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CONTROL IN LARGE ORGANIZATIONS

BY
KENNETH J. ARROW

TECHNICAL REPORT NO. 123
August 29, 1963

PREPARED UNDER CONTRACT Nonr-225(50)
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Applied Mathematics and Statistics Laboratories
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CONTROL IN LARGE ORGANIZATIONS*

by

Kenneth J. Arrow

I welcome greatly the opportunity to address a meeting of the Institute of Management Sciences in this land where beauty and efficiency have had such a happy junction. Dr. Geisler's presidential address in Paris two years ago and this one symbolize the international character of our organization and of the needs which we hope to serve. I rejoice that we are among that small number of scientific organizations who have direct international membership - we stand together as scientific co-workers, with no labels of nationality dividing us.

In considering a topic for a presidential address, I had two motivations. One, of course, was my own interests; one cannot be interesting to others about what one is not interested in. But the second was to use the occasion to bring before you a broad and significant field of inquiry, one transcending the technical papers which are, and should be, the usual objects of our concern. Especially was I interested in speaking on this area, which is implicitly relevant to everything the management scientist does, and at the same time so poorly understood as an object of theoretical and practical study. There are few results to present, but many problems. If I succeed in persuading some of you of the complexity and the challenge of the issues, I will feel well satisfied.

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* Presidential Address delivered to the International Meeting of The Institute of Management Sciences, Tokyo, Japan, August 21-24, 1963.

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I

The large organization, so prominent on our contemporary social landscape, is of great antiquity. If we had no other evidence, we would know that complex organizations were necessary to the accomplishment of great construction tasks - planned cities like Nara or Kyoto or Ch'ang-An, monuments like the Pyramids and temples of Egypt, irrigation systems such as those in ancient Mesopotamia or northern China. But we also know of organization for less material ends, for the preservation of law and order, the maintenance of peace or the prosecution of war - Persia, the efficiency of whose control mechanism and communicative system has been so well described by Herodotus and Xenophon, and the Inca empire of Peru, where a complex and far-flung state was administered in a highly systematic manner with a technology so poor as to include neither writing nor the wheel. Truly, among man's innovations, the use of organization to accomplish his ends is among both his greatest and his earliest.

But it is perhaps only in our era, and even then haltingly, that the rational design of organization has become an object of inquiry. It is characteristic of the present day, as exemplified by the groups meeting here today, that innovation, the solving of problems, is being increasingly systematized. Whereas in the past the improvement in the choice of routes was made by insight and spontaneous inspiration, today we try to arrive at the decision by solving a transportation problem. In the same way, there is an increasing interest in studying how organizations solve their problems so that one can systematically investigate optimal organization.

Let me state the problem at hand a little more precisely; since

research in this area is still in its early stages, undue exactness must be avoided. An organization is a group of individuals seeking to achieve some common goals, or, in different language, to maximize an objective function. Each member has objectives of his own, in general not coincident with those of the organization. Each member also has some range of decisions to make within limits set partly by the environment external to the organization and partly by the decisions of other members. Finally, some but not all observations about the workings of the organization and about the external world are communicated from one member to another. The word "large" in the title is meant to stress the importance of the communications element.

In this address, I wish to set forth some considerations on one aspect of the workings of an organization - how it can best keep its members in step with each other to maximize the organization's objective function. This may be referred to as the problem of organizational control. It divides itself naturally into two parts: the choice of operating rules instructing the members of the organization how to act, and the choice of enforcement rules to persuade ot compel them to act in accordance with the operating rules. Various other terms for these two problems have appeared in the literature; a widespread usage is to refer to the operating rules as control-in-the-large and the enforcement rules as control-in-the-small. It should be noted that enforcement, here as elsewhere, includes both the detection and the punishment of deviations from the operating rules.

My point of view is rationalistic and derives, with appropriate changes, from the logic of choice as it has been developed in the pure economic theory of prices and the mathematics of maximization. The rational or economic analysis of organizations has been developing rapidly over the past fifteen years, and the present account is largely derived from

the work of such innovators as Jacob Marschak, Herbert Simon, Leonid Hurwicz, Thomas Marschak, and Roy Radner. There is no intention of denying that non-rational factors, sociological and psychological, are of the utmost importance in the study and development of organizations. But a rational point of view is also needed, and indeed much of the value of studies in group dynamics will only be properly realized in the context of rational design of organizations.

