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A Resource Granularity Framework for Estimating Opportunity Costs

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SYNOPSIS: This paper presents a framework to help decision makers better measure the opportunity cost of resources with differing economic characteristics. After characterizing resources by the intrinsic lumpiness of acquisition (acquisition granularity), storability of benefits (expiration granularity), and control over the rate of consumption of available benefits (consumption granularity), this paper illustrates how these concepts can lead to improved decisions and assessment of observed practices.

Keywords: opportunity cost; resource management; time-based costing; resource granularity; costing and decision-making; cost systems.

JEL Codes: M40, M46.

INTRODUCTION

He thought that if he had put that lost thousand roubles in the bank, the interest for a year would have been at least forty roubles, so that forty roubles was a loss too.

—Anton Chekhov, *Rothschild's Fiddle*

Opportunity cost is central to decision making because it is the value of the next best alternative. A primary role of management accounting in organizations is to help measure the opportunity costs of resources, which, though simple in concept, are difficult to measure objectively. As a result, firms use cost allocations to attribute the cost of shared resources to decision alternatives. Not surprisingly, there is a long-standing debate on the relative merits of candidate procedures to estimate the opportunity costs of the resources consumed by a decision alternative. Reducing the subjectivity in opportunity cost measurement therefore holds the promise of improving the quality of decisions in organizations. This paper develops a framework to help decision makers measure the opportunity costs of resources with differing degrees of *granularity*, and shows how to apply the framework to some common decisions.

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We use the term *granularity* to characterize the coarseness of resource flows as a function of time. By definition, time has zero granularity because the flow of time is continuous and smooth. But the flow of resources through an organization is often not a continuous or smooth function of time. Resource flows become granular when we acquire resources in batches ahead of use, when we can store their benefits, or when we can control the rate at which we consume their stored benefits. We argue that these three dimensions of a resource's granularity—lumpy acquisition, storability, and controllability—are key determinants of its opportunity cost. The article demonstrates how the granularity framework provides a *systematic* approach to measuring the opportunity cost of a resource in various decision contexts.

A resource's granularity profile—the extent to which it embodies acquisition, expiration, and consumption granularity—influences the ease of estimating the resource's opportunity cost. By providing a unifying time-based characterization of resources, the granularity framework helps us evaluate existing cost allocation systems and select the appropriate proxies for opportunity cost in various circumstances. In particular, we believe that the principal objective of product-costing systems, such as activity-based costing, is to estimate opportunity cost (Balakrishnan and Sivaramakrishnan 2002). Thus, we view much of the debate surrounding product costing practices as a debate over how best to measure the opportunity cost of resources consumed by a product or other cost object. One insight of the granularity framework suggests that traditional systems may estimate opportunity cost poorly because these systems restrict themselves to either a use-based or a time-based driver in the estimation process. Because the granularity framework emphasizes that the available benefits in most resources expire with time *and* use, we see the need for a nonlinear cost allocation system. Such a system is required to consider jointly the time path of expiry of benefits and the benefits consumed due to use. As detailed in the numerical example presented in Balakrishnan et al. (2002), such a system also provides a better estimate of the cost of idle capacity.

We use several examples to identify new insights that emerge when applying the granularity framework. For instance, the framework confirms the time- and use-based pricing system for rental cars. Both time (expiration granularity) and use (consumption granularity) determine opportunity cost or the depletion of benefits, indicating the need for a nonlinear pricing scheme. Similarly, taxicab rates often include a fixed plus a mileage charge because a taxi service is a bundle of a car and a driver, resources with differing granularity profiles. These examples indicate that recognizing a product or a service as a bundle of resources with differing granularities leads to better opportunity cost calculations and therefore better decisions.

GRANULARITY FRAMEWORK

The granularity framework incorporates three dimensions of granularity: acquisition, expiration, and consumption. We define and illustrate these granularity dimensions in the following paragraphs.

