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Getting Maximum Production from Existing Capacity

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A production line faced with an increasing product demand and apparently limited capacity ordinarily will call for more facilities. In this case, though, a detailed analysis of inventory policy and machine loading solved the production problem —

GETTING MAXIMUM PRODUCTION FROM EXISTING CAPACITY

by Henry J. Johansson and Granville R. Gargiulo
Arthur Andersen & Co.

The process industry is characterized by extensive investment in production, storage, and handling facilities. This investment in capacity is often large in relation to total assets, and the depreciation, maintenance, and amortization of facilities represent a significant element of cost. Consequently, efficient utilization of such facilities is of continuing concern to management.

The growth of demand for the output of numerous processing companies, particularly in the area of consumer goods, places increasing pressure on management to approve funds for expanding capacity. This pressure stems largely from the fact that when demand exceeds the capacity to produce, the company is faced with lost sales and profits. Such was the situation confronting management in the case study described in this article.[1]

The Active Processing Company has a single plant located in the western portion of the United States. This plant receives about 70,000 tons of a single raw material annually and converts this material into several classes of end products for nationwide distribution. Variations in density, moisture content, added ingredients, and packaging result in an explosion of several product classes to over 500 individual items for shipment.

While each product flows through a sequence of processing operations, the bottleneck facility is a battery of twelve dryers, each costing somewhere between $150,-000 and $200,000. Under existing methods of operation, the drying stage consumes up to 75 per cent

[1] Names and certain data have been modified to protect the identity of the actual company involved.

of the total production cycle for any given product. In this situation, even with reasonable increases in customer demand, the drying capacity quickly reaches an overburdened state. Thus, in 1966 it was no surprise to management that the market and sales projections for the following year, reflecting across-the-board increases, immediately triggered a plant request for appropriations for capital funds to purchase an additional dryer. The urgency of this request was further compounded by an increasing backorder situation and the resultant customer complaints about poor delivery performance. However, the substantial investment required, following on the heels of similar investments in three of the preceding five years, led management to set up a task force to investigate this request in greater depth prior to final approval.

A brief but comprehensive review of the plant's mode of operation and the associated production activities and costs uncovered the following facts:

1. Little, if any, inventory was produced in anticipation of customer orders in the near-term future. Production scheduling procedures were geared for making product batches for individual customer orders, although some grouping of orders for the same product was done if these orders arrived and were processed at the same time.

2. Across all twelve dryers, about 7,000 hours of downtime over a 12-month period could be identified as being attributable to product changeovers. At production rates of 15 to 90 hundredweights (CWT) per hour—depending upon the product and dryer—this downtime was equivalent to 420,000 CWT of lost capacity per year.

3. In changing over from one product to another on any given dryer, the speed of the feed system into the dryer had to be reduced in order to allow the dryer bed to "build up" at the start of a run and "taper off" at the end of a run. The reduced speed was determined by the amount of the batch which, because it was not dried at the same consistency, could still be blended into the batch and meet the required product specifications. The net effect of the build-up and taper-off associated with each product changeover was a further loss in annual output equivalent to 150,000 CWT.

4. Since the plant was operating on a full three-shift, seven-day basis, every production hour saved would represent a contribution to profit in light of the increased demand forecast for the forthcoming year. Based on a weighted average of product profit margins and dryer rates, time saved on the dryers would permit additional sales yielding a profit contribution of about $125 per hour of dryer time.

5. Storage space was available to accommodate finished product inventory. Currently, obsolete items and production overruns used most of the space.

In light of the identifiable potential benefits of reducing dryer downtime, management sought to implement a system that would assure the most judicious use of inventories to provide additional scheduling flexibility and increased capacity without incurring a major capital expenditure. The task force set out to investigate the feasibility of such a system.

TABLE I

DISTRIBUTION OF SALES INVOICES FOR ALL PRODUCTS OVER A 24-MONTH PERIOD

Frequency of Invoices	Per Cent of Products	Per Cent of Demand
More than 1 per week	8%	
1 every week	11	
1 every 2 weeks	8	90%
1 every 3 weeks	13	
1 every 4 weeks	8	
Less than 1 per month	52	10
	100%	100%

Essentials of system

In order to achieve the above-mentioned management goals, the task force established the basic premise that the ultimate system design must include:

1. A means of forecasting future customer demand on a timely, consistent basis

2. A set of "decision rules" to optimize the use of available dryer capacity

3. Procedures for planning and controlling inventory levels consistent with the basis for allocating utilization of facilities and flexible to changing production and marketing conditions.

