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Incorporating the Opportunity Cost of Setups into Production-Related Decisions

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FINDING THE REAL OPPORTUNITY COST OF SETUP ACTIVITIES CAN HELP MANAGEMENT MAKE BETTER DECSIONS.

EXECUTIVE SUMMARY Setup activities due to product changeovers are costly disruptions to a production process, but accounting systems traditionally ignore a significant effect of setups—the opportunity cost of lost capacity. The model described here provides a mechanism for determining the opportunity cost of setup activity based on the interdependence of the product mix and lot-sizing decisions. As such, it can provide input to the development of product mix decisions and production schedules and direct management's attention to improvement efforts that offer the most opportunity for enhanced performance.

The decision to produce multiple products on common resources results in the need for changeover and setup activity between production runs. Setup activity due to changeovers represents costly disruptions to a production process. Accounting systems, however, traditionally ignore a significant effect of setups—the opportunity cost of lost capacity. The historical nature of accounting systems fails to provide management with the information needed to incorporate the opportunity cost of setups into decisions regarding the utilization of existing capacity. In addition, conventional accounting systems assume the nonproductive use of capacity by setup activity is driven by the next production run. Accordingly, full-cost accounting systems (e.g., activity-based costing) assign the cost of setups to specific products. As demonstrated here, however, the effects of setups are determined at the portfolio level because the setup requirement is driven by the joint product mix and lot-sizing decisions. Therefore, the conventional practice of assigning setup costs driven by changeovers to specific products is questionable.

Setup activity consists of internal setup time (incurred while the resource is shut down) and external setup time (incurred while the resource is operating). Internal setup activity on resources with excess capacity

Table 1: Alpha Corp.
Cost of Capacity and Resource Requirements per Product

	PRODUCTS A	B	C
Resource *w* ($1.50 per minute)			
Process time (minutes) per unit	9	15	4
Setup time (minutes) per batch	15	15	15
Units per batch	10	10	10
Setup time (minutes) per unit	1.5	1.5	1.5
Total time (minutes) per unit	10.5	16.5	5.5

	PRODUCTS A	B	C
Resource *x* ($2.00 per minute)			
Process time (minutes) per unit	10	11	6
Setup time (minutes) per batch	10	10	10
Units per batch	10	10	10
Setup time (minutes) per unit	1	1	1
Total time (minutes) per unit	11	12	7

	PRODUCTS A	B	C
Resource *y* ($0.50 per minute)			
Process time (minutes) per unit	6	12	13
Setup time (minutes) per batch	10	10	10
Units per batch	10	10	10
Setup time (minutes) per unit	1	1	1
Total time (minutes) per unit	7	13	14

	PRODUCTS A	B	C
Resource *z* ($1.00 per minute)			
Process time (minutes) per unit	5	9	19
Setup time (minutes) per batch	10	10	10
Units per batch	10	10	10
Setup time (minutes) per unit	1	1	1
Total time (minutes) per unit	6	10	20

does not incur an opportunity cost because output is unaffected. The performance of internal setup activity on constraining resources, however, results in an opportunity cost that can complicate both the product-mix and lot-sizing decisions. For example, the consumption of valuable capacity by setup activity on constraining resources can make the "optimal" product mix infeasible and/or hinder the implementation of a small-lot, just-in-time production schedule. In response, many firms focus their improvement efforts on the reduction of internal setup times, often accomplished by converting internal setup activity to external setup activity.[1]

While accountants recognize the impact of setups on capacity, the accounting literature traditionally fails to incorporate the effect of internal setup activity on production-related decisions. Efforts to simplify the problem include ignoring the effect of setups, assuming only one setup per product, or establishing a separate constraint for setup hours—thus implying that all setup activity is external to the productive resource.

The example discussed here demonstrates how to explicitly identify the opportunity cost of internal setup activity driven by product changeovers (hereafter called setup activity or setup time) included in a firm's production decisions. The demonstration includes a numerical example and a suggested format for reporting this opportunity cost to management. Management can use this approach to weigh the benefits of investing in additional setup reduction efforts, revising the product mix, and/or revising the current production scheduling philosophy.

The Opportunity Cost of Setups

Ideally, setups between production runs would be instantaneous and result in zero loss of productive capacity. In this theoretical scenario, management could produce an optimal product mix that is determined without considering the effects of setups. In practice, of course, management must select an alternative product mix that allows for the inclusion of some amount of setup time in the production schedule. It follows, then, that the opportunity cost of setups is equal to the loss of throughput (defined as sales minus unit variable costs) that results from selecting a product mix that differs from the theoretical optimum in order to accommodate the consumption of resource capacity by setup activity. To identify the opportunity cost of setups, therefore, it is necessary to determine the optimal product mix with and without the setup requirement. The following section provides a numerical example of this approach.

