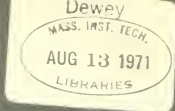


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A System Dynamics Design
and Implementation of Inventory Policies

by

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ABSTRACT

Most organizations have to cope with short term random movements in supply and demand. The usual methods of absorbing random movements utilize backlog, inventory, and sources of supply and demand which are controllable in the short run. This paper is a report of the use of system dynamics for the design and implementation of an improved information and control system to manage the absorption of short term random movements in the butane system at the Bayway Refinery, New Jersey, of the Humble Oil and Refining Company. Savings of over \$100,000 per year have resulted since implementation.

Short term random movements in both supply and demand create problems and raise costs for all organizations which offer products or services. For example, the demand for loans and the supply of deposits at a bank fluctuate daily in an unpredictable manner and yet the bank must (1) process requests quickly or lose business, (2) honor withdrawals immediately, and (3) meet regulatory requirements. Orders for manufactured products arrive randomly, frequently with five to one variations week to week and production can vary two to one from week to week. Yet the firm must meet delivery dates on the orders. Other organizations, whether they be hospitals, trucking companies or governmental agencies, face similar problems of coping with short-term movements in supply and demand.

The typical situation is shown in Figure 1. Short term random movements exist in both the normal demand and in the low cost supply. However, the low cost supply source also tends to be sluggish. Consequently, it can't react to the short term random movement. As shown in Figure 1, three methods of coping with the randomness usually exist. The first of these is an inventory or a backlog located between supply and demand. This inventory or backlog is a pool which absorbs the random surges and in so doing effectively decouples supply and demand in the short run. The second method of coping with the randomness is a source of supply which is fast reacting and can be turned on whenever needed. Overtime in manufacturing organizations or the federal funds market for banks are examples of short term sources of supply. However, these fast acting supply sources are usually expensive, so firms prefer to minimize their use. The third method of coping

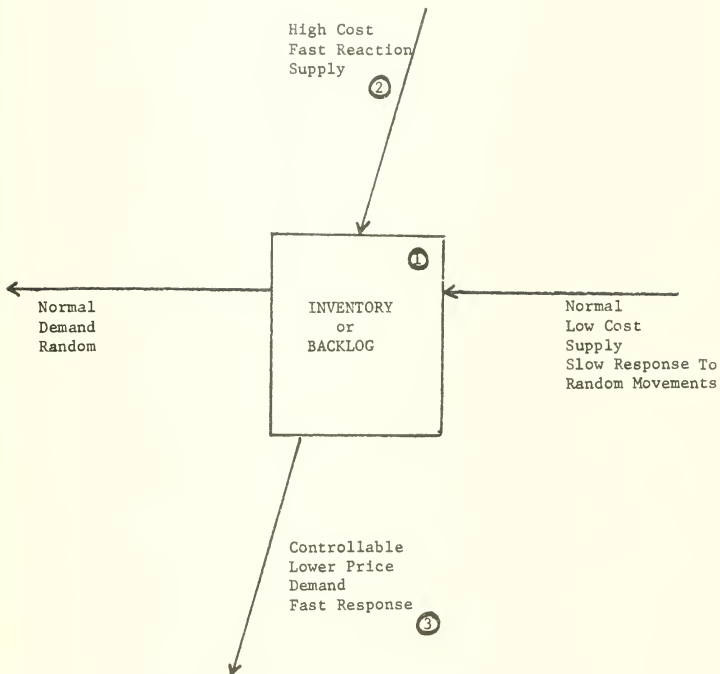


Figure 1: Demand and Supply Situation

with randomness is to control demand in the short run, usually by establishing a controllable market. In the controllable market the organization determines when the demand will be filled. A familiar example is the stand-by airfare for young people. The airlines produce a seat only when their normal demand cannot fill an airplane. Thus demand increases rapidly when supply is available. For this ability to control demand in the short run, the organization must usually accept a lower price, as in the youth stand-by fare, or offer extra services. Consequently, the organization tries to keep the controllable market from displacing any normal demand and thus reducing profits.

The problem that management faces is how to design the information flow and the decision rules for controlling the inventory or backlog, the different sources of supply, and the controllable demand in order to absorb at low cost the random movements in supply and demand. The first purpose of this paper is to show a system dynamics (Forrester, Swanson, 4,11) approach to the design of management systems to reduce the costs of randomness. The approach is demonstrated by reporting a successful application at the Bayway Refinery at the Humble Oil and Refining Company. This problem of absorbing random variation is one not normally treated in the management science literature. For example, Holt et. al. (7) in their classic work addressed the minimization of costs of a system including an inventory, workforce, which is the low cost but sluggish source of supply and overtime, which is the fast acting, but expensive supply source. However, in order to find analytically an optimal solution they were obliged to assume a linear system with quadratic costs. However, random movements do not influence the

optimal information flow and control laws in the linear dynamics, quadratic cost system. Thus, the assumption which allows an optimal solution places the problem into the only form where a separate problem of absorbing the randomness does not exist. Yet, many real world systems are neither linear nor do they have quadratic cost functions. For these systems economic absorption of short term random movement can be significant as in the example discussed below where savings of more than \$100,000 per year have been realized.

