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PRODUCTION SMOOTHING
AND ORGANIZATIONAL DESIGN*

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Abstract

It is assumed that organizations carry inventories and order backlogs to stabilize and simplify the environment in which productive operations take place. To obtain the advantages of buffering, the organization must incur the costs of carrying inventories or of delaying customers and clients. The balancing of costs and benefits is called the smoothing problem. This paper addresses itself to the question of what an organization will do when the costs of buffering are too high, but still desires smooth operations. The prediction is that firms change the "givens" to the problem. In so doing they arrive at independent strategies and cooperative strategies for solving the smoothing problem.
Production Smoothing is usually considered within the context of a manufacturing firm faced with the problem of scheduling production and employment over a time horizon. The problem arises because the firm desires to have smooth patterns of production and hence stable employment and high capacity utilization, but yet provide adequate customer service with a small inventory investment. The previous research on the topic has consisted primarily of attempts to model the smoothing problem in mathematical terms and derive algorithms for determining least cost solutions for various demand and cost characteristics. While these efforts have born fruitful theoretical and practical results, the present paper conceives of the problem from the point of view of Organization Theory. The purpose of the paper is to describe techniques by which organizations reach acceptable solutions to the smoothing problem. The techniques are concerned not with the problem of moving along the cost curve to find the minimum but with methods of altering or dropping the cost curve. The methods are ways of altering the "givens" to the problem. The quantitative tools available can then be applied to the new problem.

The approach is to first define the smoothing problem and then predict the methods by which organizations work out acceptable solutions. In so doing, the analysis will be based on the theories of James D. Thompson [20, 21].
I. The Smoothing Problem

The smoothing problem is an economic problem associated with the use of buffers. That is, organizations carry inventories (if they produce to stock) or maintain order backlogs (if they produce to order) to uncouple or buffer successive stages in the process of creating the good or service in question. The economic problem is to balance the cost of inventories or customer service delays against the advantages allowed by buffering. The question which arises is, "What are the advantages against which the buffering costs are to be balanced?"

The primary motivation for buffering is to stabilize and simplify the environment in which the organization's production operations take place [18, p. 40]. The advantages which accrue due to stability and simplicity fall into three categories.

1. Planning can serve as the primary coordination mechanism.
2. The firm can acquire fixed facilities to meet average demand rather than peak demand.
3. Coordination problems can be brought within the computational bounds of the decision unit.

Let us take a closer look at each of these points.

The need for coordination arises from the use of specialized subunits. Most organizations subdivide their operations to make use of a technical division of labor and make use of specialized human and mechanized means for the performance of the subtasks. The increases in productive efficiency which result have been known at least since
Adam Smith's *The Wealth of Nations*. On the other hand, there is created a considerable degree of interdependence between the specialized subunits and a need to relate the activities of one unit to another [15, p. 159]. However, interdependence by itself causes no particular difficulty. If the pattern of interdependence is known in advance, then equipment could be designed and individuals provided with programs of behavior which account for the interactions between subunits. Balancing assembly lines is an example. So as long as the organization can control rates of production and product mixes, it can efficiently carry out a set of highly specialized activities without the need for continuous communication to coordinate the activities. The function of inventories and backorders is to allow the organization the short run, independent control of rates of production and product mixes it needs to preprogram the specialized productive activity. Coordination by planning is a substitute for coordination by communication.

