Organizing for Product Development

Thomas J. Allen

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Abstract

In this paper, we propose four parameters that determine appropriate organizational structure for a research, development or engineering organization. Examining the positions that an organization occupies on the four parameters will determine relative need for interaction with the market and with supporting technologies as well as the need for coordination among project team members. This, along with the time needed to bring the product to market, can then be translated into an organizational structure, giving proper emphases to each of the three needs.

Introduction:

Product development organizations have, for years, experimented with and developed many new and novel ways of organizing. Project team organization traces its roots back to the problems faced in developing new products. The need for a focused and well-coordinated effort, involving many disciplines led to the formation of temporary interdisciplinary teams. This form of organization has now been carried into many areas outside of product development. What has become known as matrix organization or matrix management evolved from similar origins. While project teams enabled intense focus and coordination, they did not address the problem of helping engineers in close contact with new developments within their specialties. T. Wilson, of the Boeing Company, in the late 1950's tried to accomplish both with a new organizational form, which later came to be known as, "the matrix". New product development has thus been a fertile ground for thinking about and applying new forms of organizing. Even the currently popular 'skunk works' concept can be traced back to Kelly Johnson's famed development organization at Lockheed Burbank. However, while serious thought, and even some theoretical reasoning may have gone into the initial development of organizational forms, practitioners since have applied and modified these forms with out resort to, or understanding of, the basic principles and reasoning upon which they are based.

Organizations, are always looking for new ways to group activities together to achieve greater efficiency or effectiveness. They are constantly experimenting and designing new organization charts, searching for the ideal organization. In the process, managers have been very creative, designing all sorts of reporting relationships among people and among groups and laying these out in charts with solid or dotted lines and lines of different colors delineating varied relationships. With few exceptions, management school academics have completely ignored this activity and have failed to come to grips with the need for guidance in organizational form. The reasons for this are not readily apparent. However, few would argue with the fact that it is a neglected topic in business school curricula. In this section, we will take a small step toward redressing this deficiency.

The section will analyze organizational structure in the research, development and engineering function. The basic reason for this, of course, is that this is the focus of the entire book. Even if that were not so, there are other good reasons for focussing on Product development. First, R&D managers have been most creative in developing new organizational forms. Project organization really had its origin in research and development. The matrix organization originated here as well, for reasons that we will address at a later point.

In addition, research, development and engineering was the first business function to employ large numbers of highly educated, highly specialized personnel. In most firms, it is still true that product development employs more educated and specialized talent than any other part of the company. Other functions are changing, however. As these become more 'professionalized', employing people with higher levels of education and usually greater specialization and as their specialties gain momentum in generating new knowledge, they will come to resemble research and development. They will face many of the same problems and the organizational solutions proposed in this paper will become more germane. Thus, we will eventually see the applicability of these concepts to marketing, manufacturing, finance[1] and other functions of the business.

Most organizations are structured by grouping people by task, specialty, or geography. Leaving geography aside for the moment[2], we are left with task and specialty as the underlying bases for most organizational forms. Corporations, for example, can be structured by function and product, with either taking the dominant position. The firm can either let functions dominate, as in Figure 1, with product line groupings under each function or have product lines dominate, as in Figure 2, with functional groupings in each product organization.

[1]We have recently introduced a Financial Engineering track in the program for a MBA degree in the Sloan School of Management at MIT.

[2]We will treat location at great length in subsequent papers.

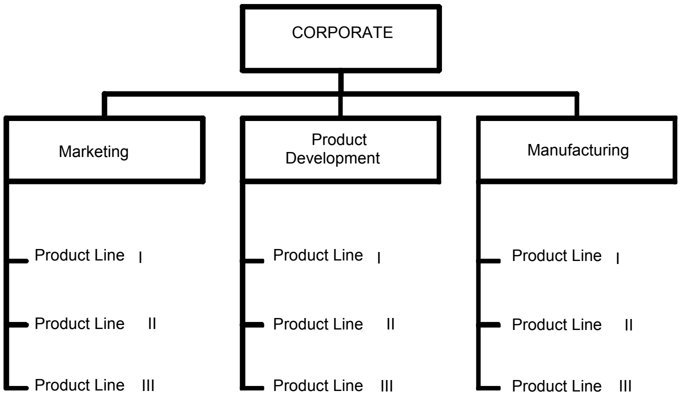

Figure 1. A Functonal Form of Organizational at the Corporate Level.

Some Background in Product Development. We will now turn to the level of the Product development organization and trace some history of different organizational forms. Then we will discuss the underlying rationale for different organizational forms and their relative advantages and costs. Finally, we will propose four parameters that determine the optimum form of organization for research, development and engineering. Positioning an organizational situation along these four parameters will prescribe the organizational structure most suitable for that situation.

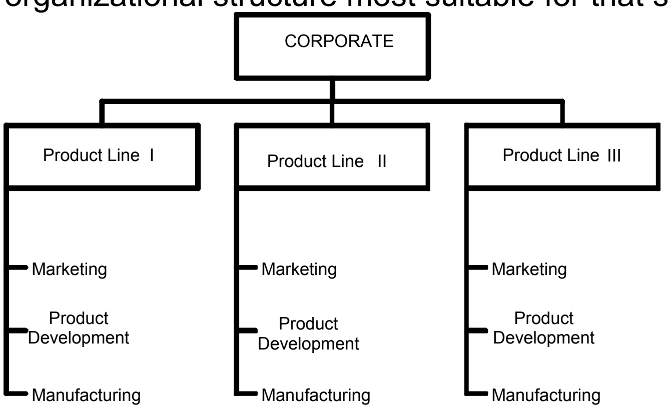

Figure 2 . A Product Line Form of Organization at the Corporate Level.