I will first discuss in the very broadest outline some typical examples of control problems in modern organizations - the large corporation, government, the economic system as a whole - considered as one great organization. From these illustrations, a brief statement of the essentials of the control problem will be derived. Next I will consider the price system as a solution to the problem of control; this is the solution most natural to an economist. While the price system has many values, it also has limitations. Consideration of these will bring out more clearly the basic problems of organizational control, and in particular the crucial role of uncertainty among the causes for the creation of organization. Finally, the need for some additional forms of control will be briefly examined. As can be seen from this summary, this address has as its primary function the delineation of the problem and of the present status of our understanding, not the presentation of any definitive solutions.

II

The issue of centralization or decentralization in the large corporation has received considerable attention in recent years. A large corporation contains many diverse productive activities, which have important connections with each other and yet are separately identifiable. The products of one activity are the inputs of another, and therefore it is costly

to the corporation if its activities are not balanced. Some commodities have to be purchased from outside, stored, transported from one place to another among and within plants, and assigned to the activities using them; some activities produce final products which have to be transported, stored, and sold; other activities produce intermediate products, such as component parts of an automobile, which in turn enter other activities, such as assembly, which produce final products or still other intermediate products. Further, the coordination is needed not only at a single point of time but over many time periods; each activity takes time, so its product can only be used in another activity beginning when the first one ends.

What may be called the classic businessman's view is to be so impressed with the complexity of coordination that great stress is placed on the need for central control. Emphasis is placed on vertical, hierarchical relations; control is exercised by orders from above, executed in detail by those below. The coordination between managers of parallel activities is, in this view, achieved by their common obedience to the plans set at higher levels. Accounting systems and other forms of reporting provide higher echelons with all the information needed to detect violations of orders, and dismissal from employment is the punishment.

Of course, the view I have just sketched is a caricature and was probably not held by anyone in all its rigidity. It is immediately obvious that higher management cannot literally know everything about the operations of individual activities and therefore cannot make all decisions. Indeed, management literature recognized this problem under the heading "the span of control." It was held that an official could not exercise effective supervision over more than a relatively small number of

subordinates, say six. In the terminology which modern management theory is borrowing from statistical communications theory, a manager is an information channel of decidedly limited capacity. This means, of course, that the junior managers must be receiving information from their juniors which they do not re-transmit. Hence, some decisions, if only trivial ones, must be made at lower levels, since the relevant information is discarded in the process of upward transmission to avoid overloading the channels.

The recognition that individual managers will inevitably know more about their own spheres of activity than higher officials has caused decentralization of decision-making to be looked on with much more favor in recent years. It has also been recognized that decentralization can improve the allocation of responsibility; on the one hand, the subordinate has greater possibilities of initiative; on the other, his successes and failures can be more easily recognized by top management.

In the terminology introduced earlier, the operating rules under a centralized system take the form, "do this or that," while under a decentralized system they rather take the form, "do whatever is necessary to maximize a certain objective function."

But the problems of articulating more specifically the operating and enforcement rules of a decentralized organization have not been faced systematically. The objective function for the corporation as a whole may be well defined to be aggregate net worth, but its value depends on the decisions of many managers; the objective function to be maximized by an activity manager must depend in some well defined way on his decisions, to provide an appropriate set of directions to him.