Acquisition Granularity

Acquisition granularity is a measure of the lumpiness in the acquisition process. The greater the ability to match quantities acquired and used, the finer the resource's acquisition granularity. Electrical power is a resource with fine, indeed zero, acquisition granularity from the user's perspective. Consumers acquire precisely the amount of electrical power they need because the technology for measuring the exact amount of power consumed, and implementing a contract for such a transaction, is available at an affordable cost. Opportunity cost is easy to estimate for such resources; it is their acquisition cost.

Contrast electricity with a resource such as a machine or a building. It is rarely possible to fine tune traditional machine capacity to demand on an as-needed basis.[1] Thus, firms typically acquire resources such as buildings and machinery in chunks and in anticipation of their use. These resources therefore have coarse or large acquisition granularity. Managers employ cost allocation schemes to proxy for the opportunity cost of these resources. Information about the *storability* and *controllability* of acquired benefits is central in developing these cost allocation mechanisms.

Acquisition granularity is related to, but distinct from, the concepts of fixed and variable costs. The cost of resources with fine acquisition granularity appears to be variable, while the cost of resources with coarse granularity appears to be fixed. However, this dimension of granularity pertains to *acquisition*—of electric power and machines—whereas the fixed-variable cost classification concerns their *use*. Even though the cost of lumber used to make furniture is variable, minimum efficient purchase quantities mean that some lumber likely possesses coarse acquisition granularity. Similarly, while we consider a full-time employee's salary to be a fixed cost, the associated acquisition granularity is not large if we can acquire this resource in smaller chunks such as a one-quarter time appointment.

Conceptually, a resource's acquisition granularity depends on the economics of the acquisition process and supply, and not on how the resource is used. Transaction costs underlie both the economic order quantity model for buyers as well as the suppliers' willingness to sell resources in discrete packet sizes. Lumpy purchase and coarse acquisition granularity result. Similarly, a resource's acquisition granularity may differ across markets because of differences in the economics of the acquisition process. It may be possible to rent time on specialized equipment in some markets; in others, buying the machine may be the only way to access the capability. The granularity of the resource differs accordingly.

Though resource acquisition may involve purchase, exchange, construction, manufacturing, growth, or discovery, for ease of exposition we shall use "lumpy purchase" to denote acquisition granularity in the following sections of the paper.

Expiration Granularity

Expiration granularity concerns the *storability* of a resource's benefits. The more storable a resource's benefits, the coarser is its expiration granularity. If a resource's benefits expire continuously and uniformly through time whether the resource is used or not, then the resource has zero or the finest possible expiration granularity. Employee time is a resource whose benefit flows continuously and cannot be stored. If we hire an employee for a day, month, or year, we must utilize the employee's services during that time; any unutilized services are lost forever. Time is a good basis for measuring the opportunity cost for resources with fine expiration granularity. Deposits in a coal mine lie near the other extreme of the expiration granularity scale. Because passage of time does not deplete the energy contained in a lump of coal, its benefits are almost perfectly storable. Such resources have coarse, almost infinite, expiration granularity. Time is not a good basis to calculate the opportunity cost of resources with coarse expiration granularity. Most economic resources, however, fall somewhere between the extremes of this range, and have finite expiration granularity.

Recall that the economics of supply and acquisition determine acquisition granularity. In contrast, expiration granularity is an *inherent* characteristic of the resource in relation to its environment. Once we rent a hotel room for a day, the benefits we purchased expire over time whether we occupy the room or not. Properly stored, a machine tool will stay sharp and usable for years. In both cases, depletion of benefits stems more from resource characteristics and less from economic considerations.

[1] New technologies can change this. Most personal computers sit idle on desks most of the time. The development of "utility" computing, where users can draw on the computing power of remote machines over a network, may eventually reduce the granularity of computing down to practically zero.

As expiration granularity relates to a resource's inherent characteristics, we measure each resource's expiration granularity in relation to its own estimated lifespan and not along an absolute time scale. Fresh fruit has a life of a few days. However, we can preserve fresh fruit for a few days, meaning that its benefits can be stored for a substantial portion of its life. Thus, fresh fruit has coarse expiration granularity. In contrast, although a roof lasts for decades, its benefits expire continuously over time. Thus, a roof has fine expiration granularity because we cannot store its benefits for later use.