A Simple Model of the Innovation Process. Innovation can be depicted very simply as a process that mediates between two streams of activity (Figure 3). One of these is the development of technological knowledge or, as we more commonly call it, 'technology'. The other is a developing set of market needs. The basic process of innovation involves the matching of information drawn from the two streams. One stream provides market needs; the other provides technological capabilities or potential solutions to meet the market needs. Both knowledge of the technology and knowledge of the market are required. Problems without solutions do not make any money and the business of starting with a solution and searching for problems can usually be very frustrating and unprofitable, as well

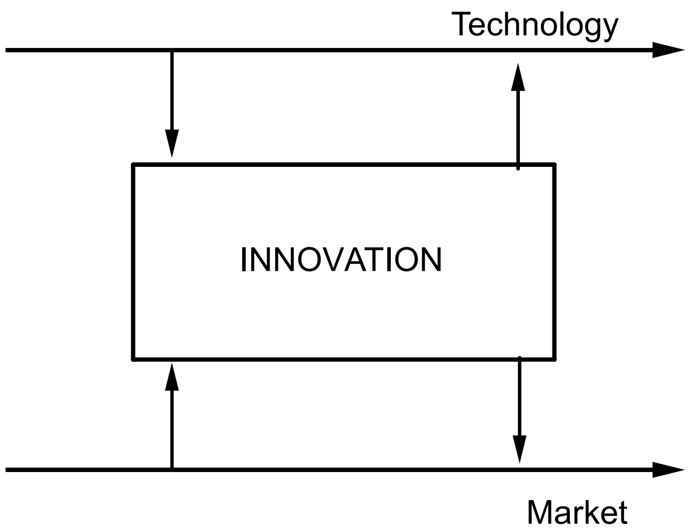

Figure 3. A Simple Model of the Innovation Process.

Departmental or Functional Organization.

Organizations can be structured to function well with either of the two streams. As we will see, the difficulty occurs when we try to structure to serve both simultaneously. In many ways, the requirement to align the organization with technology is incompatible with the requirement for a market alignment. Historically, we find product development organizations first aligned themselves with the structure of the technology stream. Technology or technological knowledge is grouped into disciplines or specialties or, as we often label them, 'technologies'. These are, in turn, hierarchically structured into sub-specialties and sometimes sub-sub-specialties, and so on. Organizations can be structured in a similar fashion around the same specialties or sub-specialties (Figure 4). This enables the staff to communicate with colleagues in their area of specialization outside the organization and, most important, to keep one another informed. Allen (1984) discovered that engineers and even scientists obtain a major portion, usually even most of their technical information through colleague contact.

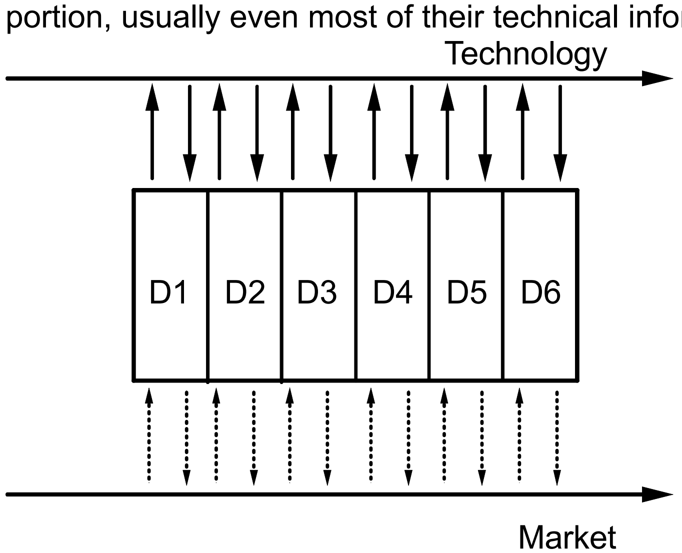

Figure 4. Organizing the Innovation Process by Departments.

Engineers and scientists do have other ways of keeping up with their fields, certainly. Journals and reports are important to the dissemination of technical knowledge. However, most such knowledge reaches practitioners through face-to-face contact with colleagues (Allen 1984). Technical professionals keep themselves current in their specialties most effectively through colleague contact.

Departmental organization, because it groups together people who share the same area of specialized knowledge, enables them to more readily communicate with each other and to keep one another informed of new developments. Thus, departmental organization provides an effective coupling to those areas of technology represented by the departmental structure.

This is a very old form of organization having its origins in the university. Universities have, since the 12th century, and certainly since von Humboldt's reforms in the 19th century, been organized around specialized areas of knowledge. Thus we find departments of chemistry, physics, mechanical engineering, history, mathematics and so on. Each of these will often have sub-groupings representing sub-specialties within each discipline. These provide clusters of individuals who share common intellectual roots and interests. They enable the groups to share knowledge gained from their own research or obtained through contact with colleagues outside the university. The system works very well, primarily because until very recently universities have not been called upon to do very much cross-disciplinary research. Industry has not had that luxury. Cross-disciplinary work is the norm in industry. Products are seldom based upon single disciplines or specialties. It normally requires a blending or integration of knowledge from different specialties to develop even relatively simple products.

The first research and development laboratories were designed to emulate the system that the engineers and scientists knew best. Engineers and scientists all spend extended periods in the university during their education. When organizing an industrial laboratory, therefore, they followed the pattern that they knew well and created specialized departments organized around specialized areas of knowledge.

This form of organization very soon encountered difficulty in relating effectively to the market. That is why the market connections are shown as dashed lines in Figure 4. In engineering terms, there is an 'impedance mismatch' on the market side of the model. The structures do not match and this creates an impedance or impediment to the transfer of information. The market is not organized in the same way as technology. Market needs are defined in the form of products and services. These do not necessarily align with technological specialties or disciplines.