Numerical Example

Alpha Corp. is a manufacturing company that produces three standardized products, A, B, and C, using four resources, *w*, *x*, *y*, and *z*. Management's objective is to select a product mix that will maximize throughput. The company limits the growth of inventory by producing to meet demand within a one-week scheduling horizon. The weekly production schedule incorporates relatively small, predetermined lot sizes due to the firm's just-in-time production philosophy. Each resource has 2,400 minutes of capacity available per week. Table 1 provides information obtained from an activity analysis of each product and resource, the initial predetermined lot sizes for each product, and the historical cost allocations per unit of capacity for each resource.

Table 2 provides information about product demand, prices, variable material costs, and allocations of fixed capacity costs resulting from the activity analysis in Table 1. To simplify the later analysis, separate allocations are made for process time and setup time. (Other costs are ignored in this example to maintain the focus on the opportunity cost of lost capacity).

In the following discussion, TP_0 is defined as the theoretical level of throughput that would result from the optimal product mix with zero setup activity given the firm's demand and capacity constraints; TP_S is defined as the actual throughput resulting from an alternative "optimal" product mix selected by management that includes setup activity for predetermined lot sizes. The opportunity cost of setup activity is defined as the difference between these two levels of throughput (i.e., $TP_0 - TP_S$). Based on the information provided in Tables 1 and 2, the theoretical TP_0 is determined by solving the following integer linear program:

Maximize:	$65A + $99B + $80C	(objective function)
Subject to:	A ≤ 200	(market demand constraint)
	B ≤ 200	" "
	C ≤ 200	" "
	9A + 15B + 4C ≤ 2400	(resource *w* constraint)
	10A + 11B + 6C ≤ 2400	(resource *x* constraint)
	6A + 12B + 13C ≤ 2400	(resource *y* constraint)
	5A + 9B + 19C ≤ 2400	(resource *z* constraint)
	A, B, C ≥ 0	(nonnegativity constraint)
	A, B, C = integers	(solution contains only whole units)[2]

Table 2: Alpha Corp. Product Demand and Profit per Unit

	PRODUCTS A	B	C
Demand per Week	200 units	200 units	200 units
Sales Price per Unit	$85.00	$124.00	$110.00
Materials $ per Unit	20.00	25.00	30.00
Throughput $ per Unit	$65.00	$ 99.00	$ 80.00
Cost of process time on:			
Resource *w*	13.50	22.50	6.00
Resource *x*	20.00	22.00	12.00
Resource *y*	3.00	6.00	6.50
Resource *z*	5.00	9.00	19.00
Total Process-time Cost	41.50	59.50	43.50
Cost of setup time on:			
Resource *w*	2.25	2.25	2.25
Resource *x*	2.00	2.00	2.00
Resource *y*	.50	.50	.50
Resource *z*	1.00	1.00	1.00
Total Setup-time Cost	5.75	5.75	5.75
Total Cost Allocations	47.25	65.25	49.25
Profit per Unit	$17.75	$33.75	$30.75

Note that the constraint functions for TP_0 contain only process times for each unit (from Table 1). TP_S is determined using the same linear program except that the constraint functions must include the effects of setups. This is complicated by the fact that setups are incurred at the batch level and that the number of required batches is unknown before the product mix decision is made. Additionally, for the product mix to be feasible, the setup times and process times must be included in the same constraint function due to the resource-consuming nature of the setup activity. To compensate for the interaction between these related decisions, the constraint functions on the next page include an allocation of setup time to each unit. This calculation requires converting the *per-batch* setup time to the unit level by dividing the setup time by the predetermined lot sizes (this conversion is provided in Table 1).[3] The revised resource constraint functions are:

$$10.5A + 16.5B + 5.5C \leq 2400 \quad \text{(resource } w \text{ constraint)}$$
$$11A + 12B + 7C \leq 2400 \quad \text{(resource } x \text{ constraint)}$$
$$7A + 13B + 14C \leq 2400 \quad \text{(resource } y \text{ constraint)}$$
$$6A + 10B + 20C \leq 2400 \quad \text{(resource } z \text{ constraint)}$$

Table 3 provides the solutions to the objective function under both sets of constraints.[4]

The difference between the two product mix solutions in Table 3 is due to the treatment of setup activity in the constraint functions. Table 4 provides the financial results for Alpha Corp. and represents a suggested format for reporting the opportunity cost of setup activity to management.