The second reason for using buffers is that they allow the firm to meet a given level of sales with a minimum investment. The organization can acquire physical capacity to meet the average level of demand rather than the peak level if the peaks can be smoothed out by varying inventories. This is particularly true for a seasonal sales pattern. Thus the use of a buffer again allows the organization to independently control the demands for capacity for short periods of time to allow an efficient utilization of the fixed facilities.
The third use of buffers is to bring the coordination problem into the computational capacity of the decision unit. The first two uses of buffers brought the demands for capacity under the control of the firm. It now has to decide how to control the demands. In trying to discover how production schedulers solve job shop sequencing problems, Pounds found that the problem did not exist for the scheduler [17]. The organization quoted lead times sufficiently long so that the scheduler had no trouble keeping the shop loaded and meeting due dates. Thus the organization utilized an amount of buffering over and above that necessary to gain control of the demand variables. As firms can derive and manipulate more complex and realistic models of the situations the buffer can be reduced. An efficient sequencing algorithm could reduce this lead time which acts as a buffer to simplify the problem. Likewise in-process inventories break up a large problem into a series of small ones which are easier to schedule. It is against these three considerations which the buffering costs are to be balanced. The balancing is what is considered in this paper to be the smoothing problem.

The above view of inventories and order backlogs is not new. Almost every production [3] and production control text [14] speaks of the uncoupling properties of inventories and to a lesser extent order backlogs. It is also well-known that buffering has its costs. The various lot size formulations [11] and capacity constrained lot size [14, p. 312] are indicative of attempts to strike a balance between buffering costs and buffering benefits. However, it is not the purpose of the present paper to derive a new problem formulation or an algorithm.
for an existing formulation but to hypothesize what the organization will
do if it considers the costs of buffering too high, the benefits too low,
or is dissatisfied in some way with current performance.

II. Organizational Problem Solving or Decision-Making

If there is dissatisfaction concerning current performance then one
would predict that theories of organizational decision making or problem
solving would be relevant. The theories are those which are stated at a
level of abstraction high enough to encompass all of the specific
organizational reactions without having to relate each one individually.
The appropriate statements are taken from March and Simon and more
recent elaborations given by Thompson [20].

In a search for programs of activity to achieve
goals, the focus of attention will tend to move
from one class of variables to another in the
following general sequence. (1) Those variables
that are largely within the control of the
problem-solving individual or organizational
unit will be considered first... (2) If a
satisfactory program is not discovered by these
means attention will be directed to changing
other variables that are not under direct
control of the problem solvers... [15, pp. 179-180]

Thus we would predict that organizations would move sequentially from
variables over which it has independent control to variables over which
it has little or only partial control. It is assumed that this sequence
is related to the organization's perceptions of success. For purposes of
analysis let us dichotomize responses into independent actions and
cooperative actions. The primary difference between the two responses
is that independent actions refer to solutions worked out by the individual organization while the cooperative strategy solves the problem with the actions of two more organizations. The dichotomy and subclasses are shown in Table I. It is predicted that the order shown in the table is the order in which the alternatives would be examined by the organization. As soon as one was found to be satisfactory, the search would stop [7, Chapter 5]. In the remainder of the paper each of these alternatives shall be discussed.

Table I
Organizational Smoothing Strategies

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III. Independent Strategies

It will be recalled that the independent strategies are attempts by organizations to solve their problem individually by changing or considering changing variables which are largely under their control. Further, it should be recalled that the first variables changed were the buffers of inventories and order backlogs. The resulting performance was somehow perceived as unsatisfactory. Of course for some firms inventories and/or backlogs will result in satisfactory conditions causing no more search.
A. Buffering Substitutes

The first independent strategy considered would be to look for buffering substitutes. That is, the organization will look for ways to reduce inventory investment by varying factors which will trade-off with inventories. For most organizations with labor intensive operations this means varying the work force or its utilization of the work force. If the organization is not faced with a marked seasonal pattern, then it will vary the utilization of its work force. That is, the organization will use overtime and undertime to reduce some of the inventory investment. The trade-off between overtime and inventory has been formulated as a transportation problem [2] and examined by servo-mechanism theory [14, Chapter 8]. An alternative, but more costly method, is to vary the length of the work week. This is typically used, for instance, in the auto industry where work weeks vary from 30 to 50 hours per week.