Combining or integrating knowledge from different specialties to develop a new product requires coordination among the specialists. The work of, or the approach taken by, one specialist can seriously affect the work of another specialist. Coordination is thus required. Specialists must coordinate their work when developing a new product or service. They must keep one another informed of what they are doing. Very often this must be on a regular, frequent basis. The departmental structure, organized by specialty is not well suited to accomplishing this. Coordinating work across departmental divisions can be very difficult. Specialists are reporting to different bosses and are often physically separated from one another. Relationships among the bosses or department heads are critical to managing the needed coordination. However, even with the best of relations among managers, the specialists are living in their own worlds, surrounded by colleagues from the same specialty. They are seldom reminded, therefore, of the needs or problems encountered by other specialists working on the product. What they usually do is to make assumptions concerning the needs or direction taken by the others as the development progresses. The others, however, may be introducing modifications in approach, so that the initial assumptions can very rapidly be invalidated.

This is the basic problem of departmental organization. It is extremely difficult to coordinate the work of the disparate specialties that are often required for the development of a new product or service. The result will be what is called 'interface' problems. These are incompatibilities in the relationships or interfaces between different parts of the product. Somebody may have made a change in approach, assuming that it would present no problem to others working on the development, when in fact, it does. This failure to communicate or coordinate the work is not necessarily the result of any mean-spiritedness or narrow mindedness by participants. It is the result of not seeing other participants regularly, and therefore not understanding what they are doing. Mutual assumptions rapidly become invalid in complex developments. That is why constant coordination may be necessary.

Project Organization.

The solution to the coordination problem was found very quickly in project organization (Figure 5). In this form of organization, specialists are, at least temporarily, removed from their departments and grouped together in a team under a common boss. They then live together in this new organizational structure while their talents are needed in development of the new product or service. Since they are more likely to see each other regularly, this makes coordination easier and allows them periodically to update their assumptions about the directions being taken by others. Thus, the coordination problem posed by departmental organization is more effectively resolved.

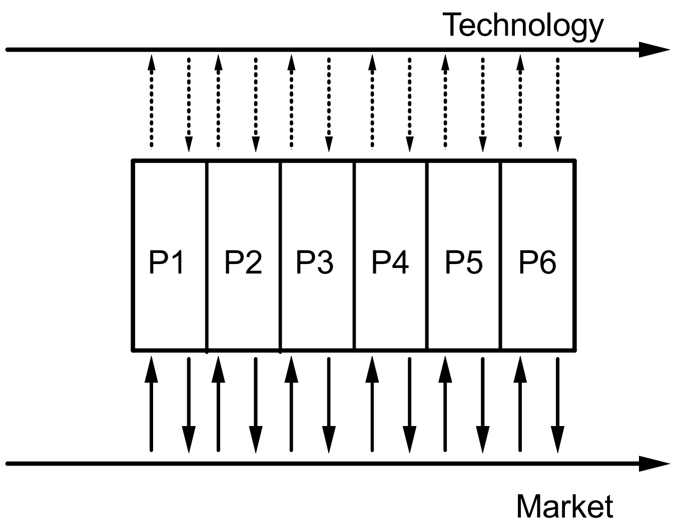

Figure 5. Organizing the Innovation Process by Project Teams.

Of course, this is not without a price. The price comes in the form of the separation of the specialists from their knowledge base. While they can now communicate more readily with others engaged in the same development, accomplishing that has made it more difficult to stay in close communication with colleagues within their own specialty[3].

The result is that the specialists are less likely to stay informed and up-to-date with respect to new developments within their specialties. They are more likely to fall behind in the 'state-of-the-art' of their specialized areas of knowledge. Remember, it is colleague contact that has been shown repeatedly to be the most effective way of keeping technical professionals abreast of current knowledge (Allen 1966; Allen 1970; Allen 1984)

[3]We are referring now to developments of what we might call "normal" size, in which there is a limited number of individuals from any single specialty in the team. It does not apply as strongly to the very large projects, with hundreds of specialists engaged. These can often have a specialized functional (essentially a departmental) organization within the project team permitting a "critical mass" of specialists within many of the specialties.

Specialists working within project teams for an extended period of time come to know the application of their specialty in the context of that particular project very well. They are, however, likely to lose sight of new developments within their field of specialization. The concentrated focus of project activity can, over time, actually lead to obsolescence. This creates the problem of reassigning the specialist upon project completion. Intimate knowledge of one development does not necessarily equip one to take on another development. Somehow, the specialist must be kept in touch with the specialty or brought up to date upon project completion.

Integrating this phenomenon across entire organizations, it becomes apparent that too heavy use of project team organization will lead to the gradual erosion of the organization's technology base. The technology, or core competencies (cf.. [Prahalad and Hamel, 1990] of the organization are stored in the minds of the technical staff. This knowledge must be kept current for the organization to be competitive. Narrowing the focus of the specialists causes them to fall behind in knowledge. The organization thereby weakens its own technology base.

The Matrix Organization. Matrix organizations were created to solve the problems that we have just described. Perhaps the first of those, to the author's knowledge, was created at the Boeing Company for the Minuteman I missile program[4.] In this form of organization, project teams and departments are supposed to interact in a way that accomplishes the necessary coordination, while maintaining current knowledge in the relevant technologies (Figure 6). This is at least correct in theory. In practice, as anyone who has worked in such an organization will testify, it seldom works out quite so neatly. There is often a high degree of contention between project teams and departments, particularly between project managers and department heads. This is an issue we will address in great detail in a subsequent paper. Beyond this, there is always the question of how much emphasis to place on project team management and how much need there is to retain to retain departmental structure. Usually, this reduces to a question of individual assignments. Who should be assigned to a project team and who should be left to work in their departments? What are the criteria on which these assignments are to

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[4] T. Wilson, who later became CEO and then Chairman of The Boeing Company was the project manager, for this program (and the author’s boss).

be based? On large projects, there is certainly a role for a set of project coordinators or integrators to assist the project manager. These people are assigned to 'system level' analyses and subsystem integration. They need to be able to think in terms of the overall system being developed to see the issues around subsystem interfaces. They need also to be sufficiently knowledgeable about the specialties to understand and negotiate the tradeoffs must often be made among subsystems. This is a rare talent and it is obvious that people such as these should be assigned to project teams and cultivated as future project managers. In large organizations, this can become a specialty on its own merits. Beyond these obvious assignments, it is often desirable to assign at least some specialists to work within the project team. Which specialists join the team and which are retained with departments? To answer this question, we need to look more deeply at the basic tradeoff, which the assets and liabilities of project and departmental organization imply

To do this, we need to move one stage deeper in our analysis.

