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Technology, Territory and Time

The Internal Differentiation of Complex Production Systems (1)

The concept of a production system as a socio-technical system (Trist and Bamforth, 1951/VOI. 11) was further developed by Rice (1958) who developed a conceptual framework for the analysis of complex production systems. He argued that "any production system may be defined by reference to what is imported into and exported from it....The [conversion] process of changing import into export may require the carrying out of either sequential or simultaneous operations, or of both. When different operations are carried out discretely, a production system may be differentiated into *operating systems*. - In that case, the management of the production system "cannot be contained in any one operating system, and a system external to the operating systems is required to control and service their activities. This is the *managing system"* (Rice 1958:41-42). The present paper explores the principles of differentiation of operating units within a complex system.

The Transition from Simple to Complex System

The typical simple production system in industry is the primary work group. Elsewhere it appears in the small workshop, the retail store, the service station, etc.

The essential feature of such a system is that management is inherent in relationships within the group: either there is no recognized leader at all, as is the case in some mining groups (Trist et al., 1963), or, if there is one, all or most of the time is spent working alongside the other members of the group on tasks comparable to theirs. The leader's contribution to the output of the group tends to be directly productive rather than indirect and facilitative.

Herbst (1957) has described certain characteristics of simple and complex behavior systems. He finds that one significant criterion of a simple system is that the relationship between input, size and output is linear. (Input and output

(1) A condensation of a paper published in *Human Relations*, I2:243-72, 1959. References in the original to then unpublished papers are here replaced by later published versions.

are here measured in money rather than in goods). In small retail stores, for example, the total amount paid in wages (input) increases at a linear rate with sales turnover (output) achieved, while sales turnover increases at a linear rate with the size of the store, measured by the number of persons employed. In a complex system the relationship is nonlinear: "The presence of an administrative unit concerned with ongoing activities increases the rate at which sales turnover increases with size of the organization, and withdrawing personnel from production tasks decreases as the organization becomes larger" (Herbst, 1957:344). Herbst (1957:337-38) has this to say about the transition from a simple to a complex system:

> As the size of the simple system increases, and depending also on the extent of both its internal and external linkages, more and more work has to be carried out on the co-ordination of component functioning, so that a critical boundary value with respect to size is reached, beyond which intrinsic regulation breaks down. An increase in size beyond this point will become possible by differentiating out a separate integrating unit, which takes over the function of both control and coordinating of component units, thus leading to a transition from a simple to a complex system. The point at which intrinsic regulation breaks down will be determined by the effectiveness of the organizational structure. The less efficient the organizational structure happens to be, the earlier the point at which intrinsic regulation breaks down.

In other words, three critical factors in the transition are size, complexity and efficiency. Herbst here seems to be implying that the efficiency of a simple system is measured by the extent to which the system can tolerate increased size and complexity without throwing up a differentiated management function. However, if efficiency is measured by the ratio of output to size-a ratio that Herbst himself uses elsewhere in the same paper-then it would appear that this assumption might not always be justifiable. If, for example, a simple system of given size could secure a greater output by becoming reorganized as a complex system of the same size, then its persistence as a simple system would be relatively inefficient. "Resilience" might therefore be a more appropriate term than "efficiency" to describe the capacity of a simple system to withstand pressures, both external and internal, toward transformation into a complex system. This would be an omnibus term embracing a number of factors of small group functioning that counter the effects of increased size and complexity. Some of these factors are considered later in this section.

Size by itself is not a critical factor. Apart from the pair, groups of six to 12 are often said to be the most stable, in both psychotherapeutic and other situations (Rice, 1958:36-37). Fissiparous forces tend to develop in groups outside this optimum range, but there is no known maximum number beyond which the emergence of a full-time management function is inevitable. Much depends on the need for differentiation that is intrinsic to the task of the group and in the way the task has to be, or is being, performed. Herbst notes, for example, that in independent retail stores, a differentiated administrative function tends to appear when the staff numbers around five, whereas stores that belong to a retail chain retain the characteristics of simple systems until the size reaches about nine. Certain services are supplied to the latter by the large organizations to which they belong. In the Durham coalfield, autonomous groups Of 41 have been shown to be effective (Trist et al., 1963). They have internally structured controls and services and lack any overtly recognized and outside this optimum range, but there is no known maximum number beyond which the emergence of a full-time management function is inevitable. Much depends on the need for differentiation that is intrinsic to the task of the group and in the way the task has to be, or is being, performed. Herbst notes, for example, that in independent retail stores, a differentiated administrative function tends to appear when the staff numbers around five, whereas stores that belong to a retail chain retain the characteristics of simple systems until the size reaches about nine. Certain services are supplied to the latter by the large organizations to which they belong. In the Durham coalfield, autonomous groups Of 41 have been shown to be effective (Trist et al., 1963). They have internally structured controls and services and lack any overtly recognized and titled leader. These groups are further discussed below.