When the demand pattern takes on more pronounced seasonal variations, then the organization considers still more costly methods since its inventory investment has grown. At this point the organization will consider varying the size of its work force through hiring and layoff. The trade-off between inventory, overtime, and workforce variation in the context of a seasonal sales pattern is probably the classic version of the production smoothing problem. This version of the problem has been formulated as a linear programming problem [12], a dynamic programming problem [1], quadratic costs [13], and as a computer simulation [22].
Another variable sometimes controllable by the organization is the product mix. By varying the labor intensity of the output, the production rate can be varied while the work force stays constant [24].

Along lines similar to product mix variation is the use of subcontracting. This represents a method of increasing effective capacity to meet increases in demand. The problem is that there may not be capacity available when it is needed. In essence subcontracting is a method of giving your smoothing problem to someone else.

For firms that are required to give immediate service but cannot use inventories, there is little left but to vary its rate of capacity utilization. The balancing of customer waiting costs versus additional capacity is a standard queueing problem. A good example is the electric utility which must be prepared to meet maximum demand that exists on any day. Although utilities have other ways to reduce the criticalness of the problem, they must absorb fluctuations in demand with fluctuations in capacity utilization.

Thus far we have sketched the well-known strategies that organizations adopt to efficiently utilize their fixed resources. The picture that emerges is that if the demands for organizational service vary then one or some combination of the following factors must also vary:

1. utilization of fixed facilities
2. inventory
3. customer service (backorders)
4. level of work force
5. utilization of work force
   a) overtime - undertime
   b) work week
6. subcontracting
7. product mix

For the majority of organizations some combination of these factors are combined into a strategy which is acceptable to the parties most affected. However, for enough organizations to make the subject interesting, the above variables cannot be combined to satisfy customers, clients, labor unions, controllers, sales managers, and production managers simultaneously. It is to the organization's reaction to this situation to which we now turn.

B. Influencing Demand

If the organization cannot devise an acceptable strategy for meeting the pattern of demand, the next step would be to try to alter the pattern of demand into a form for which the organization has an acceptable strategy.

For the business firm the controllable variables are price and promotion. The objective is to shift demand from sales peaks into the sales valleys by contracyclical pricing and promotion. Some attempts have been made to model the problem [23].
There are some attempts to make use of demand influences in the smoothing context. Research currently being performed by Michael Scott-Morton of M.I.T. illustrates the interaction between the sales manager, production manager, and production scheduler to determine the production schedule for the current time period. The firm produces durable goods which are expensive, subject to obsolescence, and yet the firm must provide some smoothing. By making use of the specialized knowledge of each participant and a graphical display device, the group tries to reach an agreeable solution by turning the appropriate "knobs" and balancing production and sales.

Another example is the NIMS (Nationwide Improved Mail Service) program of the Post Office. Part of this program is to persuade users to submit mail during the day instead of at five o'clock causing a surge in workload and delivery delays. The primary objective is to level the incoming workload. Still another example is the flower grower [4]. Most flowers are purchased for special days. These days occur mostly during one half of the year (Christmas, Valentine's Day, Easter, Memorial Day, Mother's Day, June weddings). But from June to Christmas there is only the normal funeral business. Since the growers have substantial land and greenhouse costs they would like continuous use of these fixed resources. However, the inability to carry inventory means they must have capacity to meet spring peaks and remain somewhat idle the remainder of the year. Their response is an attempt to create new demand in the form of impulse buying during summer and fall months. In this case, the organizations are not trying to shift demand from peaks to valleys but create new demand to fill the valleys.
The last method of smoothing demand is to simply refuse peak demands from non-regular customers. Although not a happy alternative, it does smooth the fillable demands.

C. Adaptations

The third independent response by an organization is that of adaptation. That is, if the organization fails to achieve an acceptable state of affairs by manipulating buffers and buffer substitutes and also cannot change the pattern of demand, it will next adapt in some form so that it can achieve an acceptable solution by manipulating variables under its control. Adaptations are also likely to be changes which are not an immediate response to a smoothing problem. However, the adaptation is likely to occur when other changes are being made, such as introduction of new product, new process, or construction of a new plant.