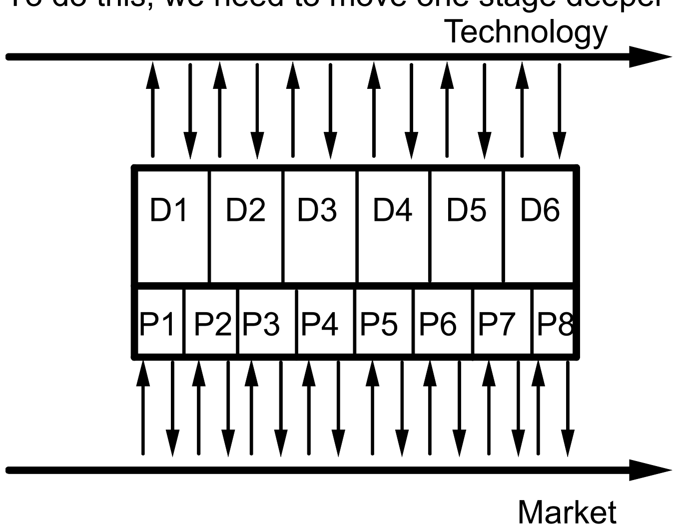

Figure 6. Organizing the Innovation Process in a Matrix Structure.

The Basic Tradeoff.

The basic tradeoff between project and departmental organization is captured succinctly in Table I. Departmental organization connects staff more effectively to their knowledge base at the cost of greater difficulty in coordinating their work with other specialists. Project team organization improves coordination at the cost of great difficulty in keeping abreast of new developments in the specialties.

The Need for Current Knowledge. Let us turn first to the issue upon which departmental organization is based. What is it that determines the need for current knowledge? Certainly not all technologies or specialties are equal in their thirst for current knowledge. Some have a greater need than others. A few moments' reflection provides the answer.

If a technology is not developing very rapidly, staying current is not so difficult. If nothing is changing, old knowledge is outdated far less rapidly. Those working with mature, stable technologies are not as impelled to communicate with colleagues and stay current. Rapidly changing technologies are very different. If new knowledge is being generated at a rapid rate, old knowledge becomes quickly outdated and there is a strong need to keep up.

Table I

The Organizational Structure Tradeoff

Organization Type	benefit	cost
departmental	provides good technological support	difficulty in coordinating work
project team	promotes coordination of individual efforts	decouples the effort from supporting technologies

There follows a very strong requirement for those engaged fast-changing, dynamic technologies to sustain very strong colleague contact to maintain up-to-date knowledge.

The rate at which knowledge advances is a very important parameter determining organizational structure. We will designate this dK/dt. The time rate of change of knowledge, dK/dt, is a parameter along which different technologies can be arrayed. It is a very important characteristic of any technology or technical specialty.

The Need for Coordination. The degree to which coordination is needed varies, as well. Not all projects need coordination to the same degree. There are instances when specialists must maintain regular frequent contact, even doing their work jointly in one another's presence. In other cases, specialists can work very independently informing one another only after extended intervals. What is it that determines this need for coordination? The immediate response is project complexity. But how is complexity measured?[5] The number of specialties or subsystems is certainly one indicator of complexity. However, something more is needed.

[5] There are, of course, many ways in which complexity can be measured. (Cf. Sussman 20??).

A project might have many subsystems, specialties or problem areas and still not require much coordination. If the subsystems or problem areas are relatively independent, then the specialists need not coordinate their work very frequently. They can work very independently of each other. It is only when their work is highly interdependent that coordination becomes critical.

So interdependence is a second parameter, which must be taken into account when deciding an organization's structure. Some developments have a very high degree of interdependence among the tasks or problems that must be solved. Taking this to a physical level, some products have highly interdependent subsystems. In the latter case, we can think of the subsystems that interact minimally as a number of 'black boxes', with clearly defined and limited interface specifications. Such a situation requires relatively little coordination. An example of this might be 'add-in' boards for personal computers. So long as these meet certain electrical and mechanical specifications at input and output, the interior design of the board is open. Since the specifications are known at the outset, no further coordination is required with either the designers of the computer's ‘mother board' or the designers of other add-in boards.

Within development projects, some activities can be highly interdependent with other activities, while others may not be. Again, this is reflected in the product. Parts vary in their degree of interdependence with other parts. So the coordination required is not necessarily distributed evenly over the project team. This will become important later in our discussion.

The Organizational Structure Space.

The two parameters, rate of change of knowledge and subsystem interdependence can be assumed to be orthogonal, at least over most of their range. This allows us to lay them out as shown in Figure 7. One dimension of this figure (dK/dt) measures the rate at which knowledge is changing or being developed in the different technologies, disciplines or specialties, upon which the enterprise and its products are based. These are perhaps a level deeper than the 'core technologies' of which (Prahalad and Hamel 1990) speak. They are the foundations upon which the core technologies are based. All these vary in their rate of change. Any business will draw on some mature, relatively stable technologies. Many will also draw upon dynamic, rapidly developing technologies in which the 'state-of-the-art' is advancing at a high, perhaps even daily, rate. Most organizations will have a mix of product developments underway at any time. Some of these will employ primarily mature, stable technologies; others will use dynamic technologies.