Complexity may be considered in terms of Rice's import-conversion-export formulation. Imports into the system and exports from it may become more diverse. Complexity of the conversion process is likely to increase through diversification of input or output, or both, or through a change in the techniques or rates of production (Rice and Trist, 1952).

Before considering these factors of size and complexity in more detail, it seems necessary to stress that an essential preliminary to differentiation of a managing system is theformation of subsystems with discrete subtasks within the simple system. Role relationships cluster around the subtasks; such clusters of relationships become potential subsystems; and areas of less intensive relationships become potential boundaries between subsystems. Clustering may be functional for subtask performance, but the associated discontinuities between clusters may be dysfunctional for integrated performance of the total task. It becomes a function of a differentiated managing system to compensate for these discontinuities. Management mediates relationships among the lower-order systems that constitute the higher-order system in such a way as to ensure that the subtasks performed by the subunits add up to the total task of the whole unit.

If the principles of differentiation of subsystems can be identified, then the effects of changes of size and complexity can be more clearly understood; furthermore, the notion of "resilience" -the capacity to withstand, without sacrifice of efficiency, the pressures toward creation of a differentiated managing systems-will become less vague.

It is postulated here that there are three possible bases for clustering of role relationships and thus for the internal differentiation of a production system. These are technology, territory and time. Whenever forces toward differentiation operate upon a simple production system, it is one or more of these dimensions that will form the boundaries of the emergent subsystems and will provide the basis for the internal solidarity of the groups associated with them.

"Technology" here is given a broad meaning. It refers to the material means, techniques and skills required for the performance of a given task. Differentiation of the input, conversion and export systems (the purchasing, manufacturing and selling of an industrial unit) is in this sense a technological differentiation; so also is differentiation of phases of the conversion operation (successive manufacturing processes) or specialization in buying or selling Particular commodities. The greater the diversity of technologies used within a group, the stronger the forces toward differentiation of fully fledged subsystems, especially when the skills of some members are so specialized that others cannot aspire to have them or even to comprehend them and when interchange of roles between members of the total group becomes impracticable. **(2)** Increase in technological complexity or diversity tends to have this effect even though the quantum of input and output remains unchanged. It may even occur where the size of the system, in terms of the number of roles, is reduced.**(3)**

The dimension of territory is straightforward: it relates to the geography of task performance. An increase in the staff of a retail store from three persons to five may not precipitate formation of a differentiated management function. If, however, the two extra persons are employed to start a branch store-if, in other words, two potential subsystems are formed, spatially separated from one another-then the forces toward differentiation will be greatly increased. Physical separation is not essential to produce this result, but a sharp physical boundary of some kind is probably necessary before territory by itself can become a basis of subsystem differentiation within a simple production system. Identification of the group with its territory is, of course, a basic feature of all human societies and is also found among many of the higher mammals. Even boundaries that are imperceptible to an external observer may have highly charged emotional significance for the members of the groups they divide-especially when territorial differentiation is reinforced by technological differentiation. Technology, indeed, seems to seek the support of territory and

(2) The obverse point was made by Rice (1958:37-39), who postulated that small work groups in modem mechanized industry usually require sufficient variety of roles (implying some technological differentiation) as to need some internal structunng, but should not have so much specialization as would lead to formation of inflexible subgroups.

(3) In her study of industrial firms in south Essea, Joan Woodward (1958:16) noted that "the number of levels of authority in the management hierarchy increased with technical complexity," while "the span of control of the first-line supervisor decreased."

only seldom stands by itself as a differentiating factor. (In many parts of India, castes differentiated from one another by their traditional occupations are also segregated spatially, living in different parts of the village or in different villages [Miller, 1954].)

The third dimension, time, is more commonly relevant to increasing the levels of differentiation in an already differentiated complex system, but it may also reinforce an increase in size in bringing about the transition from a simple system to a complex one. Forces toward differentiation probably begin to

develop when the requirements of task performance are such that the length of the working day or working week of the group exceeds the working period of any individual member. This factor of time is, of course, most pronounced in multi-shift systems. As in the case of territorial separation, subsystems tend to emerge with well-defined boundaries which, in this case, are based on time separation.

The subsystems and associated groupings described in the preceding paragraphs are those that are intrinsic to the structure of the task. Task structure is assumed to be inseparable from the type of technology and specialization involved, from the geography of the territory in which the task is performed and from the time scale of task performance-though within these limiting factors alternative structures may be possible.

Among the persons filling the roles of a production system, other groupings may occur based on propinquity, sex, age, religion, race and many other principles of association, and on occasion these groupings and related cleavages, perhaps by their coincidence with task-oriented groupings, may accelerate differentiation; or, if they cut across these groupings, they may retard it. It is the task-oriented subsystems themselves, however, which are relevant to task performance. These seem invariably to be differentiated by technology, territory, time or some combination of these. Production systems can probably not be satisfactorily broken down into subsystems on any other basis.