A well-known adaptation would be to introduce a product with a contracyclical demand pattern. In this way the total work load will remain constant throughout the period. The product must, however, have a contracyclical demand pattern and require the underutilized technology. An example is the manufacturer of air conditioners who produces room humidifiers.

An interesting adaptation was discovered in one of the early applications of the linear decision rules [6]. The study was made in a chocolate factory that had a pronounced seasonal variation with little summer demand following the Easter peak. The firm had arrived at a
strategy for smoothing which relied upon work force variation but at the same time found a way to remove the objections to hiring and layoff. The factory was located in a rural area and its operative work force consisted of the area farmers. Thus there was no objection to being laid off after the Easter peak and being rehired prior to the Christmas build-up. Since the same work force was rehired there was no training cost. The firm, through its location, had eliminated the factors which make work force variation objectionable.

The example highlights the two objections to work force variation. The first is the social consequences of laying off individuals on whom families are dependent for support. Also, most families have fixed financial obligations. The result is that work force variation and work week variation reduces the variable portion of the worker's income making the impact of variation more obvious to the individual. The second objection is the training costs incurred by continually introducing new workers.

Many of the adaptations are attempts to eliminate one or both of the objections. Vergin [22] relates that an organization used work force variation to solve its smoothing problem by hiring women who were not the sole support of their families and did not object to occasional layoffs. Also there are many firms providing non-storable services which design jobs to require little training and make use of part-time help consisting of students and women. The phone company varies its work force during the day. However, no particular problem arises since the work force consists of young women who welcome the opportunity for shopping, sun bathing, etc.
Much of the labor union activity is concerned with removing the objection concerning wage variation brought about by the smoothing problem. Some unions and firms have reached agreements concerning a guaranteed annual wage. These programs eliminate the financial variation for the worker but still allow the firm the option of varying the work week and hence to reduce inventory. It does, however, make labor a fixed resource. The control over labor cost is exercised less frequently. The problem is transformed into one of forecasting to control the size of the labor force.

In summary, it has been stated that firms seek to buffer their operations so as to simplify and stabilize the environment in which these operations take place. Next, it was suggested that for many firms sole reliance upon inventories and order backlogs to obtain the needed buffering would be unacceptable. In order to achieve an acceptable state of affairs, organizations would search among the variables it could control and which would trade-off with inventory and backorders. Failing to satisfactorily adjust operations to demand, it was predicted that the next step would be to change the demand to fit the operations. If influencing demand is not feasible, the organization will adapt to remove the objections to the available solutions. For the majority of organizations an acceptable state of affairs can be attained by one of the above mechanisms. However, with increased mechanization some industries have reached what are cooperative solutions to the smoothing problem.
IV. **Cooperative Strategies**

The cooperative strategies arise when a group of organizations act in a coordinated fashion so as to obtain solutions to joint problems. In Table I, three cooperative strategies were identified — competitive cooperation, bargaining, and coalition. These three differ primarily on the strength of commitment between the cooperators.

A. **Competitive Cooperation**

The strategy of competitive cooperation seems to evolve when the independent adaptations of organizations in the same industry become patterned. In the cases to be described, technological change and mechanization caused firms to adapt. The subset of original firms which remained after the adaptation survived because they fit into the patterned response. There is no evidence that there was overt collusion. The patterned response and resulting solution to the smoothing problem was obtained through the workings of the market. An example will provide some clarification.

The coal industry has always faced a seasonal pattern of demand the amplitude of which has been reduced recently by the loss of the home heating market [5]. The smoothing problem arises because it is difficult to hold an inventory in storage. The commodity is bulky and is subject to spontaneous combustion. Work force variation was costly, due to the unions, and of limited usefulness, due to the highly mechanized technology of coal mining. Nor was variation in capacity utilization an attractive
solution. The mechanized capacity was usually specific to a particular mine and therefore quite expensive. The alternative of acquiring capacity to meet a peak demand was to be avoided. The solution to the problem can be seen by viewing the organizational design of the vertically integrated firms.