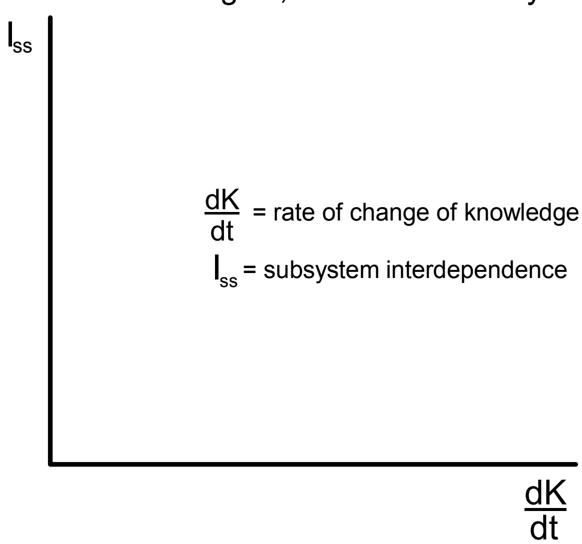

Figure 7. The First Two Dimensions of the Organization Structure Space.

Interdependence will also vary across product developments. Some of these will involve a set of highly interdependent activities. Others will comprise activities that are separate and relatively independent of each other Moving to the level of individual activities, the people engaged in any product development will be drawing on technologies changing at certain rates (dK/dt), which have certain levels of interdependence with others' activities (I_{SS}). Some developments will comprise individual activities all of which have high interdependence but with knowledge that is changing at only a modest rate. A development of this sort is shown by the 'x's clustered in the upper corner of Figure 8. Each of the 'x's represents an individual engineer or scientist. Its position is determined by the average degree of interdependence between that person's work and the work of others engaged in the development, and by the rate at which the individual's knowledge base is changing.

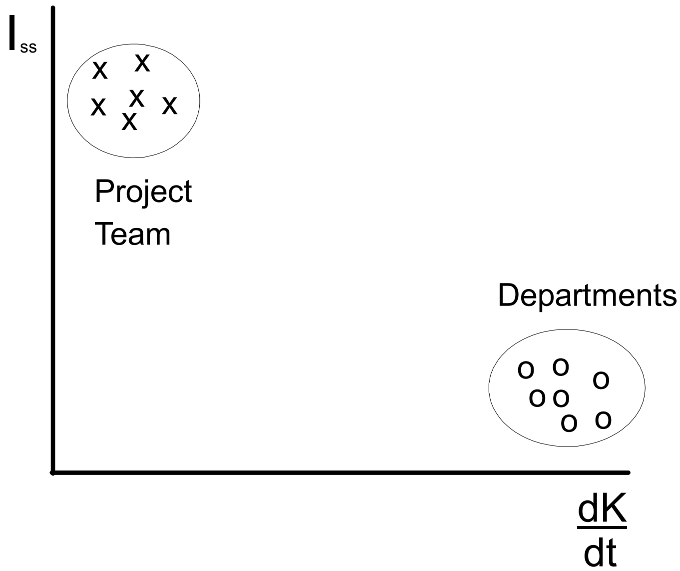

Figure 8. The Organization Structure Space. with Two Project Situations.

The 'o's clustered in the lower right-hand corner of Figure 8 represent a very different type of development. In this case, the engineers or scientists are using very dynamic technologies but can work independently of each other.

These are two extreme cases: one with mature stable technologies and high interdependencies, the other with dynamic technologies and low interdependencies. Considering our earlier discussion, one could expect that these two developments should be organized differently. With stable technologies and high interdependencies, project team organization should produce the better result. Since the technologies are not changing very much, it is not that critical to stay in close contact with them. So contact with colleagues who share those technologies is less important. However, work interdependencies are very high so it is very important to maintain close contact with colleagues who are working on the same development. The project team enables this kind of contact to occur more readily. The cost incurred derives from the separation from colleagues in the same specialty. Here this cost is low, but the benefit of intra-team contact is high. Therefore, the project team is preferred.

The second case, shown in Figure 8, is just the opposite. Contact within the specialties is very important, since the specialties are changing rapidly. Contact within the team is less important, since the activities are relatively independent of one another. Since departmental organization better enables communication among those within specialties[6] and since little interaction will be required across departments, this is the preferred form of organization. Leaving the individual engineers and scientists in their home departments will in this set of circumstances, produce better results.

[6]Provided that the specialties or disciplines are the basis upon which the departments are formed.

Obviously, in product developments such as those under discussion, there must be some point of overall responsibility. There is always ***some*** coordination necessary, even in the case shown the lower right of Figure 8. Therefore, a project manager is necessary, with the individuals in separate departments receiving some degree of direction or at least guidance from that project manager. This implies, at the very least, a weak form of matrix organization with lines of direction cutting across the departmental structure. This is a subject that we will treat in great detail in a subsequent paper.

Finally, in Figure 9, some individuals are shown as '+'s. These individuals are not concentrated in any single part of the space but are spread all around. They would be working on a development that combined a variety of technologies with different levels among them of interdependence and rate of change of knowledge. This is a very common situation; perhaps more common than the two extreme cases of Figure 8. How does one organize an effort such as this? It certainly seems to require a combination of organizational structures. Some people could be organized into a project team, while others were left in departments[7], depending upon their location in the space. How then do we decide who is to join the project team and who is to remain in the department? Some boundary must be dividing the space into two regions. Individuals positioned in one region would be organized in a project team. Those in the other region would be kept in their specialist department. How is this boundary determined and where is it positioned?

Project Duration.