Table 3: Alpha Corp. Product Mix Solution for TP_0 and TP_S Models

	UNITS PRODUCED PER PRODUCT		
Model	**A**	**B**	**C**
TP_0 (zero setups)	131	65	61
TP_S (with setups on predetermined lot sizes)	140	36	60

Observation (1)

The opportunity cost of setup activity reported in Table 4 is equal to the difference between the throughput derived from the optimal product mix with zero setup activity and the throughput derived from the product mix included in the firm's current production schedule. In other words, given Alpha Corp.'s current market demand and capacity constraints, TP_0 represents the *theoretical* benchmark of the maximum throughput achievable under conditions of *frictionless* product changeovers (i.e., zero setup times). Against this benchmark, the throughput obtained from the opti-

Table 4: Alpha Corp. Financial Results of Product Mix Decision

	Product A	**Product B**	**Product C**	**Total**
Throughput with Zero Setups (TP_0) i	$ 8,515	$ 6,435	$ 4,880	$19,830
Opportunity Cost of Setups (TP_0 –TP_S) †	585	< 2,871>	< 80>	< 2,366>
Throughput with Setups (TP_S) ii	$ 9,100	$ 3,564	$ 4,800	$17,464
Productive Capacity Costs iii	< 5,810>	< 2,142>	< 2,610>	<10,562>
Nonproductive Capacity Costs-Setups iv	< 805>	< 207>	< 345>	< 1,357>
Profit by Product Line	$ 2,485	$ 1,215	$ 1,845	$ 5,545
Cost of Excess Capacity (from Table 5)	—	—	—	< 81>
Net Facility Profit				$ 5,464

i TP_0 = Throughput per unit * # units produced in optimal product mix with zero setups (e.g., Product A: $65 * 131 = $8,515)

ii TP_S = Throughput per unit * # units produced in optimal product mix with setups (e.g., Product A: $65 * 140 = $9,100)

iii Productive Capacity Costs = Process Cost per Unit * # units produced for TP_S solution (e.g., Product A: $41.50 * 140 = $5,810)

iv Nonproductive Capacity Costs = Setup Cost per Unit * # units produced for TP_S solution (e.g., Product A: $5.75 * 140)

†The $2,366 total opportunity cost of setups represents the decrease in throughput due to the inclusion of setup activity in the production schedule. At the product level, the $585 increase in throughput for product A represents a *negative* opportunity cost due to the interaction between Alpha's product mix and lot-sizing decisions. The illogical result of having a negative cost (i.e., throughput gain) at the product level indicates that the responsibility for setups cannot be assigned to specific products.

Table 5: Alpha Corp. Utilization of Resource Capacities for Optimal Product Mix with Setups (i.e., TP_S)

RESOURCE	CAPACITY USED INCLUDING SETUPS (HOURS PER WEEK)	CAPACITY AVAILABLE (HOURS PER WEEK)	EXCESS CAPACITY (HOURS PER WEEK)	EXCESS CAPACITY COST (PER WEEK)
w	2,394	2,400	6	$ 9
x	2,392	2,400	8	16
y	2,288	2,400	112	56
z	2,400	2,400	0	0
COST OF EXCESS CAPACITY IN WEEKLY PRODUCTION SCHEDULE				$81

mal product mix based on management's current lot-sizing philosophy (i.e., TP_S) incorporates the opportunity cost of resource capacity consumed by setup activity.

Of course, the magnitude of this opportunity cost depends on factors such as market demand, resource capacities, and lot sizes. This example, however, illustrates that explicit consideration of the opportunity cost of setups can direct management's attention toward process improvement and product scheduling strategies that will benefit the firm. For example, management may be motivated to reduce the opportunity cost of setups through additional investment in setup-reduction efforts.

Alternatively, recognition of the opportunity cost of setups may provide the financial motivation to consider dynamic lot sizing as a means to reduce the number of setups required. Based on the Theory of Constraints philosophy, a dynamic lot-sizing production schedule increases throughput by combining production lots at the system's constraint.[5] For example, Table 5 shows that the current bottleneck (i.e., binding constraint) in the determination of TP_S is resource *z*; therefore, production lots at this resource should be merged first. As revised schedules are generated, the "bottleneck" may wander as new constraints emerge. The information in Table 5 indicates that resource *w* will likely be the next bottleneck because it has the least amount of excess capacity after resource *z*. The determination of a final schedule becomes an iterative process as management weighs the advantage of reducing opportunity costs against the disadvantages of other financial (e.g., holding costs) and nonfinancial (e.g., lead times) effects of larger lot sizes.

