for crop and livestock estimates depended for literally a century on the mail questionnaire directed to literally millions of farmers and returned on the average by about one-third of them. The method was founded on the proposition that farms in the United States were sufficiently alike that a sample consisting of many farmers distributed throughout all parts of the country could be considered representative of all farms. The foundations of this method, which were reasonably sound when we had twice as many, and more diversified, farms, began to be eroded some three decades ago along with trends toward fewer, larger, more specialized farms. Today a large sample can no longer be regarded as a representative sample. Advances in statistical technology, particularly in probability

sampling, have pointed the way toward the use of even smaller samples properly selected to obtain representative estimates. For several years the Statistical Reporting Service has been developing and introducing a system of area probability sampling to be associated with other data collection methods to obtain more reliable estimates. The central core of this system consists of some 17,000 segments of land comprising 0.6 percent of the total agricultural land area to provide foundation data on such items as land in farms, numbers of farms, acreages of principal crops, livestock inventories, farm labor, and wages.

In the design, allocation, and drawing of the probability samples upon which these foundation data are based, the computer performs a function roughly analogous to process or management control. The microsecond speed of the computer makes possible the solution of problems requiring thousands of iterations which can generate sample allocations which minimize cost, not for one but for a dozen items. Then the computer can be assigned the task of selecting a sample conforming to this allocation. Thus to the computer can be assigned the control, in the statistical sense, of the universe of sampling units from which the Statistical Reporting Service collects its data.

Obviously extreme care must be exercised in obtaining the data from a small sample to expand into estimates for the universe. Also, in view of the extremely high cost of the survey methods used to obtain such data--largely through personal interview--compared with the cost of mail questionnaires, exhaustive use must be made of the data. Since this is a multi-purpose sample from which the data must be gathered and processed within short and rigid time schedules, access to electronic computer power is necessary.

Computer capabilities also make feasible the computation of standard errors from the sample data, thus providing the Crop Reporting Board with indications of the reliability of some sample data for the first time in history. This is a quality advantage that was not within the realm of possibility prior to the advent of probability sampling and high-speed electronic computers.

For the estimation of yields during the growing season in order to forecast production, the information obtained through the mail questionnaire

is necessarily based upon subjective appraisals of a rather imprecise nature. Questions have to be posed in terms farm respondents can comprehend. Answers have to be accepted in terms reasonably subject to interpretation. Consequently, early season crop queries refer to "percentage of normal," relying upon each farmer's own concept of normal; and midseason queries refer to probable yield this year compared with last year. Only at harvest time can we be more specific and ask for estimated yield per acre in definable units; e.g., bushels of shelled corn with 15.5 percent moisture.

To obtain objective yield estimates, novel and highly specific counts and measures and much smaller samples are employed. For example, objective counts and measurements of fruit are related to biological time, instead of fixed calendar dates, to fit mathematical models designed to forecast ultimate yield. Biological time alludes to intervals between the occurrence of natural phenomena, e.g., full bloom and fruiting, a shifting base from one year and location to another. The aggregate area from which wheat samples are measured to make national estimates of yield will approximate one-half acre and the harvested wheat amounts to less than 1,000 pounds. Electronic equipment solves the equations utilizing the data from each of many sample plots providing numerous and precise measurements.

These sketchy descriptions suffice to indicate the degree of departure from previously established systems used to acquire crop and livestock information; also to suggest the manner and extent to which cybernetic methods are being brought into play. At this stage of development and acceptance of the new methods with their attendant high costs, they are used only to reinforce and not to replace the older methods. The time may come when there is public acceptance of the vastly greater costs of the more precise estimates to permit full reliance upon them, but that is unlikely to occur soon. At the moment, procedures are being developed for multiple frame sampling. These procedures enable the estimators to incorporate, into a single probability sample design, samples from both list and area frames. The cost advantages of multiple frame designs arise from opportunities to collect some of

the data by mail and to focus on small populations of interest. The intricacies of merging the results from the two samples into probability estimates will further test the computer.