Further, even when the objective function for the manager is defined, there remains the problem of enforcement. When the goal is stated in terms of an objective function, it becomes a matter of more or less, not of yes or no, as it would be if instructions were stated in terms of specific tasks. The top management can never, strictly speaking, know if the activity manager's objective function has been maximized; instead, their enforcement rules should be such as to encourage him to increase the value of the objective function as much as possible. In more usual terms, the problem is to create such incentives to activity managers for performance as will best enhance the corporation's net worth. There are (at least) two problems in devising incentive systems. (1) An effective incentive system creates new demands for information; the reward is a function of performance, so top management must have a way of measuring performance. This may be the objective function itself, or it may be some other, more easily measurable, index. If the index is something other than the objective itself, the manager's incentives may not be directed optimally from the viewpoint of the corporation; for example, if the index of the manager's performance is based primarily on output rather than profits, he will be tempted to be wasteful of inputs. However, an index which supplies better incentives may require more information; in organizational control, as in automobiles, cuisine, and every other commodity, the benefits of improved quality must always be compared with its costs. (2) Even if the index is thoroughly appropriate, the relation between the reward and the index remains to be determined. Suppose there is no difficulty in isolating the contribution of a manager to the net worth of the firm. The fullest incentive to the manager would be achieved by fixing a base salary and a target level of contribution to net worth

or profits and then giving the manager as a bonus the difference between his contribution to profits and the target level. If his contribution fell below the target level, the difference would constitute a negative bonus, to be subtracted from his salary. Such an arrangement would clearly not be satisfactory in spite of its desirable effects; the corporation of course intends to share in the profits attributable to the skill of its managers and not to give them all away to him, and the manager may also be reluctant to face the risks, especially if the contribution of his activity depends in part on factors not under his control and about which his knowledge is uncertain.

III

The design of control systems in large corporations is already a formidable task, but it is several orders of magnitude simpler than the control system for a government. To keep the discussion within reasonable bounds, I will confine my remarks to one particular, though very important, phase of governmental activity, the determination of the annual budget. This is the process by which it is determined how much of the resources of society shall be diverted to the different activities carried on by government. The budgetary decisions are a major determinant of the direction of government activities, though, of course, there are many aspects of government decision-making; for example, foreign policy, where budgetary considerations are secondary.

The governmental decision process has all the complexities of the corporate, but there are two major additions: the consumer-like character of the government, and the varied nature of its activities. Economic theory, as well as ordinary experience, tells us that the process of

consumer's choice is harder to make rational than the decision-making of the corporation. In theory, the corporation maximizes a well-specified objective function, profits or net worth, with no constraints other than those imposed by its technology. The consumer, on the contrary, maximizes a subjective magnitude, under a budget constraint. This implies that the consumer cannot seriously be expected to write down in any explicit way his maximand. Rather, the process of optimization consists of a series of comparisons among alternative ways of spending marginal dollars; the utility function is revealed to the consumer himself in the process. Further, the common budget constraint means that the marginal comparisons must be made among highly disparate alternatives - travel as compared with clothing, for example.

The government's choices are analogous to those of the consumer, with the additional problem that the single utility function is replaced by the great variety of utility functions of the different groups in the political system, the final choice being the resultant of political pressures in many different directions. The government's budget to be allocated among activities is relatively fixed in any one year, though there is some opportunity for change in the total. Alternatively, and perhaps better, it could be said that society's total resources constitute the budget constraint, with the government deciding both the overall allocation between public and private activities and the allocation among public activities. In any case, the budget constraint is a basic element in the government's financial decisions.

The great scope of the government's activities means that marginal comparisons have to be made among some exceedingly remote alternatives: Is an improvement in a national park to be preferred to increased defense?

These choice problems are all institutionalized in the budget-making process. Budgetary requests are made by individual bureaus and then presented to some central agency - in the United States, the Bureau of the Budget. Symbolically, the bureaus represent the utilities of different activities, the Bureau of the Budget the overall resource constraint. But of course no simple separation is possible. The Budget Bureau has to make decisions in cutting down the total requests to the desired budget total, and these decisions involve two types of judgments: (1) the relative social value of the functions of the different bureaus, and (2) the efficiency with which the bureaus are performing their functions. The first judgment has necessarily to be made in a centralized fashion; the Budget Bureau might be thought of for this purpose as the agent of the legislative authority. It is the second type of judgment, that of the efficiency with which government activities are performed, that is more relevant to the problem of control.