Each of these major system elements was studied in depth. The key aspects of these analyses are discussed in the following paragraphs.

Since the key to the system is the ability to produce to inventory, it was essential to identify what por-

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tion of the product line could be handled this way. The criterion for including a product in the system was its "forecastability," that is, whether the product exhibited a demand pattern that could be described quantitatively and thus updated consistently using statistical techniques. In order to ascertain the regularity of customer demand for each product, a distribution of sales invoices was compiled for the preceding 24 months. The results are summarized in Table 1 on page 24.

Product groups classified

Those products with less than one invoice received each month were found to exhibit irregular demand patterns and highly variable demand quantities. On this basis these items were classified as "make to order." Although accounting for more than one-half of the product line, these items did not have a significant impact in terms of total volume. The specific demand patterns of the remaining products were analyzed in greater depth in order to establish the appropriate forecasting mechanism as the basis for an ongoing procedure, including the isolation of long-term trends and seasonal requirements.

With the conclusion that 48 per cent of the products would be produced to inventory, it was then necessary to determine the way in which each product would be produced. This involved the questions of the average batch size for a product and on which dryer the product would be processed. The factors in this determination were: (1) the costs of carrying the inventory until it is needed to fulfill customer demand and (2) the costs associated with changing over a dryer (and incurring downtime) from one product to another. The quantity of a production batch was established to minimize the combination of these two costs.

The elements of inventory carrying costs which were expected to vary with the level of inventory were:

1. *Interest rate* on borrowed money which would be incurred as inventories increased and funds for other capital requirements had to be obtained from outside sources
2. *Taxes* paid on the assessed value of inventories
3. *Insurance premiums* paid on the average inventory level
4. *Damage and spoilage write-downs*
5. *Outside storage charges* which would be incurred when the limited available in-house space was filled. (This cost, while not incurred at low inventory levels, was included to ensure justification of levels that might force use of outside facilities.)

Changeovers were incurred on each production run regardless of the size of the batch. Consequently, based on product specifications and changeover compatibility, a total of 220 forecastable products were combined into 85 product changeover groups where each product in the group could be run on a given dryer in sequence with any other product in that group, without incurring downtime for changeovers or reduced output in the taper-off/build-up process.

The cost of a changeover between groups was set at the profit contribution of the volume lost due to the downtime or reduced productivity, weighted by the profit mix of all products in a group. This assessment was made because of the capacity limitation of existing dryers and the fact that any additional output could be sold currently.

Economic batch sizes for each product changeover group on each dryer were computed. A mathematical model was formulated to determine the assignment of groups to dryers in such a way as to minimize total profit contribution lost due to changeovers. The process limitations comprehended by the model were:

1. The total production requirements for a profit changeover group allocated to dryers must equal the annual demand for the group.

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TABLE 2

PROFIT POTENTIAL OF EXCESS DRYER HOURS

Dryer No.	Simulated Excess Hrs	Potential Production: Low-Margin Product Line CWT/Hr	Low-Margin Product Line Total CWT	High-Margin Product Line CWT/Hr	High-Margin Product Line Total CWT
1	0	—	—	—	—
2	1,843	18.33	33,782	28.21	51,991
3	113	23.25	2,627	35.77	4,042
4	0	—	—	—	—
5	0	—	—	—	—
6	1,470	15.11	22,212	23.25	34,178
7	0	—	—	—	—
8	4,625	30.73	142,126	47.29	218,716
9	0	—	—	—	—
10	0	—	—	—	—
11	0	—	—	—	—
12	0	—	—	—	—
Totals	8,051		200,747		308,927
Profit Margin/CWT			$ 2.10		$ 2.60
Annual Profit Potential			$421,568		$803,210

2. The annual requirements for a changeover group might be split among several dryers, but only in multiples of economic batch sizes.

3. The total production and changeover hours assigned to any dryer must not exceed the annual hours available for that dryer, where the hours available represent a seven-day, three-shift operation less allowances for breakdowns and maintenance.