If territory, technology and time, singly or in combination, provide the basis for differentiation into task-relevant subsystems, the capacity of a simple system to tolerate growth and remain efficient without becoming transformed into a complex system is apparently related to two main factors: mobility or fluidity and subsystem interdependence. If individual members move frequently from one subsystem to another, so that there are no permanent subgroups of workers coinciding with the task subsystems, then the simple system will have greater capacity to tolerate an increase in size or complexity. Such movement compensates for discontinuities between subsystems. Secondly, the more immediately and directly performance of the task of each subsystem depends upon the performance of all the other subsystems, the more Rely is the total simple system to remain viable in the face of forces toward differentiation. (Without some task interdependence it is, of course, not a production system but an assembly or aggregate of individuals.)

Exceptionally large simple production systems occur in longwall coal-mining, in a form of composite working described by Trist et al. (1963). As mentioned earlier, some of the composite groups have 41 members, working over three shifts. Both "resilience" factors operate strongly in these groups, which are internally differentiated by both technology and time. Although the individual subsystems have well-defined tasks, mobility between the subsystems allows many or all of the members to view inter-subsystem relationships from the perspective of the total system rather than from that of the subsystem they happen to belong to at any one time. Close reciprocal interdependence, necessary in these mining groups for achieving the total task, evidently helps to reinforce this global perspective.

It may well be that it is not the number of persons that limits the maximum size of a simple production system, but the number of subsystems. (A subsystem may consist of either an individual or a sub-group.) Certainly, complexity in task structuring can actually contribute to the cohesion of large simple systems. Where there are a number of subsystems interdependent in more than one direction, the complex conditions of equilibrium can be a substitute for a differentiated management function. It is the very lack of such complexity built in to the task that helps to lower the threshold of resilience in less structured simple production systems. Internal structuring for which the primary task does not cater is sought in other groupings (based on age, sex, etc.), implying involvement in other tasks that to a greater or lesser extent conflict with the primary task for which the system was constituted. In some cases it may be possible to use these factors of resilience and to restructure roles in such a way as to postpone the emergence of a differentiated managing system.

It can be inferred that, in any expanding or changing system in which no such restructuring has occurred, there is an optimum or "natural" stage for creating a new level of management. This is applicable equally to the initial transition from a simple system to a complex system and to the addition of a new level to an already complex hierarchical system.

Premature differentiation is uneconomic because the cost of adding a specialized administrative function is greater than the gain from any increase in efficiency that results. As subsystems have not been crystallized by task differentiation, government is more efficiently contained as an undifferentiated internal function. Indeed, extrinsic government, if imposed prematurely, may tend to be more destructive than integrative. This is the kind of situation in which the internal collaborative relationships, which before the change have been used constructively for task performance, are likely to be mobilized destructively against the imposed external management (cf. Trist and Bamforth, 1951/Vol II).

Postponement of differentiation of the management function beyond the optimum stage also leads to a decline in the efficiency of the system, but for a different reason. The energies of group members, instead of being devoted to the primary task, are increasingly diverted to the task of holding the group together in the face of the fissiparous forces of sub-group formation and of differentiation. This is especially likely to happen if there is imbalance in the pattern of subsystem interdependence. Individuals experience conflict between identification with an emergent sub-group and identification with the total group. Only the creation of a new level of management, which allows the subsystems to become fully explicit simple systems and which reintegrates them as parts of a higher order system, permits the energies of the members to revert to primary task performance.

Herbst (1957) used the input-size-output relationship as an index for measuring the level of behavior systems and for diagnosing whether a given system is simple or complex - The reverse approach may also be useful. If a production system known to have the structural characteristics of a simple system increases in size, and if this expansion is unaccompanied by a linear increase in output, then (other things being equal) it is worth investigating whether the system has passed the optimum stage for differentiation-either because the subsystems are in a stage of disequilibrium or because of emergence of sub-groups unrelated to the primary task of the system. The same possibility may exist if a simple system, remaining constant in size, shows over a period of time a declining output. Equally, if a structural transition from a simple to a complex system is not accompanied by the kind of change in size/output ratio predictable from a Herbst-type formula for systems of that kind, then it is possible that differentiation of the managing system has been premature.

Structure of Complex Production Systems

The forces toward transforming a simple system into a complex system, or toward increasing the levels of differentiation in a system that is already complex, are not only of theoretical interest to social scientists but also of Practical interest to those concerned with management. It has already been suggested, for instance, that working efficiency and cost are likely to be adversely affected if the timing of a change in response to the accumulating forces toward differentiation is not opportune. A second cause of inefficiency may lie in an inappropriate choice of the basis of differentiation into subunits.

In the initial transition from a simple to a complex system, the basis of differentiation is usually directly traceable to the forces leading to differentiation. Consider the example of a small privately owned workshop that manufactures simple components, all of the same kind, for the automobile industry. Raw materials are delivered and the finished products removed by the company it supplies. Administration takes up little time of the owner, who Works at a bench alongside the employees. This is the typical simple production system. Let us imagine that demand grows and, because of lack of space for expansion, the owner acquires two more workshops in the vicinity. If the three workshops are sufficiently far apart, the owner is likely to spend less time on the bench and to take a nearly full-time managerial role. The three workshops then become three simple operating systems within a complex production system. In other words, territorial expansion has led to differentiation, and it is territorially demarcated subunits that are explicitly recognized.