This paper also addresses some issues in implementation. Management science has not had an outstanding record of successful implementation (Little,8). But there is now an emerging body of experience pointing to approaches which lead to successful implementation. The discussion of implementation in this paper follows the description of the successful application to the butane system at the Bayway Refinery.

BUTANE COORDINATION

Butane gives the volatility to gasoline to start a cold engine. Butane is available at low cost so it is also a profitable ingredient in gasoline, which leads refiners to blend as much butane into gasoline as they can. However, the amount of butane blended in gasoline is limited, since too much will produce vapor lock. In the northern United States, more butane is blended into gasoline in the winter since lower temperatures require higher volatility for starting and the lower temperatures also retard vapor lock. Consequently, there is a seasonal swing in demand for butane and a consequent fluctuation in price.

At the Bayway Refinery two large caverns have been mined out of rock in order to store butane during the summer when demand is low so that it is available in the winter when demand is high. Figure 2 shows the sources of supply and the demands for butane. The major source of butane at the Bayway Refinery is the refinery itself where butane is a byproduct of several processes, especially the catalytic cracking of crude oil. The supply of butane from the refinery cannot be controlled except by slowing down the refinery which is very costly. The second source of butane is the Gulf Coast of the United States where more butane is produced than is consumed. Butane is collected from gas fields near the Gulf Coast and shipped by tanker to the Bayway Refinery. This source of supply is controllable, but not in the short run. It takes about ten days to receive butane at the caverns after the decision to purchase is made. A third source of butane, as shown in Figure 2, is reduction of alkylate manufacturing. Some of the butane produced by catalytic cracking is used as an ingredient in alkylate manufacture and by reducing the production of alkylate, butane is freed for gasoline blending. This source of supply can be activated in a matter of hours and can provide up to 9,000 barrels per day of butane. The economic demand for butane is blending in gasoline which uses about 10,000 barrels per day ranging from an average of 5,500 barrels per day in the summer to 14,000 barrels per day in the winter. Figure 2 also shows two other ways of consuming butane: (1) the refinery fuel system, and (2) the flare. When the caverns are nearly filled with butane and it appears that there might not be room to store additional butane, the butane is burned in the fuel system of the refinery up to the maximum capacity of the system, or if it is absolutely necessary to dispose of excess supply, the butane is simply burned in the

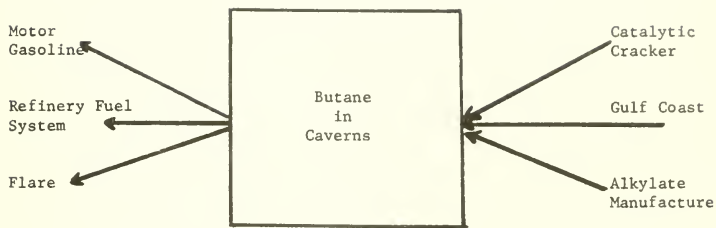


Figure 2: Bayway Refinery Supply and Demand for Butane

flare. Butane burned in the fuel system replaces a lower priced fuel at a loss of several dollars per barrel of butane. When butane is flared, there is a complete loss of the value of the butane.

THE PROBLEM

For the three years prior to this study, the butane control system had failed to achieve optimum operation. Every fall after heavy purchases of butane in the summer, the inventory neared the capacity of the caverns and excess butane produced by the refinery had to be disposed of. Slowing down the refinery or pouring the excess butane on the ground and risking the destruction of the refinery are costly methods of disposals. Instead, every fall for three years in a row, excess butane was burned in the refinery fuel system at a loss of several dollars a barrel or it is burned in the atmosphere at a complete loss. In addition, during each of the three preceding winters, when the butane inventory approached its minimum and the need for butane exceeded the supply from the Gulf Coast and the refinery, butane was acquired at an unnecessarily high price by reducing the manufacture of aklylate.

THE HYPOTHESIS

The beginning hypothesis of the study reported below is that the basic managerial policies for controlling the butane system created unnecessary cost because they were unable to cope effectively with randomness and unforeseen events. It was not believed that unfortuante random events or occasional management mistakes were the fundamental source of the unnecessary costs. Supporting this hypothesis was the fact that the same pattern of behavior had been observed three years in a row when each year a different engineer

had coordinated the butane system and different specific events had occurred. It appeared that the butane inventory was allowed to rise too high and fall too low so that it was unable to absorb any random movements in either supply or demand. Consequently, the short term and expensive control mechanisms had to respond. When the caverns were half full, there were no problems since the ability of butane inventory to move widely in either direction could absorb all the short term, random movements.

This hypothesis then was tested. The test is performed by first constructing a model of the butane system based upon knowledge of how individual parts of the system worked and of how they affect each other. Then the model is tested to see if behavior matches reality, If it does, confidence in the hypothesis grows. The hypothesis is further confirmed when implications of the hypothesis are tested in the model and the expected results are achieved. In this case the implications of the hypothesis were that basic management policy changes would have a major improvement upon behavior.

When and if the fundamental hypothesis is confirmed, the next use of the model is to design improved management policy. In this case the policy issues to be addressed were:

1. What is the desired amount of butane in the cavern at any time during the year?
2. How rapidly and strongly should ordering butane from the Gulf Coast respond to changes in the inventory?
3. What should be the time constraints in the smoothing equation for measuring yields of butane from the catalytic cracking unit?