For the Budget Bureau to judge efficiency would in principle require it to know as much or more about individual activities as the bureaus themselves. As the affairs of government have become increasingly complex and differentiated, the impossibility of such a concentration of knowledge has become increasingly patent. Traditional analysis of the budgetary process tended to stress the virtues of centralized budget-making, strict lines of control, and avoidance of duplicating activities among bureaus. Some current writers, notably Lindblom, Enthoven, and Rowen, now argue that a good deal of apparent inefficiency and duplication are essential elements of the control process. To replace the impossible demands for knowledge on the part of the Budget Bureau,

reliance is placed on the self-interest and mutual rivalry of bureaus. The bureaus act like individuals before a court; they are required to supply the information which will justify their requests, and if two bureaus have overlapping functions, the information supplied by one can be used to check on that of the other.

This theory of the invisible hand in government, though a significant contribution, is as limited a view as the earlier theory of the all-knowing Budget Bureau. The search for a more satisfactory theory of government budget control must still go on.

IV

Up to this point, the boundaries of an organization have been taken as given. The line which separates governmental from non-governmental actions, or which separates a corporation from its customers and suppliers, has been implicitly taken as well defined. But in fact we really have a nesting of organizations inside larger organizations; indeed, the whole economic system can be regarded as one large organization, and in many respects it is fruitful to do so. A socialist system is one in which the organizational unity of the economy is made explicit in its institutions, but it has long been a commonplace of traditional economics, certainly since the time of Pareto, that the apparent anarchy of capitalism conceals a complex organization fundamentally similar to socialism.

Consider the following three examples of commodity transfers: (1) An engine is placed on an assembly line to be installed into an automobile body. (2) An automobile factory receives a shipment of steel from a mill owned by the automobile manufacturing company. (3) An automobile factory receives a shipment of steel from a mill owned by a steel company.

The first is certainly a transaction within an organization and is carried out in accordance with operating rules laid down by authority. The third is a commercial transaction, the result of a contract in which goods are exchanged for money, and would usually be regarded as taking place between different organizations. Yet the second, the steel shipment from a mill to an automobile factory of the same ownership, is identical to the third in its economic content and to the first in the form of the transaction.

This continuous sequence of cases shows that drawing any boundary lines for an organization has a somewhat arbitrary element. If the entire economy is thought of as a single organization, one is led naturally to think of the price system as one of the major devices for coordinating different activities, and a great deal of effort by economists has succeeded in clarifying its virtues and limitations.

The very importance of price-mediated transactions suggests that it is worth while distinguishing them from others. The boundary of an organization then will be taken as the line across which only such transactions take place. As the examples just given show, we must be prepared in such a classification to recognize that some intra-organizational transactions will have the same economic content as price-mediated transactions.

It is important and illuminating to note, however, that many transactions have both price and non-price characteristics. Professional services, such as medicine and legal services, are not carried on solely on the basis of an impersonal cash-for-service exchange. There is an expectation of personal responsibility, of fidelity and trust; physician and patient behave in many ways more like co-workers in the same

organization than like a large manufacturer and his remote and unseen customers. Similar relations are typical of labor services agents, and in general of transactions involving goods or services where quality standards are significant and not easily checkable in detail by the purchaser. Speaking broadly, these non-market relations reflect the same sort of problems that arise in control within an organization - the need for services coupled with an incompleteness of knowledge by the receiving party about the activities of the supplier.

V

From these examples of organizations, we can abstract the central problem of organizational control. It arises when two conditions hold: (1) The objective of the organization is a function of a number of interrelated decision variables concerning individual activities; (2) the different members of the organization have different bodies of knowledge. The second condition, of course, implies that the transmission and assimilation of information is costly, for otherwise each member of the organization would transmit all his knowledge to all the others.

Uncertainty is simply the complement of knowledge; when I speak of different bodies of knowledge, I could equally well speak of different uncertainties. For definiteness, let us suppose that uncertainty can be represented by probability distributions over all possible states of the world. Then the following model may serve to illuminate organizational behavior: Each member of the organization is in possession of a signal from Nature, and his probability distribution of states of the world is the conditional distribution given that signal. (The "signal" is understood to be his knowledge based on learning and experience.) Each member

can, at a cost, transmit his signal, or a weaker signal compatible with it, to one or more other members of the organization. Each member who has received an additional signal appropriately modifies his conditional distribution. On the basis of the resulting distributions and the operating rules laid down by the organization, each manager makes a decision. The decisions made in turn generate further information which is transmitted in one form or another, and leads to new signals and new decisions. New signals are also coming in from outside the organization and also leading to new decisions. Finally, the messages being transmitted within the system are used to modify the operating rules and to execute the enforcement rules.