Alternatively, the expansion might have been achieved by adding two more shifts in the original workshop. The shifts would then become the recognized subunits and, because of the need for control and coordination over the 24 hours, the owner would again take a full-time managerial role.

We now have to consider what happens when additional forces toward differentiation operate on a production system that has already become complex and there is the prospect of extending the hierarchy by further differentiation. Here again, the forces themselves will dictate the new basis for differentiation, but not necessarily the level at which this will occur.

Reverting to our example, let us now suppose that further expansion requires all three workshops to run on three shifts. Each shift in each workshop is now likely to develop into a simple subsystem, and sooner or later the owner-manager will be compelled to realize that there are nine workshop shifts to be managed, instead of merely three workshops on one shift, or three shifts in one workshop (Table 1).

Increase in the number of subunits does not, of course, necessarily lead to further differentiation and to an increase in the number of levels. If, for example, output had been tripled by expanding from three workshops to nine, instead of by adding more shifts, the additional simple production systems so created could have become explicit without necessarily overextending the span of the overall manager's command. Even in the present example, it might be practicable to maintain direct control of the nine subunits, perhaps by employing additional staff for time keeping and recording production-that is, by increasing the size of the managing system without adding to the number of levels in the hierarchy. However, since the subsystems in this case are differentiated and interdependent along two dimensions (territory and time) that cut across each other, and therefore have to be coordinated along these two dimensions, it is likely that an additional level of management will be interposed.

The owner is now faced with a choice. He may introduce the new level by managing the three territories (workshops) through three foremen, delegating to the foreman in each workshop the task of coordinating the three shifts within it. Alternatively, he may elect to undertake coordination of the three shifts himself by appointing three shift foremen, each of whom is responsible for the work on one shift in all three workshops.**(4)** The fact that territorial differentiation preceded the addition of shifts by no means presupposes that, in the management hierarchy, territorial differentiation need occur at a higher level than diiferentiation by time.

It is now necessary to consider this choice in more detail. In fact, it is a real choice only insofar as territory and time are equally salient in differentiating the nine simple systems from one another. In terms of task relationships, this is so only when one shift in one workshop is equally interdependent with other shifts in the same workshop and with the corresponding shift in other workshops. Workshop A Shift I (A I) belongs then to two larger systems: it is part of the "A" system, within which the other systems are A 11 and A 111, and it is part of the "I" system, within which the other systems are B I and C I (cf. Table 1). In the situation of equal interdependence

TABLE I **Subunits Differentiated by Both Territory and Time**

	Time Differentiation		
Territorial Differentiation	Workshop A **Shift I**	Workshop A **Shift II**	Workshop A **Shift III**
	Workshop B **Shift I**	Workshop B Shift 11	Workshop B **Shift III**
	Workshop C **Shift I**	Workshop C Shift 11	Workshop C **Shift III**

R(A 1, A II, A III) = R(A I, B I, C I)

where R is a measure of task interrelatedness between the simple systems. Such an equilibrium may make it possible for the nine workshop shifts to be managed directly without interposing a new level of differentiation.

We have seen that the formation of subsystems with discrete subtasks is a necessary preliminary to transition from a simple to a complex system. Similarly, in an expanding complex system, the clustering of subsystems precipi-

(4) 1t was Rice who first drew my attention to this kind of choice, to which he also refers in Rice, 1958:1-77, 200-201.

tates an additional level of differentiation in which the clusters are acknowledged as explicit systems of a higher order than the constituent subsystems.

When two dimensions of differentiation are involved, with two implicit sets of systems cutting across one another, it is seldom that they actually have equal salience. Task relationships generally draw the basic units into the orbit of one system more strongly than into the other and so dictate the lines of higher order and lower order differentiation. Furthermore, even if task-oriented interrelations themselves, do have equal salience, other factors may tend to tilt the balance one way or the other. Persons who share a compact territory over three shifts, for example, may feel more strongly identified than those who share the same shift-timing over dispersed territories. Alternatively, if the dispersal is limited, going to work at the same time, and hence sharing free time, may lead to closer identification.

Failure to differentiate on the appropriate basis will create stress in relationships, because the natural groupings inherent in the structure of task performance will run counter to the groupings dictated by the formal organization. Formal boundaries will cut through these natural groupings. This will inhibit development of solidarity in the formal units, with consequent lowering of work satisfaction and morale. In general, we can suggest that, to the extent that the forrnal structuring deviates from the reality of the task situation, whether in the basis for differentiation or in the boundaries of the formal subunits, to that extent will the management function itself have to multiply and become "top-heavy" in order to deal with the resultant dysphoria. Additional controls will have to be imposed. This tendency will increase in proportion to the interdependence of the formal units. If, on the other hand, a unit is appropriately subdivided in relation to total task performance-if it is cut, so to speak, with the grain and not against it-both the internal management of the constituent subunits and the overall integration of the total task are likely to require less effort.