Since the two extreme cases[8] lie in opposite corners of the space, it is reasonable that the boundary would be one that divides the space into two regions each containing an extreme case. Such a line is shown in Figure 10. In one of the regions produced by this boundary line, project organization produces better performance. In this region, the need for coordination outweighs the need for current technical knowledge. In the other region a departmental structure leads to better performance. Here, the need for current knowledge outweighs the need for coordination. But where does the boundary lie and what determines its position?

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[7]And 'matrixed' to the project.

[8]High I_{ss}, low dK/dt and low I_{ss}, high dK/dt.

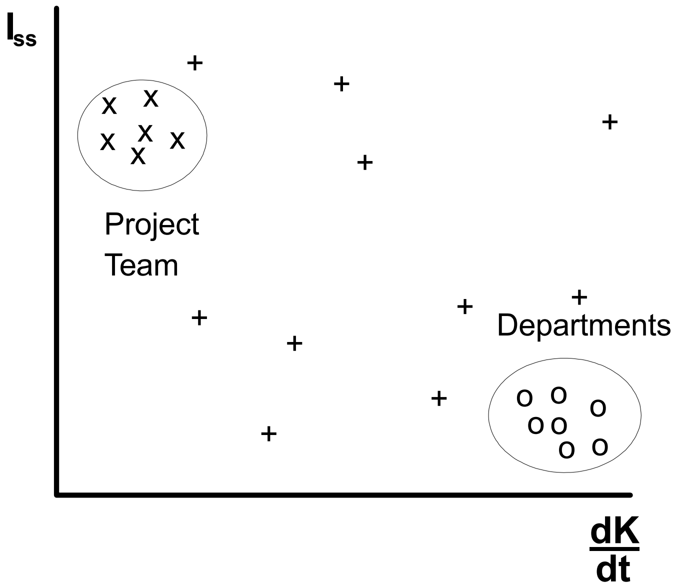
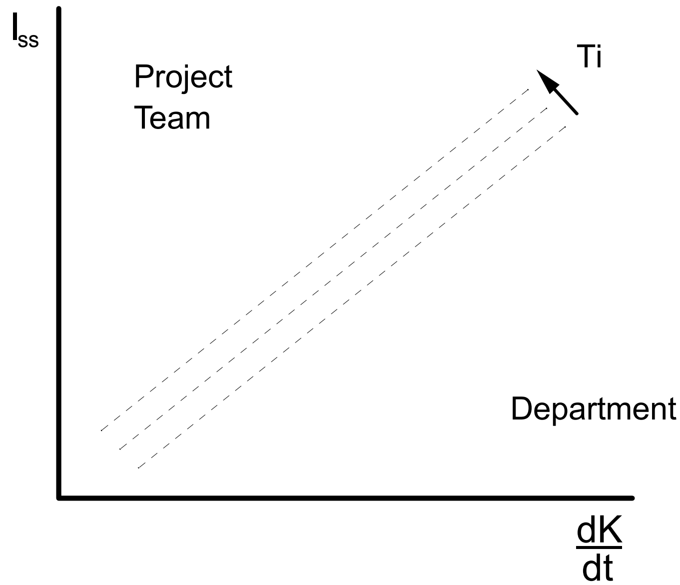


Figure 9. The Organization Structure Space. with Three Project Situations.

The answer to this question introduces the third parameter of organizational structure. This is 'time to market', project duration or more precisely the length of time that any engineer or scientist is assigned to work on the project.

The longer an engineers or scientists are assigned to a project team, the longer those individuals are disconnected from their specialist departments. So for an exceptionally long project team assignment an engineer or scientist may fall behind in even a moderately dynamic technology. To address the issue from the other direction, very short project team assignments, even those dealing with the most dynamic technologies, will not fall behind in their state of knowledge. Thus, the boundary position is determined by project duration. The lines in Figure 10 show projects of varying duration (T_i). The longer the project, the larger the region in which departmental organization produces higher performance and the greater the number of people who should be retained in their departments. The shorter the project, the larger the region where project team organization leads to higher performance and the greater the proportion of people assigned to project teams.

Figure 10. The Third Dimension of the Organization Structure Space.



Measuring the Parameters.
The axes in Figures 7 through 10 have no scales shown on them. This may be perfectly satisfactory to the academic who is interested only in the theory behind these figures. To the practitioner, however, the absence of scales renders the figures less userful. How can one determine where a particular situation will fall within this space? While we cannot provide precise scales for the three parameters (else we would have drawn them on the figures), we can give some guidance toward developing scales.

Rate of Technology Change. Measuring the time rate of change of knowledge (dK/dt) can be accomplished, at least on an ordinal or relative basis, in those specialties that have well-defined sets of journals associated with them. In those instances a good indicator of the rate at which knowledge is developing is the half-life of citations or references in the articles contained in those journals. If half the citations in a given journal are to articles published within the previous two years, the knowledge contained in the articles of that journal would be developing at a rate faster than that in a journal whose citation half-life is ten years. This does not give us numbers to place along the dK/dt axis in Figures 7 through 10, but it can provide the manager with an ability to compare different specialties along this dimension. How does one measure citation half-life? Fortunately, it is not necessary to go through the journals and make the required computations. The Institute for Scientific

Information has done it for us. They publish this figure annually for all journals covered by their *Science Citation Index*9.

Interdependence. Such a convenient measure is not as available for interdependence among activities (I_{ss}). This is a parameter that is familiar to most experienced project managers, however. When partitioning the overall problem and making task assignments, the wise project manager attempts to partition at points of ***minimum*** *interdependence*. This is most clear when some tasks must be assigned outside the organization, through subcontract or purchase. For ease of management, it is wise to try to minimize interdependence. So the ideal is for the partition to be made to enable definition of a 'black box' with well-defined interface specifications. The interface specifications define the external envelope for the subcontractor or supplier to work within, in designing the contents of the 'black box'. Anything can be done within the black box, just so long as it requires inputs and produces outputs that remain within the specifications. Such a partitioning makes it much easier to work with a supplier or subcontractor. When interdependencies are high in such a relationship long periods of negotiation are required and much time will be given to meetings between parties, during the development. Moreover, the probability of eventual incompatibilities and system problems is increased. So the wise project manager tries to minimize interdependence at the interface between firms (or even other parts of the project manager's own organization).