Because of the inherent links between the expiration granularity of a resource and the storability of its benefits over time, we use the term "storability" for ease of exposition.

Consumption Granularity

Consumption granularity pertains to the *controllability* by the user of the rate at which she can extract available benefits. The greater the user's ability to vary the rate of benefit extraction, the greater the resource's consumption granularity. The user has considerable discretion in extracting available benefits from raw materials. Thus, the rate of benefit extraction can display extreme discontinuities or lumpiness because the user can accelerate or slowdown the rate of benefit extraction. A use-based metric is appropriate for measuring the opportunity cost of resources with coarse consumption granularity. In contrast, the user's inability to control the rate of deterioration of a stone sculpture standing in open weather means that the rate of benefit extraction is constant. This resource therefore has fine consumption granularity. A use- or consumption-based measure does not appropriately measure the opportunity cost of using a resource with fine consumption granularity.

Due to the inherent link of a resource's consumption granularity to controllability by the user, we often use the term *controllability* for expositional clarity. Also, we note that definitions of expiration and consumption granularity are with respect to normal and expected use. When we employ resources for purposes other than what we call normal and ordinary, their granularities may change. The resultant estimates of opportunity costs may also change because opportunity costs depend on the context in which resources are used.

USING THE GRANULARITY FRAMEWORK TO MEASURE OPPORTUNITY COST

This section discusses a systematic approach for estimating opportunity cost as a function of a resource's granularity profile. Figure 1 provides a companion flowchart.

Lumpy Acquisition

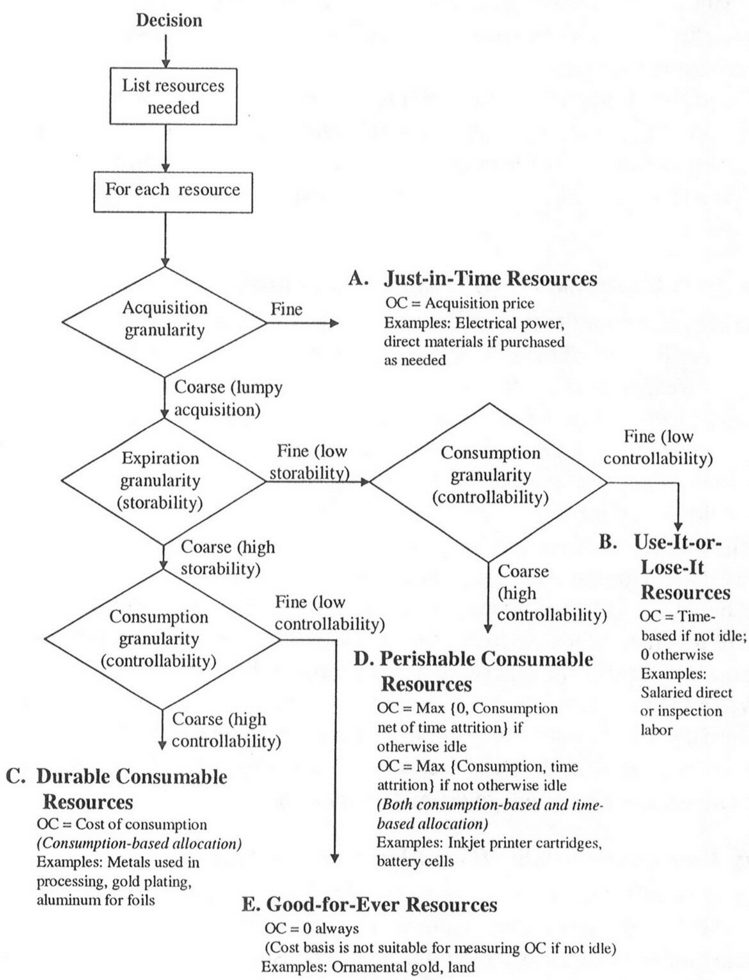
When a resource has low acquisition granularity—it can be acquired when needed—its acquisition cost is also its opportunity cost as noted in Node A in Figure 1. We can readily identify the opportunity cost of "*just-in-time*" resources such as utilities or a can of soda from the vending machine. Although we often term such opportunity costs as variable costs, recall that lumpiness pertains to acquisition while variable cost pertains to use.