Flexibility is not entirely lacking. Imposition of a managing system helps to crystallize the selected basis and boundaries of differentiation of operating systems. Therefore, provided that the salience of two dimensions is not too unequal, differentiation at the higher level along the dimension of lower salience may increase the salience of that dimension to a point where it exceeds that of the other. This would not appreciably increase the difficulties of management. Similarly, if prior clustering of subunits is not too strong, the emergent boundaries can be supplanted by formal boundaries that do not necessarily coincide with them. Such flexibility, however, occurs only in marginal cases.

So far, instances of only two orders of differentiation have been discussed----- by territory and time. We have seen that there is, subject to certain limiting factors, a choice between

- first-order differentiation by territory and second-order differentiation by time; and
- first-order differentiation by time and second-order differentiation by territory.

A third possibility, provided the salience of the two dimensions is roughly equal, is to accept only one order of differentiation, operating systems being differentiated simultaneously by the time dimension in one direction and by the territorial dimension in the other. This is illustrated in Table 1, which shows three time subdivisions and three territorial subdivisions, making nine subunits in all.

Theoretically, there is yet another way of compressing differentiation by two dimensions into one level. This occurs when the two dimensions, instead of operating at right angles, coincide and reinforce one another. Time and erritory coincide in this way when shift working is used in highly mechanized road construction. A piece of mobile equipment-the common technology---is operated by one team on one stretch of road in Shift 1, by a second team on a fresh territory in Shift II, and so on. In longwall coal getting, time and technology coincide as differentiating dimensions, territory being undifferentiated: a different technology is used on each of three different shifts on one coal face. Both these combinations are fairly rare in industry, where it is territory and technology that most frequently coincide as reinforcing dimensions: in manufacturing operations, more often than not, each of a group of technologically differentiated subunits has its own discrete territory of task performance as well.

When all three dimensions of differentiation occur (if, in the example of the workshop, several products are manufactured in each of the three workshops on three shifts), the theoretical choice of order of differentiation is greatly increased. Assuming that differentiation occurs only once along each dimension, there are six combinations of three levels of differentiation, six more of two and one of one level. It should be noted that in the seven combinations involving differentiation by more than one dimension at one level, the simultaneous differentiation may be either *cross-cutting* or *coincident and reinforcing*.

When there are more than three levels, at least one dimension will become the basis of differentiation at more than one level. In a large manufacturing concern, for example, there may be first-order differentiation into purchasing, manufacturing and sales (technology); second-order differentiation of manufacturing into product units (technology, probably reinforced by territory); third-order differentiation of the product units into departments responsible for various phases of the process (again technology plus territory); and so forth. Time differentiation will occur in a multi-shift concern, but a 24-hour command is narrowed down into eight-hour commands at only one level in any segment of a hierarchy. It may nonetheless occur at different levels in different segments of the same total hierarchy.

Very often the internal structure of a large organization is the cumulative result of many small local changes. Adherence to a particular pattern of differentiation adopted in response to one change may limit the possible responses to subsequent changes. Insofar as the enterprise is a system, a change in one area will affect other areas. Accordingly, any organizational change must be planned in the context of the total structure, to ensure that it provides for the most efficient performance of the primary task of the enterprise.

To sum up, therefore, any production system, complex or simple, can be defined along the dimensions of territory, technology and time. A large system is broken down into progressively smaller systems along one or more of these dimensions at each level. The smallest systems are sometimes coextensive along one or even two dimensions with the overall system, but more often in a manufacturing organization they are shorter along all three dimensions. Each component system, however, has boundaries that serve to separate it from parallel systems and also boundaries that form part of the higher-order system's boundaries. Work-oriented relations crossing the former boundaries should be more intensive than those that cross the latter; if not, it can be inferred that an inappropriate basis of differentiation has been adopted and that the efficiency of the total system is less than optimal.

Internal Differentiation and Problems of Management

Where a complex production system is differentiated into subsystems, the total task is also broken down into subtasks associated with these subsystems. As Rice (1958:228) has pointed out, such a hierarchy of tasks may often lead to situations where "decisions taken within one component system which are consistent with its primary task may appear irrelevant or even harmful in a system of a different order." Differentiation into subsystems therefore throws up a managing system which has the reintegrative function of seeing that the constituent tasks of the subsystems are so performed that they add up to the overall task of the system as a whole.

It is suggested here that the way in which a task is broken down-in terms of the dimensions along which the subsystems are differentiated and in ternis of the intrinsic interdependence between them is a major determinant of the kind and quality of management required, including the kinds of control mechanism that will be appropriate. Fundamentally, of course, the dimension along which the system is differentiated at a given level is the dimension along which the major controls have to be exercised to secure reintegration.

Differentiation by territory, technology and time, singly and in combination, can at any one level take on seven different forms-three one-dimensional, three two-dimensional and one three-dimensional. These are set out in Table 2.