THE MODEL

Figure 3 is a flow diagram of the model. The model represents the inventory of the butane, the three sources and three uses of butane, and the information system and control policies by which the butane system is managed. In the flow diagram the rectangle is the inventory of butane. The solid arrows flowing into the butane inventory represent the three sources of butane: (1) shipments from the Gulf Coast, (2) a product of the catalytic cracking process, and (3) reduction of alkylate manufacture. The segmented rectangle in the flow of butane from the Gulf Coast represents the average, ten day delay to move butane from gas fields in Texas and Louisiana to the Bayway Refinery in New Jersey. The solid arrows leaving the inventory represent the three uses of butane: (1) gasoline blending, (2) burning butane in the refinery fuel system, and (3) flaring butane to the atmosphere. The values in the flows of butane represent the control policies that govern the flows. There is a control policy in each of the six flows of butane. The dashed arrows show the information flow from information source to the policy which uses it. As we can see the policies that control inventory all use information about the size of the butane inventory.

The Demand for Butane. Demand for butane to blend in gasoline is an exogenous input to the model. The average demand for butane is highly predictable, but there are two types of unpredictable events to which the butane control system must respond. First, gasoline is blended in large tanks as a batch process and shipment from these tanks is in discrete units by pipeline or barge. Any delay in pipeline or barge availability postpones

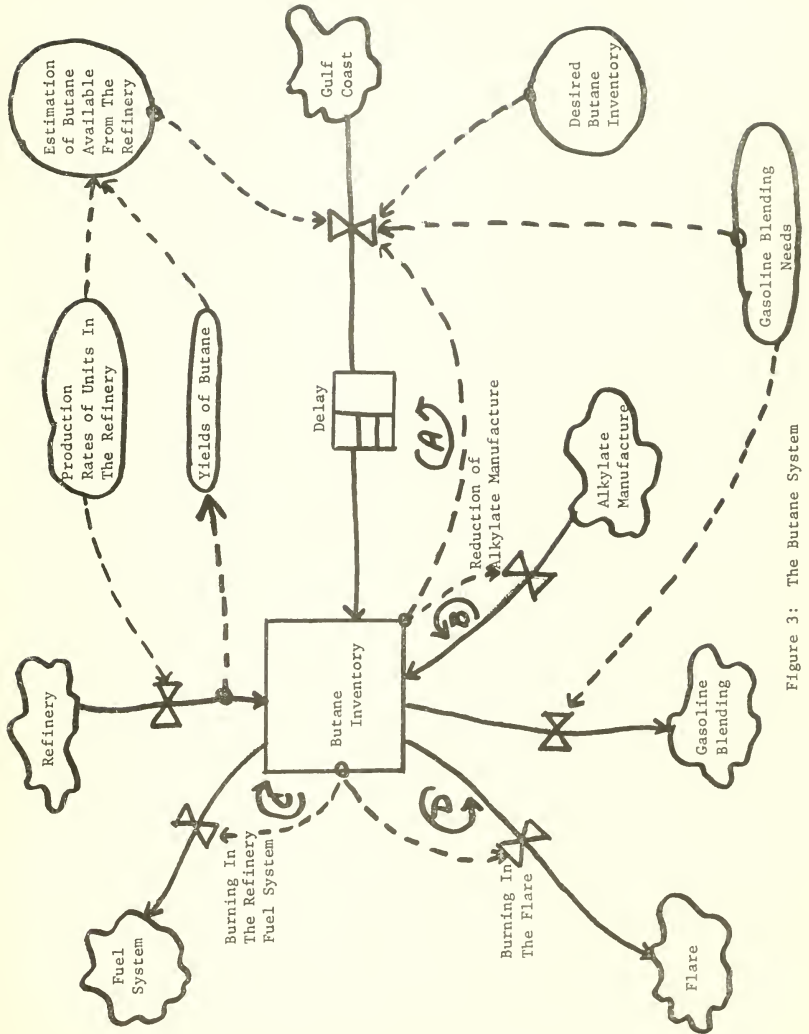


Figure 3: The Butane System

scheduled blending which forces variation in the use of butane from zero to 25,000 barrels per day with little advance notice. However, the daily variations are negatively correlated so that random unforeseen shifts in the blending of butane in gasoline are small week to week. The second unpredictable event is the long term shift in butane demand due to a shift in the weather or a change in demand for gasoline at retail.

When formulating the model it was decided not to represent directly the day to day short term random movements in butane demand due to transportation delays. The relevant aspect of the random variation which must be represented in the model is the effect of the randomness on the butane coordinators control actions represented in the equations defining the control policy. The demand for butane was thus represented as an exogenous time series incorporating the seasonal demand, long term growth, and the possibility to introduce long term shifts in demand.

Supply of Butane from the Refinery. The other exogenous input to the model is the production of butane by the refinery, most of which is produced by the catalytic cracking unit. This too is subject to daily random movements and unforeseen long term shifts. Here the problem is to identify the long term shifts in butane yields while ignoring the random movement, which is done by averaging the butane yields. The model represented the daily random movements by a random noise generator available in the DYNAMO language and it also represented the long term shifts in the butane yield by an exogenous function added to the parameter of expected yield.