We restrict the following discussion to lumpy resources because storability and controllability only pertain to resources acquired ahead of use. The article next considers the problem of estimating the opportunity cost for resources with extreme granularity profiles. Intermediate cases are discussed in the final paragraphs and also in the next section.

Low Storability, Low Controllability ("Use-It-or-Lose-It" Resources)

Let us consider a resource with nonstorable benefits, the consumption of which cannot be controlled by the user. This resource has fine expiration and fine consumption granularity. Such a resource—human resources, for example—is a *pure capacity resource* as identified in Node B of Figure 1. We can justify a time-based allocation of the cost of such a resource to a decision under the

FIGURE 1
Opportunity Cost (OC) Decision Tree Based on the Granularity Framework



assumptions of factor market efficiency and full capacity utilization. That is, a *duration* driver appropriately measures opportunity cost. As an example, time is the correct basis to estimate the opportunity cost of human resources.

Seen in the context of the granularity framework, using a duration driver to measure opportunity cost implies that the benefits from the associated resource are not storable, and that the user has no control over the rate of benefit extraction. Time is a poor basis for measuring the opportunity cost of resources that do not meet these conditions.

High Storability, High Controllability (Durable Consumable Resources)

As noted in Node C of Figure 1, resources such as raw materials possess coarse expiration and coarse consumption granularity because we can store these resources for a long time and can extract their benefits at will. These resources yield benefits only when we use them, and future benefits do not decay appreciably with time when stored for later use. We can estimate opportunity cost through a metric of consumption, referred to in cost accounting parlance as a *count* or *quantity* driver. As an example, the weight of metal is the appropriate driver for estimating the metal's opportunity cost in making machined parts. Similarly, we can use the number of passages through a tollbooth to measure the loss of stored value in an EZPass® transponder. The count measure could also be in units of time. We measure the useful life of a light bulb in hours of illumination because we control when to turn the bulb on and consume the resource.

To relate to traditional practices, consider a resource whose cost is normally allocated using a count-based driver. In the granularity framework, this choice implies that the attrition in benefits of the resource is solely a function of it being put to use; there is no time-based attrition in future benefits. This characterization puts the resource at an extreme end of all three dimensions of the granularity framework.

Low Storability, High Controllability (Perishable Consumable Resources)

Many resources have benefits that expire with time while also affording the user a significant degree of control over the rate of benefit extraction. Even if it never left the garage from the time it was purchased, a ten-year-old car is not likely to retain its value. However, it is unlikely to last for ten years if it is driven 25,000 miles a year. A machine can become obsolete or wear out from use. A battery cell may lose its charge gradually over time without being used or through intensive use within a short period, as suggested in Node D in Figure 1.

We should estimate opportunity costs of such resources by considering the decline in their remaining benefits due to consumption as well as to the passage of time. When a resource has no alternative use, we should measure its opportunity cost by comparing the decision's resource requirement (consumed benefits) with the unavoidable decline in benefits during the period spanned by the decision (loss due to time). Because loss of benefits due to consumption typically exceeds time attrition, the opportunity cost of the otherwise idle resource is the *excess* of the consumption over the time attrition. When the resource has alternative uses, the opportunity cost for the decision at hand depends on the greater of the consumption rate for the alternate use and the attrition due to the passage of time. As we detail in the next section, the unifying granularity framework alerts us to the need for such *nonlinear* allocations to estimate opportunity cost.