Multidimensional differentiation can be reinforcing, crosscutting or mixed, though the examples given in Table 2 are all of reinforcing differentiation: that is, at the level of differentiation in question, each component system is differentiated from every other along both the named dimensions. Examples of cross-cutting and mixed differentiation could also be added.

Types of task dependence have been classified in some detail by Herbst (1961) and Emery (1959/Vol. II). Forpresent purposes it is relevant to consider the extent to which, at a given level of differentiation, the component systems

Table 2
The Seven Basic Forms of Differentiation at One Organizational Level

Differentiated dimensions	*Undifferentiated dimensions*	*Examples*
I. Territory	Technology and time	(a) Separate sections within a factory, or separate factoties making same product (b) Marketing organization; chain of retail stores
2. **Technology**	Time and territory	Shipbuilding
3. **Time**	Territory and technology	Typical multi-shift structure in process and other industries
4. **Territory and** technology	Time	(a) Quasi-independent product units (b) Consecutive manufacturing operations
5. **Technology**	Territory	Longwall coal-mining
6. Time and territory	Technology	Mechanized road making with shiftworking
7. Territory, technology and time		Milk: collection, processing and bottling, delivery

(Note: The examples of two- and three-dimensional differentiation given are of a "reinforcing" type. Brief notes on these examples are given in the text.)

of a larger system are *co-dependent* on supplies, equipment and services, and interdependent for the attainment of the end result or goal of the larger system. One or both of these types of dependence may be present. Emery points out that interdependence may be further classified as cyclic, convergent or divergent. Distinctions can also be drawn between simple and complex dependence and between reciprocal and nonreciprocal dependence.

If the differentiation variables were separately considered in relation to all the dependency variables, the resultant number of combinations would be enormous. Here it will be sufficient to examine the three basic differentiation variables in a little more detail and to discuss a few models that occur fairly frequently in industry. From these the implications of other models can be inferred.

There is one other respect in which the present discussion is restricted. While the basis on which subsystems are differentiated and the nature of their dependencies are the internal System elements that create a particular pattern of demands on management, it is also a function of management to mediate in certain ways between the system and its environment (which may include successively larger systems of which it is a part), and environmental factors will inevitably impose certain other demands. Such factors, for example, may call for additional control mechanisms within the system. The more complex and diverse these environmental factors are, the greater the number and variety of control and service functions likely to be differentiated within the managing system, and the greater the consequent complexity of intra-system relationships. Here, however, environmental factors are held constant and attention is focused on internal factors relevant to the relations of a manager with his or her immediate subordinate group.

DIFFERENTIATION BY TERRITORY

It is characteristic of operating systems differentiated from one another only along the territorial dimension that the output of the total system to which they belong is the added sum of the outputs of the constituent systems. Output from one system can be high, low or even absent without directly affecting output from the others. In other words, where differentiation is only territorial, interdependence is minimal.

The extent to which the systems are co-dependent, on a single source of supplies, for example, or on centralized service functions, can vary considerably. Spatial segregation can be an important factor here, though not necessarily a determining one. To take the examples given in Table 2, if the territorially differentiated units are neighboring sections in the same factory, for example, the series of groups of workers on groups of looms in the textile mills described by Rice (1958), they are likely to draw their input from the same source and to be jointly dependent on a number of centralized services. If, however, the units are separate factories making identical products in different parts of the country, their co-dependence may well be less. Canneries and other food-processing plants are often dispersed in this way in order to be close to agricultural sources of supply. Decentralized control over input is practicable in such cases but is less appropriate where the factories (perhaps dispersed to be close to their markets) share a common and limited source of supply. Co-dependence may also extend to output: the smaller the fluctuations of output pennissible in the total system, the greater the centralized control over the outputs of the constituent systems.

Putting it another way, we can say that where a unit is differentiated into territorial subunits, the individual subunits and the total unit are the same "length" along the input/output dimension. The constraints on procurement of input and on disposal of output that operate on the whole unit will place upper limits on the autonomy that can be given to the subunits. The stronger these external constraints, the greater the co-dependence of the subunits

Problems may arise when territorially differentiated subunits have had to be created only because of the size of the total command. For example, in large sales organizations it is common to find one or more interposed levels of management that are unrelated to task boundaries. The commands for which such managers are responsible are not "systems" at all, but aggregates, with boundaries determined by administrative convenience and no unique "whole" task to integrate them. Those managers whose authority is inevitably constricted tend to be seen by their subordinates as a barrier between themselves and their "real" boss, and vice versa.

However, in other cases, so long as the territorial boundaries conform to the reality of the task structure and so long as subunit performance can be measured separately, this is one of the easiest kinds of command to manage, especially if the subunits are roughly equal in size. Because the operations of his or her subordinates are not interdependent, the superior is not concerned with maintaining collaborative relations between them. Indeed, competitive relations are often more appropriate. Their homogeneity makes comparisons straightforward, and a highly productive subunit can be used as an example and pacesetter for the others. Subject to the external constraints on autonomy, substantial delegation is possible, which means that a fairly large number of units can be included in one command, producing a flat hierarchy.