In a similar fashion, the really wise project manager tries to minimize interdependencies among individual task assignments within the project team. This is, of course, constrained by the talents and specialized knowledge of the individuals. Tasks must be assigned to the people best suited to performing them. Nevertheless, there is usually some latitude in this, and it is within this freedom that interdependence can be minimized. That this constraint operates and that eliminating interdependence is not always possible, or in some cases even reducible, is attested by the fact that there will always be developments falling in the upper portion of the space. Thus, while we again lack precise measurements, interdependence is not an unfamiliar concept. Astute project managers use the concept regularly.

[9] A similar comparison can conceivably be performed on the basis of patent citations. Patents, however, are classified by industry codes rather than technologies or disciplines and there is, as yet, no publicly available source for patent citation half-life.

The measurement of interdependence has been formalized in what is called the Design Structure Matrix (Steward 1981; Morelli, Eppinger et al. 1995). In this approach, interdependence is measured in terms of expected and required information flows. A project is first partitioned into subsystems or subproblems and a matrix is laid out, relating tasks to one another. When one task requires information from the output of another task, this is indicated in the cell connecting the two in the matrix. This is a strong indicator of interdependence between the two tasks. The marginal values from the matrix can be used to measure the degree of interdependence of any task with all other tasks in a given project. This measure provides at least a relative indication of position on the I_{ss} scale. Developments and parts of developments can, in this way, be positioned along the I_{ss} axis.

Finally, we have our third parameter, project duration. This is easily measured, and hopefully, predicted. To be more precise, since we are working at the level of individuals and the tasks in which they are engaged, this measure is the length of time over which the task must be performed or during which the individual will be working on the development. This is what determines position on the time duration axis

Normal Industrial Practice. While all of this makes sense to the author and, perhaps, even to the reader, these rules are not normally followed. Normal industrial practice ignores the rate at which technologies are developing. It takes scant notice of project interdependencies. Organizing is instead based almost entirely on project duration, and then it is backwards. For short term developments, projects of three to six months let us say, people are left in their departments. It is considered too disruptive to form project teams. If a project is to last five or six years on the other hand, it is the usual policy to form a project team and assign all the engineers and scientists to it.

This is completely opposite to what is called for by the present analysis and results from basing the organizational structure on the wrong parameters. Project teams are formed for long duration projects and departmental organization is used for short projects. This fails to take account of the relation between project duration and the loss of specialized knowledge. It thus results in the decision going in a direction opposite to what the foregoing theory would dictate.

High Interdependence *and* Rapid Technology Change. Many project situations fall into the upper right hand corner of the Organizational Structure Space depicted in Figures 7 through 10. Such projects have both high degrees of interdependence and rapidly developing technologies. There is no clear way to classify on the basis of project duration (Figure 11). There are two possible ways to deal with such a situation. First, it might be possible to re-partition the basic problem to reduce interdependencies. A more likely solution will be to cycle staff between project team and departments for short periods of time, to prevent them from being away from either their project team or departmental colleagues for too long. This will enable them to keep up with their disciplines while still being able to coordinate reasonably with other team members. The price for this is, of course, considerable disruption to the project.

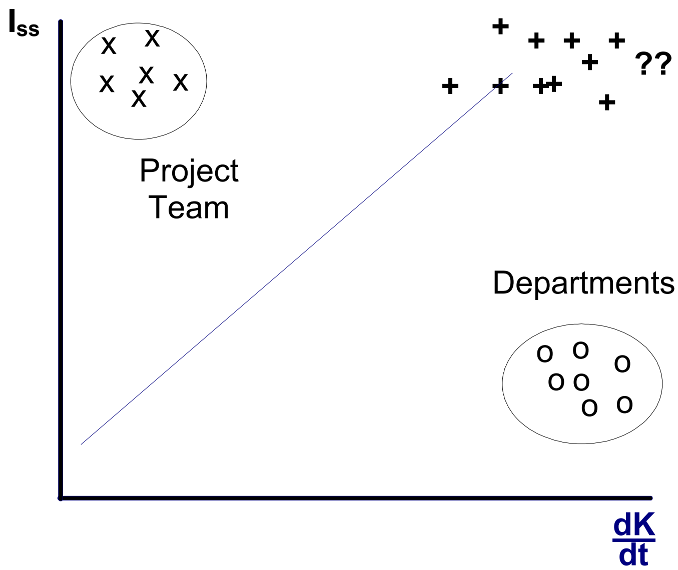


Figure 11. High Interdependence Combined with Rapid Technology Change..

The Market.
At this point, the reader should be asking, "What about the market?" We must not forget the market side of the innovation model. Customers' and society's needs change, in many different ways and at different rates. Markets vary in their dynamism, just as technologies do.

Some market niches may be stable, with little change in requirements from year to year. Other markets are undergoing rapid and constant change. This must have implications for organizational structure. The project form of organization is better able to cope with a rapidly changing market. It provides a single, well-defined interface with the market. The project manager and supporting staff become a conduit for the transmission of market information to those engineers and scientists working on the technical aspects of the development. Therefore, the more rapidly changing are market requirements, the more one will want to use project team organization. This introduces a fourth dimension into our model and makes several issues including its graphic representation more complicated.

It Is More Difficult.

The fact that market change (dM/dt) is often the result of technological advance makes any attempt to represent dM/dt and dK/dt as orthogonal very difficult. A shift or advance in technology can very often stimulate existing markets or open completely new ones. Similarly, market changes can stimulate technology change. While there is considerable evidence that the market provides the stimuli for most 'commercially successful' innovations, (Utterback 1976), technology push has contributed several very important products that have completely changed markets or created entirely new markets. Witness the impact of the pocket calculator, the personal computer, facsimile transmission or the mobile telephone.