With 12 dryers and 85 product changeover groups, the alternatives for assigning groups to dryers were reasonably numerous and the best assignment less than obvious. While a linear programing model would have been suitable to solve the problem, an approximation method[2] was used in order to facilitate a solution in the feasibility study and to derive simple decision rules for scheduling production on a day-to-day basis. The approximation method involved:

1. Identifying the product changeover group on each dryer that had the lowest profit loss/CWT based on the total changeovers incurred in producing that product group's annual demand in economic batch sizes

2. Relating, by index numbers, the difference in profit loss/CWT between all other product changeover groups and the one identified above

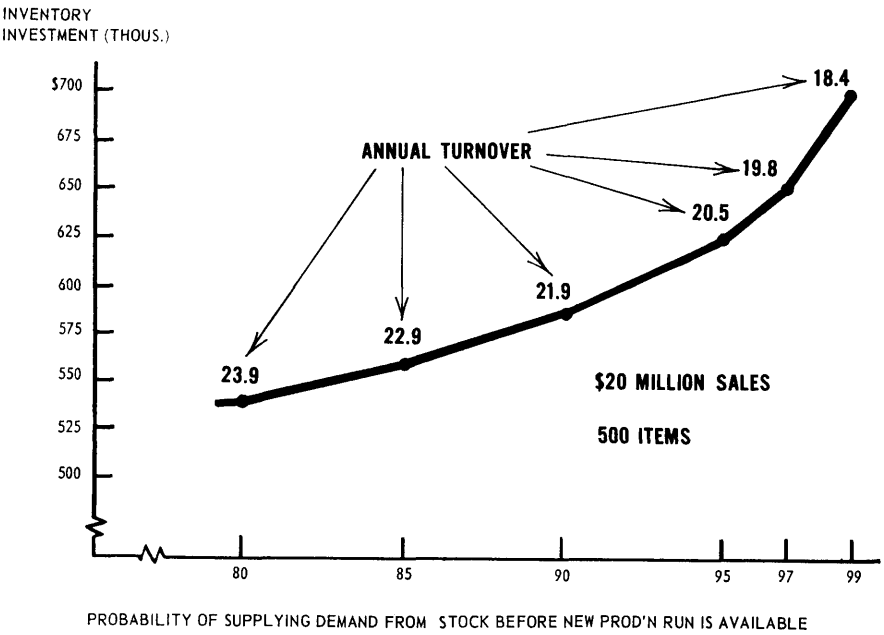
3. Assigning the lowest profit loss/CWT group to each dryer first and then the other groups in order of ascending index number (smallest difference from the least penalty group).

The assignments, of course, had to meet the limitations mentioned above.

The assignment decision rules that evolved were "load the fastest dryer first" and "load in order of the product changeover group's relative demand; greatest first." Intuitively, these rules made sense. It