Acquisition of Butane from the Gulf Coast. The coordinator of the butane system estimates the amount of butane he needs to import from the Gulf Coast by estimating the gasoline blending needs of butane and the generation of

butane from the refinery. The average use of butane for gasoline blending ranges from 5,500 to 14,000 barrels per day while about 6,500 barrels per day are produced at the refinery. If estimated needs exceed refinery production, the coordinator decides how he will make up the deficit between reducing butane inventories and bringing butane from the Gulf Coast. He then sends his purchase requirements to the Gulf Coast. The purchased butane arrives at Bayway in about ten days.

The representation of this process in the model is divided into two parts: (1) the arrival of butane to fill the expected deficit between needs of butane and that produced by the refinery and (2) the adjustment of the butane inventory to its desired value. Since the average needs of butane in gasoline blending and the expected production of butane from the refinery are known in advance and proper planning and advance ordering is done, the model simply calculated the arrival of butane from current data representing effective planning. The other determinant of butane imported from the Gulf Coast is the attempt to adjust the butane inventory to its desired levels. This adjustment may require either an increase in butane imports over the expected deficit if inventories are too low or a reduction of the import of butane if inventories are too high. The butane ordered from the Gulf to adjust inventory is:

$$\begin{array}{l} \text{Butane Ordered} \\ \text{from Gulf to} \\ \text{Adjust Inventories} \end{array} = \frac{\text{Desired Butane} - \text{Actual Butane}}{\text{Time to Correct Inventory}} \\ \text{Inventory} \qquad \qquad \text{Inventory} \\ \text{(initially 30 days)}$$

The difference between the desired butane inventory and the actual butane inventory divided by a constant which is an average correction time.

The longer the correction time, the smaller will be the effect of inventory upon the arrival of butane from the Gulf Coast. The correction time was estimated to be thirty days which may appear long, but the relationships of the butane coordinator at the Bayway Refinery with headquarters in Houston dictates that adjustment in ordering butane from the Gulf be done slowly and smoothly which results in the long correction time. The desired inventory is seasonal. It peaks at 230,000 barrels at October 1 and reaches a low of 30,000 barrels on April 1. This curve had been set when the caverns were dug, had been sanctified by tradition, was widely known, and was rigorously followed. Yet, as we shall see later, this curve of desired inventory was a cause of the unnecessary costs.

The butane ordered for inventory adjustment enters a ten day third-order exponential delay (for an explanation of this delay see Forrester, 4, p. 87) which represents the time it takes to gather the butane and ship it to New Jersey.

The actual flow of butane to New Jersey is the sum of the butane ordered to fill the expected deficit of butane and the adjustment for the butane inventory. The transportation of butane from the Gulf Coast is limited to 4,500 barrels a day. This limit is imposed by the capacity of crude oil tankers to hold butane in crude oil.

The model represents the flow of butane from the Gulf as a continuous process, even though butane arrives in batches about every six days when the crude oil tankers arrive. The continuous representation is not realistic, yet it appeared adequate since (1) the arrival of tankers is precisely scheduled so that the discreteness is compensated for in the planning process and (2) it was hypothesized that the cause of the problem is the overall system interaction not in details of one part.

Short Term Control of the Butane Inventory. Short term control of butane is accomplished in three ways. The first of these is reducing the manufacture of alkylate to produce additional butane when the inventory is low. The control process is a feedback loop which interconnects inventory and the reduction of alkylate manufacture (loop B, Figure 3). The representation of this control is very simple. Whenever the butane inventory falls below 50,000 barrels, alkylate manufacture is reduced to produce ten percent of the difference between 50,000 barrels and the butane inventory each day.

The second short term control of butane is handled by burning butane in the refinery fuel system, which is a feedback control process linking the butane inventory and burning in the fuel system (loop C, Figure 3). The control of burning is represented very much as is the reduction of alkylate manufacture. As the butane inventory exceeds 220,000 barrels, ten percent of the difference between the butane inventory and 220,000 barrels is burned in the fuel system each day. Thus, if the butane inventory is 230,000 barrels, the model burns 1,000 barrels of butane in the fuel system each day.

The reader may notice a paradox. The model formulation assumes that butane begins to be burned as the inventory exceeds 220,000 barrels and yet the desired peak inventory is 230,000 barrels per day. This seems inconsistent. However, it describes behavior. The butane manager finds himself tied into the traditional curve of desired inventory which peaks at 230,000 barrels. Yet during actual operations the random use and the movements in the production of butane and the prospect of prolonged hot weather in the fall and the consequent reduced utilization of butane present the butane coordinator with the prospect of excess butane and no storage capacity. Such a situation is intolerable. It might cause the slow down of the refinery. There is only

a 10,000 barrel excess capacity when inventory is 230,000 barrels and if gasoline is not blended for two days for some reason, the 6,500 barrels per day refinery output will exceed the storage capacity. Some storage capacity must always be available, for even the short term burning of butane takes several hours to implement and capacity must be available to cope with surges during the several hours. Since burning butane in the fuel system is traditional in the fall, and the risks of not having capacity to store a surge of butane are high, the butane coordinator makes sure that he always has some excess storage capacity by burning butane even before the desired butane inventory is reached.