VI

It has already been observed that many of the transactions within an organization are similar to those that take place in the market. This has led both theorists and business firms to suggest that prices can be used to regulate transactions within the firm; these are usually referred to as "transfer prices." In the purest form, a price is attached to each commodity or service produced or consumed by any activity in the organization; if the commodity is sold to, or bought from, other firms, the transfer price has to be the same as the market price (with some modifications in the case of imperfect competition). The operating rule for the manager of each activity is then to maximize its profit, as computed by valuing its inputs and outputs at the transfer prices.

This is straightforward, but merely restates the control problem as that of choosing the correct prices. They have to be such that, if each manager does choose his inputs and outputs so as to maximize profits,

then for each intermediate good (one not bought or sold on an open market) the total supply and demand by all activities balance.

If the organization calculates its optimum by the Lagrange method for constrained maxima, where the constraints are precisely that the activities producing intermediate products produce enough to meet the requirements of the activities consuming them, then the Lagrange multipliers are the prices. This method of determining the prices is itself centralized and does not satisfy the informational limitations which are the heart of the organizational problem. Of course, radical improvements in the techniques of constrained maximization, such as the modern work in linear and nonlinear programming, decrease the costs of centralized information handling and thereby reduce the problem of organizational control. But, as has been shown in many different forms, an informationally economical decentralization is possible if we solve the constrained maximization problem by a suitable form of successive approximations. If the prices are first set by guesswork, each manager can make a set of tentative decisions. If the resulting inputs and outputs of intermediate goods match, then the prices were indeed the correct ones; if not, the normal procedure would be to raise the prices of those intermediate goods for which demand in the aggregate exceeds supply, and lower those for which the contrary is true. Under certain assumptions as to the technologies of the activities, this process will converge to the optimum for the organization.

The price system, conceived in this way as a process of successive adjustments, is a satisfactory way of choosing operating rules when the appropriate assumptions hold. Each tentative set of rules is defined by

the tentative set of transfer prices; the successive adjustments in the prices, and therefore in the rules, require information only about the supplies and demands of the individual activities, information which would have to be transmitted under almost any sensible control system; and there is a guarantee that the decisions at least tend toward full optimality for the organizations.

Though the price system for operating an organization possesses these merits, and though I believe that it is capable of much greater use than it now receives, it has intrinsic limits. Indeed, the very existence of large organizations in the commercial world is a proof of the existence of these limits. When the price system is fully operative, the large organization is equivalent to a large number of separate activities whose connections are the same as those of unrelated firms. Hence, the large organization would have no differential advantage in economic competition, and we would not expect to find it so dominant.

The difficulties in applying a price system to the control of an organization can be classified into four mutually interesting types: (1) the choice of enforcement rules; (2) the complexity of the operating rules; (3) the limits on the theoretical validity of the price system, and (4) the presence of uncertainty, which we have seen to be inherent in the problem of organizational control.

The first problem, the choice of enforcement rules, has already been discussed in some measure in the case of the large corporation. Since we have supplied each manager with an objective function, the profits of his branch evaluated at transfer prices, the most natural enforcement rule would be an incentive system; the payment to the manager should be a strictly

increasing function of the branch profits. If the slope of this relation is close to one, then the branch manager is bearing most of the uncertainties due to successive revisions of the transfer prices for which, as a risk-averter, he may well require a large fixed compensation. If the slope is close to zero, then the incentive effect to the manager is small.

The second problem, the complexity of the operating rules, can be appreciated only after a little reflection on the scope of a really thoroughgoing price system. The need of coordination in time is perhaps the chief source of complications; deliveries of specific commodities have to be made at specific times, and in a pure price system there would have to be a separate price for each commodity for each possible date of delivery. One might, to take an example from the government's sphere of activity, use a price system to settle traffic problems; there would be varying prices to be paid for different priorities at intersections and in passing lanes. It is not hard to see the confusion such a system would cause; a traffic signal may lead to an allocation of traffic which is less than optimal in some theoretical sense but it is a far simpler system to operate.