EXHIBIT I

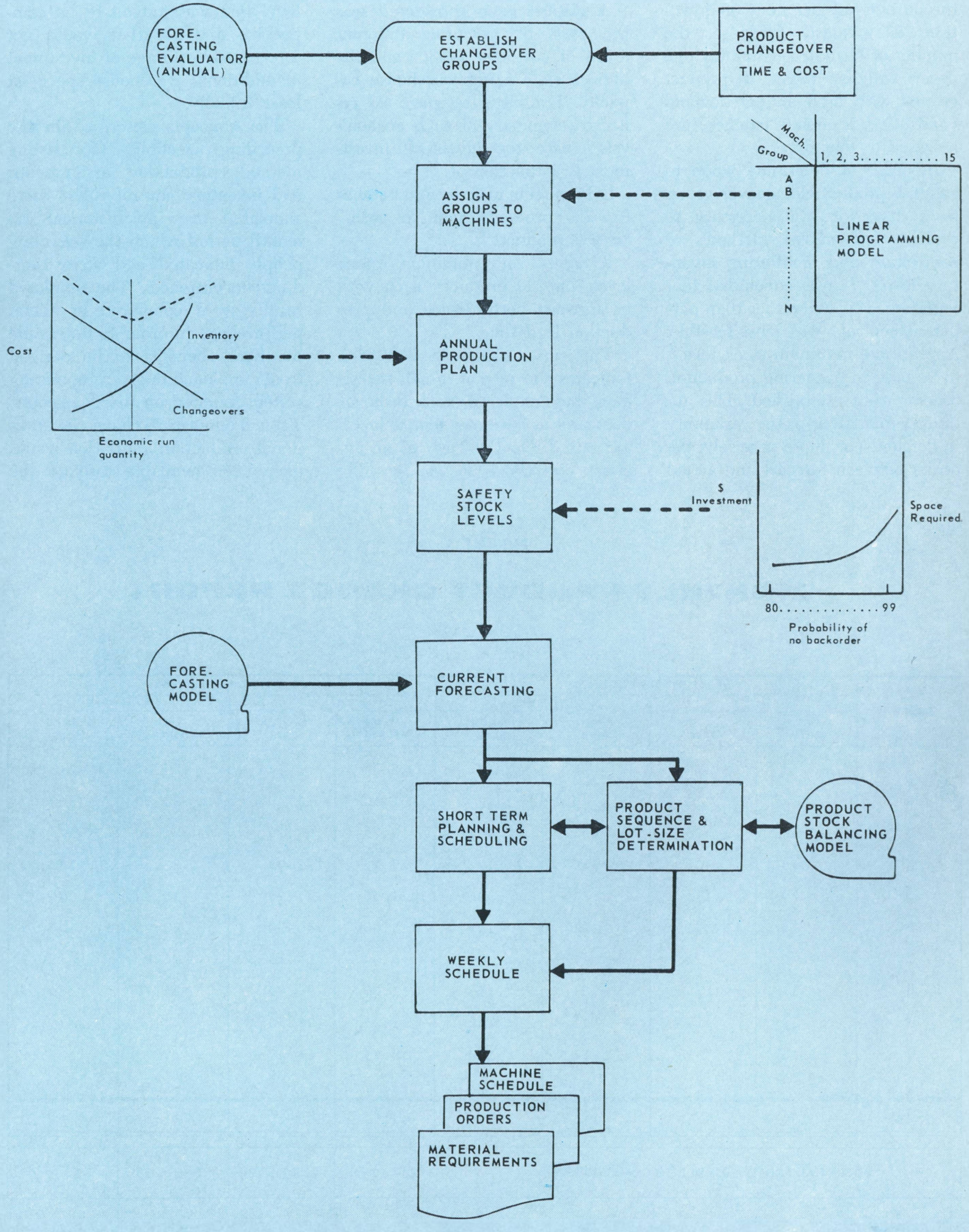
EFFECT OF PROTECTION LEVEL ON INVESTMENT AND TURNOVER



[2] Robert O. Ferguson and Lauren F. Sargent, *Linear Programming: Fundamentals and Applications,* McGraw-Hill Book Company, 1958.

EXHIBIT 2

INTEGRATED PRODUCTION PLANNING AND INVENTORY CONTROL SYSTEM



seemed reasonable to assign production to dryers such that the number of changeovers on the higher-speed dryers is minimized, since the potential for lost profit is greatest on these dryers where the output lost per hour of downtime is greatest. Likewise, the number of changeovers on any one dryer will be fewer if product groups with high annual demand (and larger economic batches) are assigned to that dryer.

In order to determine when to assign a product changeover group to a dryer, it was necessary to evaluate alternative methods of controlling and monitoring inventory levels. It was concluded that a periodic review (rather than perpetual control) was most feasible. Appropriate minimum stock levels, to be used in triggering production orders, were established. This required an analysis of the variability in demand (or, more precisely, the errors between forecast and actual demand) and the variability in production processing times, both of which affect the amount of safety stock needed to assure a policy level of "off-the-shelf" delivery (customer service).

A critical issue considered was the costs of providing different levels of customer service and the impact on existing warehouse capacity. Exhibit 1 on page 26 reflects a summary of such an analysis where the inventory investment is a function of:

1. Producing in economic batches for 220 products and "to order" on 280 products

2. Safety or minimum stock levels on 220 products, each with its forecast performance and production lead time.

The curve shown in Exhibit 1 indicates the rate at which investment increases and stock turnover decreases as customer service levels are raised. On the basis of an average cost/CWT it was possible to translate the dollar investment into units (CWT) and relate the physical quantity to the warehouse space currently available. This type of evaluation guided management in setting a customer service policy level that was judged to be competitive and yet that would not force outside storage or investment in additional warehouse space, at least initially.