The vertically integrated firms in the coal industry were usually steel companies that had acquired mines so as to guarantee a continuous source of high quality coking coals. They designed their mines, however, to produce only the minimum amount of coal as determined by the seasonal and business cycle fluctuations. In Figure 1, the sales pattern shows a seasonal variation. The firm faced with this pattern would design its capacity as shown and purchase from others an amount indicated by the shaded portion. The result is that the integrated firm can acquire equipment specific to rates of output and guarantee continuous utilization of capacity. The large non-vertically integrated coal firms have reacted
similarly. The demand is not directly controlled by the firm in this case. The coal companies have acquired twenty year requirements contracts from public utilities. However, this differs from vertical integration only in legal definition.

The problem with using subcontracting or outside purchases to meet peak demands was mentioned earlier in the paper. It requires that there exist organizations that are willing to accept the fluctuations on a regular basis so that the integrated firm can depend upon them to meet its peak. It is this point that suggests the cooperativeness of the solution. In the coal industry there are many small firms which could not mechanize their facilities due to the large capital requirements. Instead they have remained very flexible. They generally are not unionized, have favorable locations which permit them to compete, or have owners willing to accept low rates of return. Their flexibility and the design of the integrated firms have allowed them to exist. Collectively this structure of large, integrated firms and small, independent firms represents a cooperative solution to the smoothing problem.

Technological change has brought about similar reactions in the oil industry [16]. The refineries of most of the integrated companies are designed to provide a large fraction of the firm's marketing requirements. The remainder is purchased from the small refineries. Further, the small refinery is designed to be flexible so that he can quickly adjust product mixes and rates of output. The flexibility of the small
refinery allows the large refinery to be designed for specific rates of output and guarantee continuous use. The large refineries have cost curves as shown in Figure 2. These are contrasted with those of the flexible plant. The rising variable costs make through-put maintenance a primary objective of the production smoothing program. Rising available costs are another reason for buffering. Again there is a cooperative solution to what is a critical production smoothing problem. It is also probable that the total industry cost for meeting demand is less than it would be if all plants were designed to be flexible.

The picture which emerges from these examples is that technological change can lead to expensive plants and/or rising variable costs. The result is that continuous operation is the desired mode of operation.
without overcapacity. Reports for public consumption indicate that the paper industry is currently going through the adjustment process initiated by technical change [9] and that some firms are solving smoothing by organizational design [10]. It should not be inferred that production smoothing causes vertical integration. This is probably not true. Production smoothing is a major consideration when designing the balance among the vertically integrated components.

B. Bargaining

A bargaining strategy evolves as a solution to the smoothing problem when two organizations, a customer and a supplier, attempt to coordinate more closely their respective operations.

A good example of the conditions conducive to bargaining are a highly mechanized production facility, producing to customer orders, and customers want, and can get elsewhere, quick delivery service. Although this sounds like a nightmare which must be solved by overinvestment, Dutton relates a descriptive study of a corrugated box manufacturer with just this problem [8]. What developed was a close relationship between supplier and major users with the result being a stable work load on the production facility. The smooth load was attained by a negotiation process between the producer and the customer. The producer would seek agreement from the customer to increase lots, split lots, delay delivery, or speed up delivery so that the producer could smooth the work load. The objective in this case is to smooth out the demand pattern and is similar in concept to the independent strategy of demand influence. It is
different, however, in that the influence is continual and requires an organization designed to handle the communication between schedulers, salesmen, and customers. The transactions between producer and customer cannot be programmed in advance. Therefore coordination depends upon communication and cannot be planned in advance [19]. The demand influence strategy can make use of programmed, standardized transactions which greatly simplify the coordination and communication involved. The success of the operation depends on the amount of cooperation in the bargaining process.