The third short term control of butane is flaring butane as shown by the feedback control loop D in Figure 3. The flare is used only in an emergency when there is no storage space left for butane. In this model all excess butane is flared when the inventory is full at 240,000 barrels.

Having seen the above parts of the model and the flow diagram in Figure 3, the reader should now understand the nature of the model. The complete model was written in about 150 DYNAMO statements which includes all equations, parameters, inputs, and output specifications. It took five afternoons and parts of the evenings to conceptualize the problem, outline the model, code and debug it, and obtain the first good simulation run.

Simulation of Behavior Under Old Policies

Figure 4 shows the output of the simulation model using the previous information flow and control policies which have been described above. The graph shows slightly more than one year of behavior of the butane system. The variables plotted in the upper part of the graph are the actual inventory of butane and the desired inventory of butane. The scales are shown to the

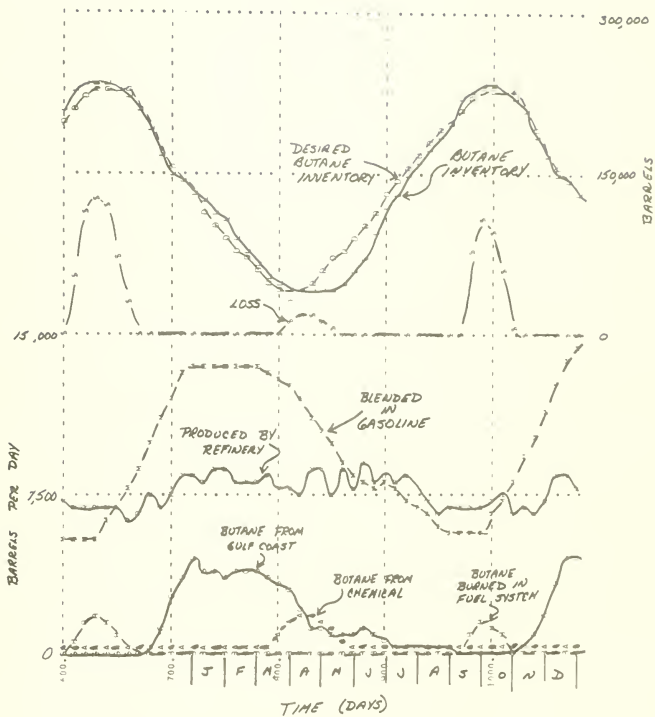


Figure 4
Simulation Output of Old Policies

right of the plot and range from zero to 300,000 barrels. In the middle of the graph is the plot of dollar loss due to burning butane in the fuel system, flaring it, or reducing the manufacture of alkylate. In the bottom half of the graph are shown all the rates of flow of butane into and out of the inventory. The scales are to the left and range from zero to 15,000 barrels per day. The time scale of this run is in days of which the part shown is the last third of a three year or 1080 day run. The months of the year are also marked in the scale.

As we can see, the various control mechanisms have been very effective in keeping the actual inventory of butane close to the desired inventory. This close match between desired and actual inventory shows that inventory is not being used to absorb random movements. This tight control of inventory required other mechanisms to absorb the randomness which in this case is the burning of butane in the fuel system during the fall of each year and reducing the manufacture of alkylate in the late winter and early spring. The model calculated several hundred thousand dollars in unnecessary costs over the three-year period.

Comparison of the model behavior with reality gave confidence that the model represented reality adequately enough to be used to design an information and control system to improve the management of the butane system. The general characteristics of the model fit those of reality. Actual inventory and desired inventory followed closely in reality. Burning butane had comparable timing and amount. Reduction of alkylate manufacture occurred in reality as shown in the plots of the computer simulation here. Unnecessary costs calculated by the computer model approximated reality closely.

Analysis of the Behavior of the Old Policies. When we look at the behavior of the former policies, we discover that the problems occur when the inventory is near capacity or nearly depleted. When butane inventory is near its peak, available capacity is only 10,000 barrels. Ten thousand barrels represents less than two day's utilization of butane in October. If for some reason gasoline is not blended for a day, which is possible, the coordinator will face a serious decision of how to handle the excess butane. In addition, the peak in inventory comes when gasoline blending consumes about 6,000 barrels a day and the refinery is producing about 7,500 barrels a day of butane. Thus, there is a normal excess that must be disposed of which helps force burning. Only the rapid increase in blending demand keeps the burning requirement low. Unfortunately, the butane system coordinator faces the possibility that a warm fall will depress the demand for butane. If lower blending rates are prolonged only ten days, butane capacity is exceeded. The peak in inventory comes at a time when there is no effective method for reducing supply and the probability of demand falling below supply is high.

In addition we note that the burning of butane begins almost immediately after the last shipment of butane from the Gulf Coast is received. Butane is being shipped from the Gulf in order to fill the inventory and then it is burned.