High Storability, Low Controllability (Good-Forever Resources)

As seen in Node E of Figure 1, cost is not a suitable basis for estimating the opportunity cost of these resources. The benefits from such resources do not expire with time, and the owner does not have any significant measure of control over the benefit consumption rate. Land used for residential purposes is an example of this kind of resource. The benefits from land do not deplete over time and the user generally cannot influence the rate of benefit extraction.

Intermediate Storability and Controllability

Many resources fall in between the extreme cases of storability and controllability considered in the preceding paragraphs. Benefits are often storable to some extent and controllable to some extent, implying that the resource has finite expiration and consumption granularities; Node D in Figure 1 is the closest characterization. We discuss below how traditional costing systems may incorrectly cost this class of resources. Such systems rely on one driver per resource or cost pool, whereas the arguments above suggest the need for multiple drivers for allocating the costs of such resources.

ILLUSTRATIONS OF THE GRANULARITY FRAMEWORK

This section describes how the granularity framework provides a unifying framework to better measure opportunity cost for decision making and to sharpen insights into observed practice.

Exploiting Acquisition Granularity

Acquisition granularity stems from the economics of purchase and supply. We can therefore conceive of business models built on changing a resource's acquisition granularity. The rationale for a wholesale business stems from the difference between the manufacturers' economics of resource supply and the retailers' economics of resource purchase. A time-sharing arrangement for a condominium in a beach resort reduces the condominium's acquisition granularity. Buying machine time, hiring temporary workers, and renting a part of a building are other examples of business models that reduce acquisition granularity.

Changing acquisition granularity also affects the ease of measuring opportunity cost. Firms using just-in-time operations management often buy required components instead of making them. In this context, outsourcing a part is equivalent to "leasing" for a short time the facilities and other resources needed to make the parts. Outsourcing parts reduces the lumpiness of the resources used, and the resulting measurement error. In a similar fashion, postponement and commonality strategies discussed in the literature on supply chain management delay product customization, allowing for greater flexibility in resource usage. Thus, these strategies move resources toward Node A in Figure 1, increasing our ability to measure their opportunity cost more accurately.[2]

Pricing Resources

In efficient markets, resource prices reflect the value or the *opportunity cost* of consumed benefits. The stored benefits of resources at Node B (fine expiration and consumption granularities) expire continuously over time, regardless of whether the benefits are used. Thus, time must be a factor when pricing these resources, such as labor, and in determining their opportunity cost.

More generally, the price structure should include all factors that affect available benefits at a given point in time. For instance, operators price the storage capacity of a grain silo by per cubic foot per day because both time and volume affect the magnitude of remaining benefits. Opportunity cost and therefore price become nonlinear when factors other than time affect the future benefits. Why does a rental car contract usually specify a rate per day plus a charge for mileage over a certain limit? The granularity framework recognizes that the future benefits of this car depreciate with time as well as usage. For instance, a rental car firm may seek to maintain a fleet of cars less than two years old and with less than 60,000 miles on the odometer. If the firm purchases cars for \$35,000 each, expects salvage value to be \$11,000, and expects to rent the car for 300 days per year, it values resource expiration at $\frac{(\$35{,}000 - \$11{,}000)}{600 \text{ days}} = \$40$ per day. The decay rate in miles is $\frac{(\$35{,}000 - \$11{,}000)}{60{,}000 \text{ miles}}$ = \$0.40 per mile. Thus, the benefit used by a customer who rents for a day is the maximum of a day's worth of time decay (\$40) and usage decay at the rate of \$0.40 for each mile actually driven. Because normal use corresponds to 100 miles per day,[3] the car rental company may charge the customer a rental rate of \$40 per day plus \$0.40 per mile for miles in excess of 100 miles per day. The nonlinear price is required because the resource has a medium level of consumption granularity, which allows the user to extract benefits at a rate exceeding the time-driven attrition in stored benefits.

We can generalize the above insight when more than two factors determine the remaining benefits of a resource. Each of these factors can serve as a driver or allocation basis, depending on the relevant factors for a given decision context. For example, the amount of goods a truck can carry may be bounded by volume (if carrying straw), weight (steel rods), risk (nuclear fuel), or value (diamonds). Thus, it is no surprise that common carriers such as United Parcel Service consider multiple factors such as weight, volume, value, and distance in their tariffs.