The concepts described in the preceding section (forecasting method, production assignments, and inventory control rules) were simulated over an historical 12-month period which the operating people indicated had no extraordinary occurrences. The simulated results were compared to actual performance in order to determine the likely benefits to be derived from implementing an operating system founded on these concepts. Table 2 on page 26 shows the additional production hours that would have been available through the

EXHIBIT 3

MONTHLY PRODUCT CHANGE REPORT

JULY 1967

DRYER	NO. OF PRODUCT CHANGES				PRODUCT CHANGE HOURS			
	1967		LAST YEAR		1967		LAST YEAR	
	THIS MONTH	YEAR TO DATE	THIS MONTH	YEAR TO DATE	THIS MONTH	YEAR TO DATE	THIS MONTH	YEAR TO DATE
1	5	53	24	176	5.00	55.25	29.25	210.50
2	4	81	20	127	4.50	97.00	24 75	160.00
3	10	75	24	171	10.75	67.25	24.00	175.50
4	15	126	26	172	15.25	123.75	32.50	185.00
5	9	104	21	94	11.00	111.25	18.50	90.75
6	15	91	21	145	15.00	80.00	20.75	143.75
7	5	71	7	61	5.00	67.25	6.25	61.25
8	15	115	21	153	11.00	98.75	26.75	160.25
9	15	117	21	160	11.25	98.50	24.00	175.50
10	16	93	11	130	10.75	66.25	7.75	113.25
11	0	0	0	0	0	0	0	5.50
Total	109	926	196	1,393	99.50	865.25	214.50	1,481.25

POTENTIAL PROFIT LOSS DUE TO CHANGE-OVERS	$14,737	$133,952	$36,465	$246,521

EXHIBIT 4

INVENTORY VALUE - MONTHLY SUMMARY REPORT

JULY 1967

INVENTORY CATEGORY	INVENTORY			SHIPMENTS	TURNOVER		
	PLANNED	CURRENT MONTH	AVERAGE MONTH Y.T.D.	AVERAGE MONTH Y.T.D.	AVERAGE MONTH Y.T.D	ANNUAL	
						PROJECTED	PLANNED
A	$11,252	$14,276	$10,718	$10,825	1.01	12.12	8.04
B	104,423	110,372	83,215	163,934	1.97	23.64	11.88
C	105,392	64,953	69,788	111,660	1.60	19.20	13.20
D	80,623	103,106	85,728	86,585	1.01	12.12	12.60
E	51,100	48,550	56,819	63,069	1.11	13.32	14.00
F	30,976	15,419	15,467	86,615	5.60	67.20	35.16
G	54,166	33,794	26,327	84,773	3.22	38.64	21.00
H	157,746	164,223	149,318	337,459	2.26	27.12	21.24
I	8,938	7,844	5,901	5,842	.99	11.88	7.56
J	42,128	41,795	26,753	10,701	.40	4.80	8.00
TOTAL	$646,744	$604,332	$530,034	$961,463	1.81	21.72	16.00

TABLE 3

ADDITIONAL INVENTORY INVESTMENT AND COST

Products produced to inventory	
Cycle stock (one-half batch size)	105,000 CWT
Safety stocks (95 per cent service level)	97,000 CWT
Products produced "to order"	
Average inventory in plant pipeline	18,000 CWT
Overall average inventory	220,000 CWT
Less: current average inventory	50,000 CWT
Additional	
Inventory	170,000 CWT
Investment (at cost)	$850,000
Carrying cost (at 20 per cent)	$170,000

use of the dryer assignment rules developed. In order to identify the range of potential profit contribution associated with this "freed-up" capacity, the excess hours were applied to producing the lowest-margin product line or the highest-margin product line.

The offset to this profit potential is, of course, the increased cost to carry the higher levels of inventory that would be generated by producing in economic batch sizes and the added safety stocks. Table 3 at left summarizes this cost for all 500 items.