Market dynamics can also affect project duration. Changes in the market can precipitate efforts to accelerate projects, through the commitment of increased resources. To simplify our discussion and for representation purposes, however, we will treat dM/dt and dK/dt as well as dM/dt and T_i as though they were orthogonal.

The Relationship Between Market Change and Technology Change.

If we work with the assumption of orthogonality, we can plot dK/dt versus dM/dt as shown in Figure 12. In this representation, we show the lines dividing the project team and department regions as curves. This is done in the belief that at the extremes, high rate of change in technology will make it more important for the project members to remain in their departments. Certainly, a dynamic market will be better served by project team organization. However the countering demand to keep the *engineers and scientists* in contact with their specialties, we would argue, is more important. Under these circumstances, the project team should comprise systems integrators and technically knowledgeable people, who can translate market needs into the language of the disciplines. The question thus becomes not one of 'either or', but one of staffing both the project team and departmental forms of organization simultaneously.

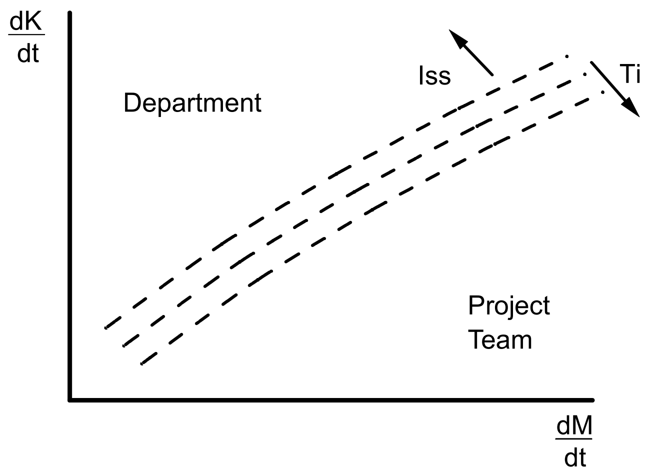


Figure 12. Bringing Market Dynamics into the Analysis.

In Figure 12, the effects of project duration and subsystem interdependence are shown as working at cross-purposes. Increasing interdependence, ceteris paribus, favors project team structure while increasing duration favors departmental structure. Perhaps this is better shown in a three dimensional diagram (Figure 13).

In this figure, the space devoted to project teams or departmental organization is determined by a surface passing through the three-dimensional space. This surface slices across the I_{ss} vs.: dM/dt plane and leans away from the dK/dt axis. Its projections are shown in Figure 13. The volume in front of the surface is the region for project team organization. The region behind the surface is the region in which matrixed departmental organization will produce higher performance.

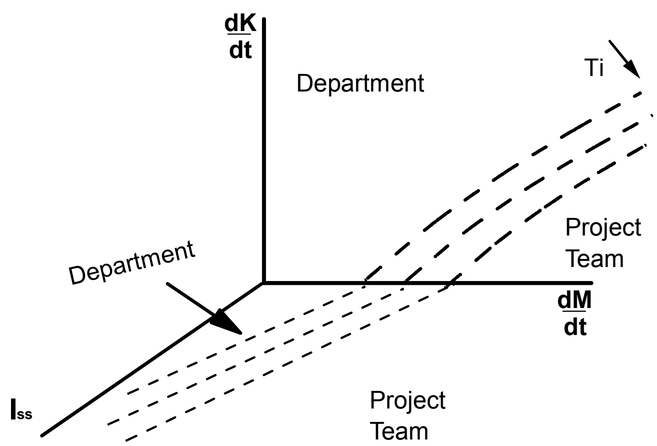


Figure 13. The Four Dimensions of the Organization Structure Space.

A Modest and Partial Empirical Confirmation.

(Marquis and Straight 1965) obtained measures of performance and information on whether people were organized in project teams or left in departments for 40 large development programs. They obtained two different performance measures from customers. These were technical performance and cost/schedule performance. Performance in terms of cost and schedule were highly correlated, so they combined them into a single measure. They then found that the way in which technical performance and cost/schedule performance related to organizational structure depended on the type of people they were considering. More specifically, it depended upon whether the people were concerned with the administration of the project, (e.g., those from accounting, purchasing or legal departments), or whether they were more concerned with the technical aspects of the project (engineers and scientists.)

The projects were all long term, running several years in duration. We do not know anything about interdependence, but we might reasonably assume that the technical staff were working from a more rapidly changing technology base than were the administrative staff. Their results are summarized in Table II.

Table II
The Relationship Between Organization Type and Performance for Two Classes of Personnel Assigned to Projects

	Type of Performance	
Staff Type	Budget & Schedule	Technical
Technical	No Difference	Departments
Administrative	Project Team	No Difference

From (Marquis and Straight 1965)

This is hardly a conclusive test of the theory, but it does show results in the direction that the theory would predict. For the performance measure most relevant to them, administrative staff (using more stable technologies) performed better in project teams. Technical staff (using more dynamic technologies) performed better when kept in specialist departments

Summary.
Where does all of this lead us? First, we now have a rational scheme for defining the appropriate structure for a product development organization. This structure must provide for good communication with both the sources of technical knowledge and of market intelligence. The organization must also enable very complex technical tasks to be coordinated effectively. These often conflicting goals can be accomplished if we fully understand the circumstances facing a project. What we

have done, in this paper, is to give the manager the concepts or tools to interpret different situations, so the most appropriate structure can be employed. In a subsequent paper, we will be more specific. We will examine organizational structure in detail. We will discuss the issues of implementation and, finally, the roles and responsibilities of different managers in making the organization work.

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