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[2] We thank a referee for this observation.

[3] In locations where the firm expects usage of less than 100 miles per day to be the norm, it may prefer offering unlimited mileage from both costing and a marketing viewpoint.

Pricing and Managing Bundled Resources

Products and services often comprise bundled resources. For example, a taxicab is a bundle of an automobile and a driver, two resources with different granularity profiles. Relative to the driver, the car has lower time-based attrition in future benefits and affords greater control over the rate of benefit extraction. Observed pricing schemes reflect the resulting nonlinearity. We conceive of the startup charge for a taxicab as the (driver's) value lost due to waiting and the per-mile charge as a use-based depletion of the car's future benefits. To contrast, notice that we do not observe such a nonlinear scheme in bus or subway fares as often because a schedule allows for matching the supply and use of the driver's time.

Drawing from a Japanese carmaker's experience, Suzaki (1987, 103) discusses the cost reductions from recognizing different granularity profiles of individual resources in a bundle. He focuses on the loading and unloading time for container trucks and argues that in a bundled configuration, the driver is not a fully utilized resource because he must be paid for his time while waiting for the container to be loaded or unloaded. Suzaki (1987) indicates that firm procured extra containers to unbundle the two resources, enabling it to convert the driver's waiting time into gainful activities. The granularity framework provides a conceptual basis for this intuitive decision.

Capacity Costing

Distinguishing between time- and use-based attrition in stored benefits affects the valuation of idle capacity. Leveraging the Consortium of Advanced Manufacturing-International (CAM-I) model, Klammer (1997), McNair and Vangermeersch (1998), and others argue for splitting available time into idle and used capacity, and for further partitioning of used capacity into productive and nonproductive components. They also recommend that we convert the percent time in these categories into dollar terms to get management attention and to justify investments in remedial actions.

For an example, suppose a machine costs $876,000 and lasts for four years. We expect to use the machine for one eight-hour shift each working day. Assuming 250 working days in a year, the expected usage for the machine is 2,000 hours out of a possible 8,760 hours in a calendar year. The CAM-I model allocates $219,000 (= $876,000/4 years) to each year. Dividing through by theoretical capacity of 8,760 hours yields a rate of $25 per hour (= $219,000/8,760 hours in a year). Thus, unused machine time of 6,760 hours each year (= 8,760 – 2,000) is assigned a value of $169,000 (= 6,760 hours × $25 per hour).

Applying the granularity framework highlights that the CAM-I approach does not distinguish between time-based and use-based attrition in future benefits. By assuming that the future benefits decay purely as a function of time, the CAM-I approach implicitly places the machine at Node B of Figure 1. However, we reasonably expect the rate of use to affect a machine's life. That is, not using the machine today allows us to "store" at least some of its benefits for use later. As illustrated below, this feature alters the estimate of the cost of unused capacity.

Suppose that, if never used, the machine becomes obsolete with zero salvage value in 10 years. We value the machine's time-based expiration at $10 per hour [= $876,000/(10 years × 8,760 hours per year)]. Suppose further that a fully utilized machine can provide 12,000 hours of productive use before wearing out, meaning that the use cost per machine hour is $73 (= $876,000/12,000 hours). Finally, assume for simplicity that the machine's time-based attrition of benefits can be approximated by a constant rate over its life, resulting in our machine losing $10 in stored value for each unused hour.[4]

[4] We assume a smooth function for ease of exposition. Time-based decay may be nonlinear, perhaps a step function, that could be approximated by piecewise linear attrition rates for different time horizons. Introducing such features into the framework adds complexity but does not alter the conceptual insight.