One practical difficulty that sometimes arises in such a command, however, is that the competitive situation gets out of hand. The superior may become so involved in resolving problems of real or imagined incomparability between the subordinates that he or she loses sight of the primary task of the system. The subordinates, for their part, are liable to seek short-term competitive advantages that may be detrimental in the long run; or alternatively they may go into collusion to protect themselves from competitive stress by establishing safely attainable norms. The common restrictive practices in industry and commerce are special cases of this form of organization.

There is another management problem that may occur in manufacturing units. This is the tendency for the subunits to develop an "individuality" that is based on more than their territorial differentiation from one another. Here we are not concerned with the general tendency of groups to develop a structure and culture that apparently transcend what is needed for attainment of their overt goals. We are concerned more specifically with a tendency to supplement territorial differentiation by technological differentiation. This is pacesetting of a special kind. In a manufacturing operation such as weaving, identical machinery may be used to turn out several varieties of one product. Even though all varieties are spread equitably among all subunits, individual subunits may develop a special proficiency in some. They acquire what Selznick (1957) called a "distinctive competence." This distinctive competence may be encouraged, perhaps almost accidentally, by assigning more of these varieties to the subunits in question. Such specialization is the beginning of technological differentiation. Management needs to be alert to such incipient changes and to recognize their implications. It is not simply a question of deciding whether the gains from specialization-probably in improved efficiency and quality-outweigh the disadvantages of reduced flexibility in production planning. Different methods of management are required: competition ceases to be an appropriate control mechanism when the subunits become heterogeneous. In the extreme situation, the varieties, by ceasing to be interchangeable, acquire the status of separate products, and the territorial differentiation becomes secondary to what is, in effect, technological differentiation between product units. Management of such units is discussed in the next section.

DIFFERENTIATION BY TECHNOLOGY

In cases of differentiation by technology, the notion of distinctive competence is very much present. The organization is built up around clusters of specialized skills and often specialized equipment, too. Members of a subunit that is differentiated from others along the technological dimension derive solidarity from their distinctive competence, often by exaggerating its distinctiveness. Preservation of that distinctiveness may become the primary task of the subunit. Management of a unit in which the subunits are differentiated (and therefore have to be reintegrated) along the technological dimension involves using the specialized contributions of the subunits to perform the primary task of the whole. To achieve this, the solidarity that the subunits derive from distinctive skills should be sufficient for them to maintain their viability as separate systems, but not so great that they lose sight of the total task of the larger unit. To strike such a balance is no easy task. Perceived threats to the integrity and distinctiveness of subunit skills mobilize the energies of subunit members toward preservation of the subunit at the expense of the unit as a whole. Closed-shop movements in departments of automobile factories and demarcation disputes in shipyards are familiar examples.

Operating systems are seldom differentiated from one another by technology alone. Perhaps the nearest approximation to this is in enterprises such as shipbuilding, where what is being made is also the territory of task performance. Even in shipbuilding, however, there is some supplementary differentiation by territory and time: certain jobs have to be done elsewhere in the yard and certain jobs on the ship itself cannot be started until preceding jobs are complete. The occupational groups at work on the ship at any one time have shifting and overlapping territorial boundaries, and it is along the technological dimension that they have primarily to be coordinated. Conventional longwall goal getting involves differentiation by both technology and time (Trist et al., 1963). The team working on a particular section of the coal face over a 24-hour period is subdivided into shifts where workers are distinguished from one another both by the times they work and by the kinds of tasks they do. Reinforcing differentiation by technology, territory and time may occur in a milk business: milk is collected from the farms in the afternoon and evening and brought to the central depot; there it is processed and bottled during the night; and next morning it goes out on the delivery rounds.

In industry, technological differentiation is commonly accompanied by territorial differentiation. The word "department," for example, often carries both connotations. Where the two are combined in this way, the former distinction always seems to be primary: territorial differentiation supplements and reinforces the technological. To some extent the combination also facilitates coordination by giving the technological groupings the security of a clear-cut physical boundary-contrasted with the vague and shifting boundaries of the shipyards.

DIFFERENTIATION BY TIME

In the ordinary multi-shift situation, where the subunits are differentiated from one another only by time and share a common terTitory and a common technology, their co-dependence is considerable. For example, maintenance failures on one shift affect the others. Generally this co-dependence is accompanied by a circular form of successional interdependence: each shift not only completes certain operations, exporting the material outside the total unit, but it also passes on some semi-finished material to the next shift for completion.

Throughput time is a major determinant of interdependence. The longer the throughput time, the higher the proportion of semi-finished to finished material at the end of each shift; also, the less likely it is that individual shift performance, in terms of quantity and quality, can be measured precisely. Continuous operations of process industries provide an obvious example, but the production lines of the engineering industry also contain at any one time components in various stages of completion. Another factor that reduces the clear-cut self-containment of the shifts in the most highly automated industries, where shift working is most prevalent, is that the functions of so-called production workers have increasingly been taken over by the machines themselves. The task of the workers is to monitor and maintain, and the consequences of things they do or fail to do are often not immediately and clearly visible: the benefits or otherwise may fall upon succeeding shifts.