A very similar story is seen in March of each year when butane reaches its lowest levels. At this time butane is nearly at the empty level of 30,000 barrels (30,000 barrels provides the minimum pressure needed to move butane out of the cavern). Here we see the desired level of butane inventory is 30,000 barrels which gives no cushion to meet an unexpectedly high demand

or lag in the deliveries of butane. In February and March 10,000 barrels represents about a day's utilization of butane. With 7,500 barrels per day being produced by the refinery, about 4,000 barrels must be brought in from the Gulf each day in February and about 3,500 barrels in March. Thus, if for some reason an unexpectedly cold March occurs or if a shipment of butane from the Gulf Coast is delayed, especially by storms in the Atlantic which occur in February and March, 10,000 barrels of butane will be needed in two or three days.

At both the peaks and the valley of the inventory, inventory cannot be used to absorb random movements. Part of the reason for this is that the timing of the desired inventory does not occur at the natural valley of the inventory. The natural valley in inventory should occur when the need for blending in gasoline drops below the butane produced by the refinery which occurs at about June 1. The natural inventory peak occurs at the time when butane used in blending gasoline rises and surpasses the production of butane by the refinery. This normally occurs in late October which is when the peak in the desired inventory occurs. Unfortunately when the peak and valley in the desired inventory were so near the limits of the inventory, there is no cushion to absorb random but probably events.

New Policies

The principal and most important change in the policies is a new desired inventory. Under the new policy, the minimum inventory is 50,000 barrels on June 1 compared with 30,000 barrels on April 1; the new maximum is 190,000 barrels on December 1 compared with the old policy of 230,000 barrels on October 1.

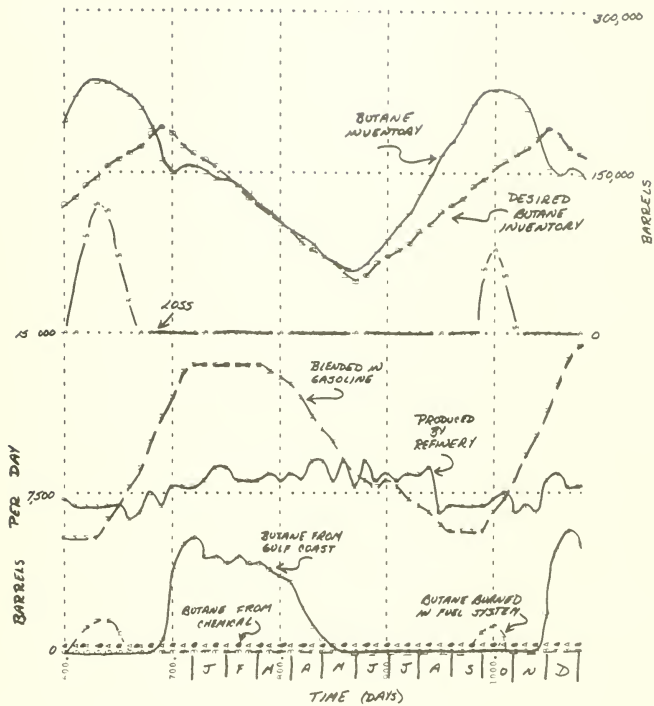


Figure 5

Simulation Output of New Policies

The time to average yields of butane from the catalytic cracking unit was set at ten days.

The equation controlling the long term supply of butane from the Gulf Coast is unchanged while the time to correct the butane inventory is set to 15 days instead of 30 days in the old policy.

The policies controlling the burning of butane in the fuel system, controlling the burning of butane in the flare, and controlling the reduction of alkylate manufacture are unchanged.

Behavior of the New Policies. Figure 5 shows the output of the simulation run with the new policies. The variables and scales are identical with those in the first run of Figure 4. The simulation of the new policies showed a reduction of unnecessary costs due to burning butane or making chemicals by several hundred thousand dollars over a three year period. The net gain to the company of the new policies is predicted by the model to be over \$100,000 annually. (n.b., the first model contained estimates of certain parameter values and exogenous time series which underestimated the savings that a more detailed model predicted and reality confirms. However, the recommended policy was unchanged as the parameter and exogenous time series estimates were improved.)

The reasons for the savings from the new policy are: (1) timing the valley to occur at the natural valley of inventory, (2) delaying the peak in order to avoid the condition of importing butane from the Gulf just to burn it, and (3) allowing the inventory to absorb random changes at the peak and valley by lowering the desired peak and raising the desired valley. By shifting the inventory low to June 1, which is a time when demand for butane is about equal to the refinery production of butane, a delay in shipment of

butane from the Gulf Coast has a much smaller affect on the need to draw butane from the inventory than a delay in April 1. As we can see this has been completely effective since no butane is supplied by reducing the manufacture of alkylate. However, this simulation run does not show such dramatic results in reducing burning of butane in the fuel system. While burning has been cut in half near day 1000 in the simulation runs, it has not been eliminated. The reason for burning in the run is that in the summer the refinery simply produced more butane than could be blended with gasoline or stored. However, simulation of a model with more accurate parameter estimates predicted that the new policies would also eliminate the burning of butane, which proved correct when implemented.

Sensitivity Tests of the New Policy. The sensitivity of the new policy to changes in (1) the time to correct the inventory, (2) the delay in gathering and shipping butane from the Gulf Coast, and (3) the time constant in smoothing yields were tested. The results are in Figure 6. As we can see, wide variations in the parameters have little effect upon costs.