The Post Office is another organization using the bargaining strategy. It has a customer relations department which negotiates the timing of billing and advertising mailings of all major users. The objective is to smooth the demands for service made by users requiring large amounts of service. The bargaining is to work out the timing to the satisfaction of the user and the Post Office's operations.

The Post Office will also bargain concerning the amount of work performed by the user and the department. The user can reduce his postal rate by doing a large portion of the sorting and packing. This process varies the department's work load by a mechanism similar to subcontracting except the work is performed by either the user or the producer.

The second strategy, bargaining, is again one which depends upon cooperation between organizations to solve the smoothing problem for one or both organizations. The bargaining strategy, like the cooperative
strategy, requires an appropriate organizational design as well as cooperation. For bargaining the organization must be designed for efficient communication between the interested parties. It seems to be a fruitful area for mechanized information retrieval and display devices.

C. Coalition

A coalition is formed when a group of organizations acts as a single unit to solve a common problem. Although the anti-trust laws severely limit the forms of coalitions, the concept does have theoretical significance. Two examples can also be discussed.

The best example of a coalition designed to solve a smoothing problem is the electric power networks consisting of many independent electric utilities. The electric companies produce a non-storable commodity which must be provided without delay and the consequences of a stockout are significant. If every firm had to provide capacity to meet rare occurrences of peak demand, the investment would be substantial. By coalescing the utilities can pool their resources and reduce the total investment needed by all the firms in the network. At the same time the firms are restricted in the amount of independent activity they can undertake. There must be some subordination of individual interests for the good of the network.

The second example of coalition action is the coal industry. Earlier it was discussed as an example of competitive cooperation. Recall that integrated firms had designed their organizations to meet estimated
minimum requirements in order to guarantee continuous operation. In 1954, 1958, and again in 1961, recessions depressed the level of demand below the level for which the integrated mines were designed. Rather than reduce output, the large coal companies coalesced to try to enforce minimum wage laws to apply to the non-union firms. This was followed by attempts to close marketing channels which the small producer needed to transport his output. Both attempts went under labels compatible with the enforcement of wage legislation (Walsh-Healy Act and the National Bituminous Coal Wage Agreement of 1950). However, the real purpose was to reduce the output of the non-integrated mines [5, Chapter 7]. The coalition behavior was necessary to achieve continuous operation. With the return of economic prosperity, the collective action declined.

This last section has described cooperative solutions to production smoothing problems. The examples have emphasized the fact that the mechanized technologies create conditions conducive to fostering cooperative solutions. These solutions were seen to be both evolutionary and deliberately planned.

V. Summary

The present paper has tried to analyze the production smoothing problem from a broad descriptive point of view with respect to possible solutions. It was first assumed that organizations attempt to stabilize and simplifying the environment in which their basic operations take place. The primary mechanisms for this were to carry inventories and order backlogs. The smoothing problem arose due to the fact that buffers have
costs. In simple balancing buffering costs against buffering advantages, the organization may not obtain an acceptable state of affairs. The major portion of the paper concerned itself with the ways in which organizations attained an acceptable state.

Following theories of organizational decision making it was hypothesized that organizations would first change variables under their control and move to variables partially controlled in their attempts to find a solution. The search was dichotomized into independent and cooperative strategies. The independent strategies consisted of first searching for buffer substitutes, second, changing demand to the advantage of operations, and then adapting to remove objections to otherwise feasible alternatives. The cooperative solutions consisted of competitive cooperation wherein a series of independent adaptations become patterned into a cooperative solution. Bargaining was a process of mutual adjustment so as to help solve the smoothing problem for the producer. And last, a coalition was formed when it was feasible and a problem sufficiently critical arose to force collective action.

With increasing mechanization of productive operations, the smoothing problem will arise quite often. The descriptions put forth in this paper can provide ideas of a normative nature as these smoothing problems arise.
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