Furthermore, in most industries-indeed, in the society at large-night work is considered unnatural; a certain stigma is attached to it. Those who work while the rest of the world is asleep tend to feel cut off from society-and no doubt some select nightwork for this reason and may even become neurotically addicted to it. This is not the place for a discussion of the psychology of shift work: the point to be emphasized is that nightshifts often have a distinctive "atmosphere" of their own.(5) This is particularly true where a group of workers is permanently on nightshift. Nightshifts are less differentiated in this particutar respect in enterprises such as chemical plants, steel plants or power stations, where continuous operations are dictated by the basic nature of the technology, and also where all shifts rotate.

It is clear that differentiation by time calls for positive managing skills to maintain the tempo and quality of work and to prevent the circular dependence from becoming a deteriorating cycle. The managerial problems inherent in this model make it important to eliminate avoidable complexities. Many of these stem from a failure on the part of management to conceptualize second and third shifts as discrete systems. Outside the industries where continuous operations are intrinsic to the technology, the second and third shifts have generally been introduced in order to supplement production from single-shift working without increasing capital investment; the notion that they are supplementary tends to be perpetuated not only in management attitudes but also in organization. Rice (1958) has given a good example of this kind of situation in a textile mill and also indicated that acceptance of the organizational consequences of three-shift working can lead to higher productivity and improved quality.

An avoidable complication occurs when the overall head of the three shifts also has the additional role of first-shift supervisor. The 24-hour responsibility of the overall head naturally cannot be discharged if he or she is regularly tied for eight hours to one shift only. A separate first-shift supervisor is therefore necessary. Related to this is a tendency to confuse first-shift control and service functions with headquarters functions, usually because office hours more nearly coincide with first-shift hours than with those of other shifts. The first-shift supervisor may be given responsibility for such functions as pertain to all shifts, or alternatively-and less frequently-certain services that are decentralized to the second- and third-shift supervisors are, for the first shift, retained under headquarters control. It is appropriate either to centralize such functions fully under the head of the total command or to decentralize them equally to the three subordinates, but not to delegate them to one or two subordinates only (cf. Rice, 1958:46). Difficulties of coordination are also increased if one shift supervisor-commonly on the third shift-has an operating command that is smaller than the other two. Equalization of shift commands, by allowing the heads of the three shifts to collaborate as equals, may reduce the load on the managing system to an extent that more than offsets the cost of increased third-shift working. (This is not possible, of course, where there are wide fluctuations in the load, for example, in some engineering firms, and a "spill-over" nightshift is required irregularly in order to absorb these fluctuations and to maintain a steady dayshift load.)

The head of this kind of command therefore has to take specific precautions appropriate to the pattern of differentiation and interdependence: he or she needs to be aware of this 24-hour responsibility, to attend shift hand-overs as often as possible, to avoid delegating either too much or too little to the first-shift head and to avoid giving too small a command to the third-shift head. Meetings of the superior with his or her subordinates as a group help to emphasize the complementary contributions of the shifts to the total task of the command. Meeting the subordinates only individually makes it more difficult to ensure that all three shifts work together coherently. There are possibly advantages in a form of shift rotation that periodically alters the order of dependence of the shifts.

Where there are only two shifts, although the general problems are very much the same as in the three-shift situation-especially the sharing of territory and equipment-the reciprocity makes equilibrium easier to sustain because dependence and power balance each other. There is one drawback in having only two shift heads reporting to one superior: it is too small a command. Coordination and control of two subordinates generally give the superiors too little to do. They may tend to bypass their immediate subordinates, withdrawing authority and responsibility from them. Consequently it may prove desirable to combine, at the same level, differentiation by time with crosscutting differentiation by territory and/or technology. As was pointed out earlier, however, it is unlikely that the task structure will be such that interrelatedness along the time dimension will be equal to interrelatedness along the territorial/ technological dimension.

(5) 0ften, too, the level of attention is lower and mistakes are more numerous (cf. Hill and Trist, 1955).

In all cases of crosscutting differentiation, where two dimensions of differentiation are compressed into one level, formation of subgroups is to be expected along one dimension or the other. It has to be realized, however, that such groupings have no formal identity in this kind of structure, so that controls and services must be either fully centralized or else fully decentralized to the individual subunits.

Though the few models discussed here touch only the fringe of all the possible variations, they serve to indicate the different kinds of demand placed on management according to the types of boundary that separate the subunits and according to the type and degree of dependence between them. Consideration of these factors may be relevant to the selection, training and placement of managers. Though it is probably a little far-fetched to suggest that management of territorially differentiated units requires a special kind of person, it is certainly clear that techniques of management appropriate in that situation cannot effectively be transplanted into a situation where the units are differentiated along other dimensions and the patterns of co-dependence and interdependence are more complex.

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