Implementation

Psychological theory (Bennis, Berne, Chin, 1) and observation elsewhere (Schlager¹⁰, Westerman¹²) indicate that successful implementation of a management science analysis of this type frequently requires that the operating people be involved in the analysis. First, operating people need to be confident that the results are correct, and second, when they are involved in and influence the course of the study, they do not view it as a threat to their position. Rather, if they have psychological ownership in the study, implementation is merely putting into effect results of their own thought and work.

Time Constant for Smoothing Yields of Butane from Processes in Refinery	Time Constant for Adjusting Butane Inventory When Ordering Butane from Gulf	Delay in Shipment of Butane from Gulf	Percent Increase in Total Loss
Recommended Policies			
10	15	10	
30	15	10	1.96
20	↓	↓	1.21
15	↓	↓	.67
5	↓	↓	-.74
1	↓	↓	-.87
10	45	↓	1.79
↓	30	↓	1.19
↓	20	↓	.24
↓	10	↓	-.14
↓	5	↓	.66
↓	1	↓	11.7
↓	15	20	.63
↓	↓	15	1.13
↓	↓	5	-1.37
↓	↓	2	-1.57
1	1	20	15.4
5	5	20	12.4
30	45	20	6.7

Figure 6: Effect Upon Total Loss of Parameter Changes in the Recommended Policy

After the model was constructed and a few runs obtained, but before thorough analysis and design had been accomplished, it was shown to the people managing the butane system. Fortunately, the model was programmed in DYNAMO which is an easy language to understand and learn. The butane coordinator looked at the original model, commented that it certainly was interesting, but said it was useless as a design or operating tool because it left out many details of the real situation. During the next month an analyst and the butane coordinator built a more representative model which turned out to be triple the size of the model described here. The larger model was analyzed, and improved policies designed. These improved policies were very similar to those indicated by the original model. Construction of a model by the coordinator was very important, even though the recommended policies were very similar to those suggested by the original model. The coordinator now understood the model and its behavior, and the resulting recommendations were his not those of some management scientist.

Initially the operating people did not have sufficient confidence in the model or in the new policies to implement them immediately even though the coordinator had specified the model and had designed new policies. Instead, the model was used as an operating tool for the management of the butane system. Each week the current condition of the butane system was entered into the model, five or six possible future patterns of supply and demand were assumed, and several possible decisions established including the one calculated from the equations of the recommended policy. Then each decision was simulated with each possible future and the decision which did well for all the possible futures and which made sense intuitively was selected. For six months the decisions calculated by the policy equations and those selected by the

manager after the procedure described above, were in agreement. One exception occurred where management did not agree with the decision calculated by the recommended policy. Several months later management regretted deviation from the recommended policy. With this six months experience the coordinator and others concerned with butane coordination had developed such confidence in the recommended policies that, the weekly use of the model as an operative tool was abandoned, and the decisions were calculated from the policy equations.

The new policies are used to this date.

Current Uses of the Model

Once butane system management had confidence in the new policies, the model was used for decision making only once again. In the summer of 1969, the catalytic cracking unit was pulled out of operation for its once-every-three-years overhaul. Since this is a major disruption in the refinery complex at Bayway and affects the need for and the supply of butane, a planning device was needed to determine the amount of butane to have in inventory when the catalytic cracker stopped operation; and to determine the ordering of butane in anticipation of the start-up of the cracker. The model proved itself very useful. It had been expected that changes in the catalytic cracking unit would alter the amount of butane generated. One of the uses of the model was to design decisions for good operation if assumptions about when the catalytic cracker would come on stream and assumptions about yield of butane from it were wrong. As it turned out the original planning assumptions about the butane yield were wrong, but no problem occurred in part because of the answers yielded by the model.

RESULTS

Since the new policies for controlling the butane system were implemented, butane has not been burned in the fuel system, flared to the atmosphere, nor has there been a need to stop making alkylate in order to get butane. Thus, costs of over \$100,000 a year have disappeared.

Since the first study, system dynamics has been used elsewhere in the Bayway refinery. First, it has been used to check the design of a new chemical processing unit. A design change resulted. Second, the hydrogen balance of the entire refinery has been modeled to help control the refinery. Third, an entire production-distribution system for a chemical has been designed and the design has been implemented. This study (a) examined where to place new investment among processing units and regional inventories in order to expand total capacity, (b) designed the information and control system for the entire production-distribution system, and (c) set down rules for choosing among alternative transportation modes for different conditions of inventory and demand.

A LESSON FOR IMPLEMENTATION

Management science has less than an outstanding record of implementation even though these studies have shown potentially significant improvements. One industrial dynamics study illustrates the point (Fey,3). Even though improved control policies had been implemented and were saving over \$100,000 a year (Carlson,2), eventually the policies were abandoned. Similar stories of failure to implement abound, e.g., the failure to implement the

aggregate production, workforce and inventory policies of Holt, Modigliani, Muth, and Simon (7), at the paint factory which was the subject of their famous study.