All the costs cannot be expressed in monetary terms. Modern probability sampling increases our dependence upon cooperation from respondents. This incurs objections to invasion of privacy; objections that are minimized under present voluntary reporting systems.

Applications Facilitated by Integration

These objections can be eliminated in potential applications of these same methods to individual farming operations. Today we have in a number of States significant numbers of farmers reporting management data into central points for electronic analyses. In many instances these represent modern outgrowths of the old farm management analytical services conducted in agricultural colleges for research and demonstrational purposes. In general, the participating farmers can now receive individualized analytical results for which they are willing to submit data and to pay the price. Thus far they have been interested chiefly in getting back data that facilitate the preparation of tax returns. By comparison, they have shown relatively little interest in the use of these analyses for production planning and control. The opportunity is nevertheless there for far more detailed and continuous use for these purposes, especially if the operations are large enough to justify the expense. The justification can be more easily seen, the larger and the more dispersed the farming operations that are brought under unified and centralized management.

It takes little stretch of the imagination to visualize how these computer analyses can be applied to horizontally integrated farming operations to overcome space and time limitations stressed by Brewster. Where these impediments are less severe and other difficulties have been successfully overcome, as in huge cattle feeding lots, broiler chicken plants, and egg laying houses, the introduction of automation and cybernation is both startling and commonplace. But even in these instances the possibilities are far from being fully exploited.

Immediate opportunities awaiting exploitation abound as vertical integration of farming operations spreads into factor supply and product processing and distribution. One can visualize data intensively collected on farms, utilizing methods already employed for crop estimating and transmitted over radio equipment already installed in farm field trucks. The data would serve as computer inputs that can be translated and relayed to such diverse outlets as insecticide and herbicide suppliers, fertilizer applicators, aerial spraying outfits, and harvesting crews prepared to respond in accordance with contractual arrangements worked out well in advance of actual needs. Financial requirements likewise can be anticipated and geared to computer outputs, transmitted automatically to banking institutions which are prepared to provide credit in the amounts and at times needed. Field harvesters and packers can be alerted and scheduled on the basis of computer outputs that can at the same time give fairly precise orders for packaging supplies, transportation, refrigeration, grading, and storage services.

Some Occupational Requirements

Scientists are spending entire careers extracting the fuller meaning and implications of selected fragments of Norbert Wiener's ideas. Whole groups of the next generation of agriculturists are going to gain livelihoods from applications of cybernetics to agriculture viewed in the broad. Farms and farmers will constitute subsets in the analyses.

That consequence may not be particularly disturbing. The most frightening aspects of cybernation applied to farming stem from institutional, sociological, and conceptual impacts that appear likely to ensue. In the current agricultural statistics program of the Statistical Re-

porting Service increased difficulties are encountered in ascertaining what is a farm, what workers should be properly classified as either farm or agricultural labor, who can or will furnish reliable data on integrated farming operations, what can be reported as a valid price received by a "farmer" enveloped in an integrated enterprise, where can one ascertain prices paid in units and terms comparable with other farmers, how can contractual terms be converted to standardized prices suitable for aggregation and averaging. Identities of even the most basic elements underlying our reporting system will have to be reviewed and redefined. Many prospective answers to such questions violate logic based upon traditional concepts, some conflict with our sense of integrity, others impinge upon our sense of the ridiculous. These reactions are symptomatic of cultural shocks that are likely to pervade the whole fabric of American agriculture. They point up the fact that technological changes induced by cybernation will call for the reformulation of economic theories on which we rely for a rationalization of much of our work. Obviously, this cannot be done by any one agency or group, public or private, acting independently or in isolation. A lot of this adaptation of human intellectual concepts to oncoming technology is overdue, the intensity of need is growing at accelerating rates, and the abrasive interfaces with deepseated values and beliefs are proliferating.

Some research, academic, and educational institutions serving agriculture have their work cut out for them. Conferences, seminars, public dialog leading to the reformulation of economic theories, will bring these problems to the surface and expedite work on them. There will be a need to uncover genius in many quarters not only to capitalize on Dr. Wiener's genius, but also to clean up the debris left in his wake.