The third problem, the limits on the theoretical validity of the price system, has received a great deal of attention in the literature of welfare economics. There are two basic conditions under which the price system is invalid, in the sense that the equilibrium prices do not represent an optimum: One is that there are increasing returns (or, more generally, non-convexity) in some of the activities, and the other is the presence of externalities, relations between the productivities of different activities which are not classified as commodity transfers.

Smoke emitted by one activity may, for example, interfere with the productivity of another. Externalities are essentially a matter of classification; we can always call any externality a new commodity and attach a price to it. Indeed, the elimination of externalities can proceed much farther within an organization than in the market; there is no technically satisfactory way in the marketplace for making the smoke producer pay for his damage to others, but an organization can fix a price for the privilege of emitting smoke and order it to be paid. Of course, special enforcement rules are needed to make sure that the appropriate payments are made. Further, the elimination of externalities increases the list of commodities and thereby again complicates the operating rules.

Although the matter is too technical to be discussed in a brief space, it can be asserted that increasing returns can be handled by modifications of the price system, but these necessarily introduce some degree of centralization. There is still room for significant research to minimize the informational requirements needed for optimal allocation under these conditions.

VII

The fourth difficulty in applying the price system, the presence of uncertainty, is of major importance and yet has received relatively little theoretical study. The one case that has been studied in some detail is that in which all activity managers have the same information about the world outside the organization. Clearly, the appropriate transfer prices can easily depend on the unknown state of the outside world; the simplest illustration would be the case where production plans have to be made now for sale in the future, and at a price which cannot be known now with

certainty. We may regard the organization as being faced with a probability distribution of states of the world, product prices in the example. For each state of the world, there will be a corresponding set of transfer prices, so that each activity manager will be faced with a probability distribution of transfer prices. The instructions to maximize profits is no longer meaningful; it must be replaced by the operating rule of maximizing the expected value of utility of profits, where utility is a strictly increasing function.

If the organization itself is risk-neutral, then it would want each activity manager to maximize expected profits. But now the already-mentioned problem of enforcement rules becomes even more acute. If the reward of the manager depends in some measure on his observed profits and if he is a risk-averter, he will wish to play safe by following a course which leads to more predictable profits, even if the expected value is lower. To avoid this outcome, the organization should provide insurance against unfavorable external contingencies, which the manager may buy at his option. In this way, it can be shown that the manager will be motivated to maximize expected value and at the same time have all the protection against risk that he wishes.

Such a system does really exist in the sense that a manager is not normally held accountable for unfavorable outcomes or credited with favorable ones if they are clearly due to causes not under his control. However, there is a deep problem here which is well known in insurance theory and practice under the name of the "moral hazard"; it is, in general, almost impossible to separate causes outside the organization from the efficiency of the manager himself. If an activity does badly,

it may be because of external uncontrollable events, or it may be mismanagement. To distinguish between them may never be completely possible and, to the extent that it is, may require costly information. Thus, the occurrence of a fire may be partly due to failure to take precautions or may be completely independent of them; the fire insurance company will not only charge a premium but also engage in additional information-gathering in the form of inspection of premises.

Still further complications occur when the different managers have access to different amounts of information about the external world; this is the problem treated by Marschak and Radner in their theory of teams. Though operating rules can indeed be devised, the problem of enforcement has not yet been approached except in a very rudimentary case (studied by Good and McCarthy).

VIII

Even without going any farther, it is clear that in the control of the typical organization, perfect decentralization is not possible because of the limitations on enforcement rules associated with uncertainty and risk aversion. The top management of the organization will always have to have some information about the internal workings of the individual activity. This is far from saying that they have to have complete information. One of the most promising lines of study is that of sampling inspection - it should be equally applicable to the control of the quality of management as to that of goods. A relatively small amount of information, properly chosen, may have large incentive effects.

The problem of organizational control is just beginning to be analyzed systematically. Already it is clear that price theory and programming methods will have to join in an unfamiliar synthesis with information theory and sampling statistics to achieve the state where the rational design of the organization becomes a reality.

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