There are undoubtedly many reasons for implementation failures and the reasons vary from situation to situation. Psychologists and social psychologists have focussed upon the human factors (Bennis, Benne, Chin, 1). But the inability of the human mind to comprehend a complex situation may also be a barrier to implementation. As Forrester (5) has pointed out, the human intuition does not comprehend correctly the behavior of even relatively simple managerial or social systems. Forrester argues that intuitive predictions of behavior of such systems are often wrong. Yet management scientists present recommendations about improving the behavior of the complex systems and we should expect that often the recommendations are counter to the intuition of the decision maker which makes it likely that the recommendations will be rejected.

For example, Swanson (11) argues that even in the simple three variable, two feedback loop production, inventory, workforce example of Holt et. al. (7) the optimal decision rules will occasionally generate behavior in response to a random sales input which looks like bad management and may result in the manager getting fired. In one twelve month period the optimal policy generates six months of 10 percent to 30 percent underutilization of the workforce followed by six months of very heavy overtime.

It isn't sufficient that decisions be optimal, they also have to look optimal in the minds of management. If the human intuition cannot recognize optimal behavior in even simple systems, then implementation will fail until

management develops a more correct concept of proper decision making behavior. Then if implementation is to succeed, emphasis should be upon changing the mental model of the decision maker or upon giving his intuition support when thinking about complex systems. One way to change mental models and to support decision making is suggested by the summary reported above and by work of others [Gorry (6), Little (8), Morton (9), Schlager (10), Westerman (12), and Wright (13)]. Since the intuition of a manager cannot cope effectively with even simple interacting systems, he needs a tool to help him make decisions. A model used as an operating tool has proven very successful both in this study and in those cited just above.

This model has two roles: First of all, it aids the decision, but probably more importantly, it educates the decision maker and those who influence him about the nature of good decision making in the particular situation.

A model used as an operating tool will be different from a model used for optimal design. First, the operating model should be for the decision maker not the analyst. The decision maker should be heavily involved in its construction and he should greatly influence its content. The model also should have output which the manager finds useful and understandable. The model also will change as the manager learns more and develops curiosity about the effect of additional influences.

Second, the model should be transparent, i.e., the manager should be able to understand the model easily and he should be able to uncover the causal mechanisms which generate any specific set of results. The requirement of transparency will preclude the use of many, highly sophisticated

mathematical languages or particularly difficult simulation languages.

Third, the model will have to represent much of the details of reality. It cannot simply illustrate the nature of things. It must be able to predict with a high degree of accuracy.

Finally, the model will be based upon data and it must be able to accept data in the form collected by the organization.

With these characteristics, the model will almost certainly not be able to be solved analytically. It will require computer simulation or computer search techniques. Such a model will probably be more complex than a model used for design. For example, the original model of the butane system described above proved to be a very good policy design tool, but was expanded in size by a factor of three before it proved acceptable to the coordinator as a decision aid to his weekly decision making. But experience has shown that models which are scientific in orientation, elegant, simple, analytically tractable, also don't result in implementation (Little, 8). However, these design models have an important and necessary role. Their simplicity allows them to pinpoint places where significant improvement can occur. Thus they form the guidelines to be followed when using operating models to find economic improvement. However, operating models often appear to be needed in order to bring about implementation.

BIBLIOGRAPHY

1. Warren G. Bennis, Kenneth D. Benne, and Robert Chin, The Planning of Change, Holt, Rinehart and Winston, New York, 1961.
2. Bruce R. Carlson, "An Industrialist Views Industrial Dynamics," Industrial Management Review, Vol. 6, No. 1, Fall 1964.
3. W. R. Fey, "An Industrial Dynamics Case Study," Industrial Management Review, Vol. 4, No. 1, Fall 1962.
4. Jay W. Forrester, Industrial Dynamics, The M.I.T. Press, 1961.
5. Jay W. Forrester, "Counterintuitive Behavior of Social Systems," Technology Review, Vol. 73, No. 3, January 1971.
6. G. Anthony Corry, "The Development of Managerial Models, Sloan Management Review, Vol. 12, No. 2, Winter 1971, pp. 1-16.
7. C. C. Holt, F. Modigliani, J. F. Muth, and H. A. Simon, Planning Production, Inventory and Workforce, Prentice-Hall, Inc., 1960.
8. John D. C. Little, "Models and Managers: Concept of a Decision Calculus," Management Science, Vol. 16, No. 8, April 1970.
9. Michael S. Scott Morton, Management Decision Systems: Computer-Based Support for Decision Making, Harvard University Graduate School of Business Administration, Boston, 1971.

10. K. J. Schlager, "How Managers Use Industrial Dynamics," Industrial Management Review, Vol. 6, No. 1, Fall 1964.
11. Carl V. Swanson, "Designing Information and Control Systems for Effective Response to Demand Changes," Proceedings of the 1970 Summer Computer Simulation Conference, ACM/SHARE/SCI, Denver, Colorado, June 10, 1970.
12. J. Westerman, "Case Study: Implementation of Industrial Dynamics," unpublished M.S. Thesis, Sloan School of Management, M.I.T., May 1966.
13. Richard D. Wright, "Designing Corporate Growth Strategies: An Industrial Dynamics Implementation," Sloan School of Management Working Paper, No. 540-71, M.I.T., May 1971.

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