The net potential of implementing a new production scheduling and inventory control system was

EXHIBIT 5

CUSTOMER SERVICE LEVEL REPORT

	FORECASTABLE PRODUCTS						NON - FORECASTABLE PRODUCTS						TOTAL					
1967	FEB.	MAR.	APR.	MAY	JUNE	JULY	FEB.	MAR.	APR.	MAY	JUNE	JULY	FEB.	MAR.	APR.	MAY	JUNE	JULY
ORDERS	319	438	413	437	406	412	31	25	31	21	18	10	350	463	444	458	424	422
LATE SHIPMENTS	134	115	121	135	135	138	21	14	9	11	3	7	155	129	130	146	138	145
ATTRIBUTABLE CAUSES:																		
SWITCHING OF ASSIGNED CARS	26	5	0	2	12	1	0	0	0	0	1	0	26	5	0	2	13	1
LACK OF TANK CARS	6	0	1	0	1	0	0	0	0	0	0	0	6	0	1	0	1	0
SPECIAL CARS REQUIRED	36	23	40	53	58	66	3	0	1	0	0	0	39	23	41	53	58	66
QUALITY PROBLEMS	2	0	0	0	1	0	1	0	0	0	0	0	3	0	0	0	1	0
LOADING DELAYS	25	18	29	40	30	31	0	4	2	0	0	0	25	22	31	40	30	31
OTHER CAUSES	8	37	24	19	32	33	7	7	1	5	1	0	15	44	25	24	33	33
TOTAL	103	83	94	114	134	131	11	11	4	5	2	0	114	94	98	119	136	141
NET LATE SHIPMENTS	31	32	27	21	1	7	10	3	5	6	1	7	41	35	32	27	2	4
% SERVICE LEVEL WITH ATTRIBUTABLE CAUSES DEDUCTED	90.2	92.7	93.4	95.1	99.7	98.3	67.7	88.0	83.8	71.4	94.4	30.0	88.2	92.4	92.7	94.1	99.5	99.0
% SERVICE LEVEL-- OVERALL	57.9	73.7	70.7	69.1	66.7	66.5	32.2	56.0	70.9	47.6	83.3	30.0	55.7	72.1	70.9	68.1	67.5	65.6

in the range of $241,000 to $633,000 contribution to profit, depending upon the products produced with the extra capacity. This assessment does not include the fact that additional capacity investment in new dryers could be avoided for at least one more year. Needless to say, management was enthusiastic about the results of the feasibility study and approved a program of systems implementation.

Essentially the system included the elements that were used in the feasibility study simulation. Specific responsibilities, procedures, forms, data files, and reporting systems were established to support the planning and control requirements. Exhibit 2 (page 27) is a schematic representation of the total system. Broadly, the system functions in two major segments:

1. Quarterly, planning and control criteria are re-evaluated and updated. This includes:
   a. determination of new "forecastable" products to go on the system
   b. evaluation of revised product changeover groups based on updated costs and changeover times
   c. reassignment of product changeover groups to dryers, as required
   d. re-evaluation of economic batch sizes and minimum stock levels.
2. Day-to-day scheduling and control in accordance with the revised criteria established during the quarterly update. These include:
   a. short-term forecasting and periodic inventory monitoring to determine "when" and "how much" to produce of each product changeover group
   b. determination of the quantity to produce of each item in a group using a stock-balancing procedure
   c. issuance of appropriate production schedules (including dryer assignments), production orders, and raw material requisitions.

Management was naturally interested in a continuous evaluation of the system's performance and a means of appraising how well the identified potential was being attained. Several key management reports are shown in Exhibits 3, 4, and 5 (pages 28, 29, and 30). The product changeover summary in Exhibit 3 is intended to identify the effectiveness of the dryer assignment rules. Exhibit 4 displays a top-level inventory investment report while Exhibit 5 shows a track record of customer service performance and problems.

"Look before you leap" is probably the underlying theme of this case study. Often, the best way to achieve additional capacity is far from obvious. Certainly, the economics—particularly in the process industry—warrant a careful investigation of the alternatives. The case described clearly demonstrates that the judicious use of inventories goes a long way toward providing increased production flexibility.

Perhaps a second, but no less important, indication of this study is the power of meaningful quantitative techniques used to structure and analyze the problem. These techniques facilitate a reasonably precise identification of the payoff of alternatives and provide a sound basis for the design of the operating systems which must eventually be implemented if the identified benefits are to be achieved.