Depending on the success of the above two strategies (i.e., setup time reduction and dynamic lot sizing), recognition of the opportunity costs driven by setup activity may provide management with the impetus to invest in additional capacity at the constraining resource. The methodology provided above can be used for sensitivity analysis to project the impact of additional capacity at the current bottleneck and reveal the next system constraint.

Observation (2)

The opportunity cost of setup activity due to product changeovers cannot be assigned to specific products. Consider the distribution of the opportunity cost of setups across the three product lines. Compared to the TP_0 benchmark (which ignored setups), the TP_S solution shows that the nonproductive use of capacity to set up for the production of each product had a negligible effect on the throughput provided from product C, significantly reduced the throughput provided by product B, and resulted in an *increased* amount of throughput from product A. In other words, the throughput from product A increased as a result of adding downtime for setup activity to the production schedule. The illogical result of negative opportunity costs (i.e., throughput gains) at the product level indicates that individual products are not responsible for setup activity. This effect serves to question the conventional approach of assigning setup costs for product changeovers to individual products.

Cost allocations to setup activity attempt to provide management with an indication of the product-level responsibilities for this nonproductive use of capacity. If the cost allocations provide a good proxy for opportunity costs, both of these measures should be similarly distributed across the three product lines. Table 4 indicates that this is clearly not the case. (To facilitate this comparison, Table 4 segregates the costs allocated to setups for each product from the allocations for actual process time). Due to its low volume, product B is allocated the least amount of setup costs; the majority of the opportunity cost of setups, however, is due to the need to reduce the production of product B to accommodate the setup activity included in the production schedule. On the other hand, product A received the highest allocation of costs for setup activity, but, as mentioned above, the opportunity cost assigned to product A is actually negative because the throughput from product A increased when setup activity was added to the production schedule. In sum, the cost allocations fail to reflect the relative contribution of each product to the total opportunity cost of setup activity.

The inability of cost allocations to proxy for the opportunity cost of setup activity is due to two factors. First, full-cost accounting systems, such as ABC, do not recognize the priority of constraining resources. Setups on constraining resources result in an opportunity cost equal to lost throughput. Setups on nonconstraints do not incur opportunity costs because they do not reduce throughput. Setups on constraints, therefore, are more costly than setups on nonconstraints. In the example, the binding constraint is currently resource *z*, so setups on this resource are the most costly. Based on the historical capacity costs shown in Table 1, the accounting system will assign the greatest cost (i.e., $2 per minute) to setups on resource *x*, compared to only $1 per minute on resource *z*.

Second, linear cost allocations in full-cost accounting systems fail to capture the interaction between the joint product mix and lot-sizing (i.e., frequency of setups) decisions. For example, allocating the cost of setup time to product A assumes that product A is driving the demand for setup activity and the resulting opportunity cost of lost throughput. The requirement to set up for product A, however, is due to the presence of products B and C and the need for changeover from one of these other product lines. Product A is actually offsetting the overall opportunity cost of setup activity by contributing an increased level of throughput to the firm.

Model Improves Decision Making

Management can make improved product mix and lot-sizing decisions when informed of the opportunity cost of setup activity due to product changeovers in the current or projected production schedule. Conventional accounting systems do not provide this information. In addition, cost allocations serve as a poor proxy for the opportunity cost of setup activity because allocations fail to recognize the priority of constrained resources and/or the interaction between the product mix and lot-sizing decisions. Rather than hide the effect of setups in historical cost allocations, firms can use the approach described above to recognize the opportunity cost of setups explicitly and monitor the impact of setups on corporate performance. ■

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1 Shigeo Shingo, *A Revolution in Manufacturing: The SMED System*, Productivity Press, Stamford, Conn., 1985.
2 Integer linear programs (ILP) are optimization problems in which some or all of the decision variables are restricted to integer values. An excellent introduction to ILP is found in *Spreadsheet Modeling and Decision Analysis, A Practical Introduction to Management Science, 4th Ed.*, Cliff T. Ragsdale, South-Western, Cincinnati, Ohio, 2004.
3 This adjustment may result in a product mix solution that includes partial batches.
4 The integer linear programming solution was determined using the Excel tool, Solver. The application of Solver to product-mix decisions is discussed by David Perkins, Jonathan Stewart, and Scott Stovall in "Using Excel, TOC, and ABC to Solve Product-Mix Decisions with More than One Constraint," *Management Accounting Quarterly*, Spring 2002.
5 Eliyhu Goldratt discusses this approach to production scheduling in *The Haystack Syndrome: Sifting Information Out of the Data Ocean*, North River Press, Croton-on-Hudson, N.Y., 1990.