Together, these assumptions imply that the expected expiration rate per year is $213,600 [(expected productive use of 2,000 hours × $73 per hour) + (6,760 unused hours × $10 per hour)]. At this expiration rate, the machine will last for 4.10 years (= $876,000/$213,600 per year) if we use it for 2,000 hours each year. Similarly, we estimate that the machine would last 2.58 years if we use it for 4,000 hours each year. The nonlinearity in expected life of the machine emphasizes the joint effect of time- and use-based depletion in stored value. Assuming 2,000 hours of use, the machine has 6,760 hours of idle capacity in year 1, valued at $67,600.[5] This dramatically lower estimate relative to the CAM-I model estimate of $169,000 arises because the granularity framework recognizes that not using the machine today allows extra use in the future.

Costing of Idle Capacity for Make-or-Buy Decisions

The granularity framework suggests that we frequently underestimate the cost of in-sourcing in analyses of make-or-buy decisions. To illustrate, continue the above example and assume that the firm currently uses the machine for 2,000 hours each year. Suppose that the firm discovers a new but temporary use, perhaps making some previously out-sourced components that would increase the use to 2,100 hours during the current year. What is the opportunity cost of the capacity used to make the components in the classic make-or-buy analysis?

The traditional approach assigns zero as the cost of using this capacity resource, arguing that there is no other opportunity lost from using the machine capacity to make the component. However, doing so ignores the distinctions between the time- and use-based attrition of benefits. Because it explicitly considers expiration (time-based) and consumption (use-based) granularities, our proposed framework leads to a different answer. Depletion of benefits is greater under the make decision when use-based attrition exceeds the time-based attrition. In our example, instead of costing the otherwise idle capacity used in the make decision at zero, we should cost the capacity resource at $63.00 per hour, consisting of $73.00 use-based value, which is avoidable, less the $10.00 per hour for time-based attrition, which is unavoidable.

DISCUSSION AND CONCLUSION

To facilitate efficient decisions and contracts, accounting data should capture the economics of resource acquisition, expiration, and consumption. We believe that applying the granularity framework will help accounting data attain these characteristics. This framework recognizes three characteristics of resources:

- *Acquisition granularity*: the lumpiness in resource acquisition;
- *Expiration granularity*: the storability of benefits over time; and
- *Consumption granularity*: the user's ability to vary the rate of extracting and consuming the benefits of the resource.

Our analysis suggests that estimating the opportunity cost of a resource with a non-zero granularity may require the use of multiple cost drivers, which can generally be achieved through a nonlinear combination of time-based and count-based assignments. The argument for nonlinear cost assignment is fundamentally distinct from activity-based costing (ABC), in which we create multiple activity cost pools and employ a single cost driver for each pool. The need for multiple drivers arises because systems that assign costs based solely on use-counts, or consumption, ignore the time-driven decay in the benefits of a resource. The importance of the error from ignoring the time-decay depends on its magnitude relative to use-based rate of resource depletion.

[5] The granularity framework pertains to measuring opportunity cost. It therefore offers no insight into how the firm should deal with the cost of the unused capacity—charge to income statement, charge to product, and so on.

Expiration specification error (ESE) results when cost systems use a driver that does not completely capture the underlying decay in future benefits. This error is minimal for resources at the extremes of the expiration granularity spectrum. Time-based assignments entail no ESE for resources with fine expiration granularity and count-based assignments entail no ESE for resources with coarse expiration granularity. However, the ESE can be large for resources with intermediate expiration granularity. When the resource allows a sufficient degree of control to the user, which is true for most consumables, its useful life may end well before it becomes obsolete with the passage of time. This nonlinearity implies that traditional analyses can over-cost resources that are not fully utilized. We require two drivers to appropriately capture the time-based and use-based measure of opportunity cost of under-utilized resources.

One avenue for future research is to develop an implementable rule for partitioning an organization's resource set into a manageable number of granularity classes. Aggregating individual resources into classes creates intra-group heterogeneity, increasing the error in measuring opportunity cost. Optimal cost systems trade off this error against the costs and other consequences of using a larger number of resource pools (see Lim and Sunder 1990, 1991; Datar and Gupta 1994).

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