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"Granularity, Time and Control of Economic Resources"

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Granularity, Time, and Control of Economic Resources

Abstract

Opportunity cost is a central concept in decision making. It is difficult to measure because it is the value associated with opportunities foregone. In this paper, we characterize three time-based dimensions of resources to help understand and estimate opportunity costs. These dimensions capture the intrinsic lumpiness of resources with respect to their acquisition (acquisition granularity), the extent to which they retain their usefulness over time (expiration granularity), and the extent to which the decision-maker has control over the consumption of these resources (consumption granularity). We illustrate how these concepts may be used in decision making. We show how the granularity framework points to a non-linear cost assignment procedure using *multiple* cost drivers for some resources.

Keywords Opportunity cost, Resource management, Time-based costing, Resource granularity, Costing and decision-making, Non-linear cost systems.

Granularity, Time, and Control of Economic Resources

I. INTRODUCTION

Opportunity cost being the value associated with "the road not taken," this central concept of managerial decision theory has soft, hypothetical and subjective foundations. Its measurement presents practical difficulties. In single-person contexts, decision maker's subjective estimates of opportunity costs are used as inputs into models of decision making under uncertainty. In multi-person contexts, the absence of objective measures of opportunity costs further exacerbates the agency costs. In either context, a reduction in the subjectivity of opportunity costs holds the promise of helping make better decisions.

In this paper we identify an objective property of economic resources that may help systematize estimation of opportunity costs. We call this characteristic *granularity*. It has three dimensions. We provide examples of how granularity analysis of resources may help us estimate opportunity costs, and possibly make better decisions. However, there is no free lunch. Whether the gains of granularity analysis we propose are worth the costs remains to be assessed.

Profit maximization occurs when the marginal cost of a decision equals its marginal revenue. To evaluate this optimality condition, one must assess the opportunity cost of resource outflows and value of resource inflows associated with a decision. The usefulness of a management accounting system for the purpose of decision making is a function of how well it captures these opportunity costs, an issue that the accountants and managers have long grappled with.[1]

We must understand the determinants of opportunity cost in any given decision context before we can evaluate existing or proposed cost accounting procedures. In this paper, we address this issue by exploring the intrinsic nature of resources, and by examining the economics of resource acquisition and usage.

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[1] Textbooks stress the central role of opportunity cost in decision making. Maher, Stickney and Weil (1994, p. 26) and Horngren, Foster and Datar (1994, p. 399) define opportunity cost as the return foregone from the resource's best alternative use. Demski (1994, p. 266) emphasizes that opportunity cost provides an indication of returns that are available with options that were excluded from the analysis. These and other textbooks in general do not address measurement issues. Zimmerman (1997, p. 486) writes: "Inside the firm, market prices do not exist to guide the allocation of scarce resources. Management must devise alternative accounting and administrative systems to allocate scarce resources…Unit cost data are a substitute inside the firm for the lack of market prices…Full absorption costs,

Efficient management of resources calls for organization of resource entitlements and obligations over time in a Pareto-efficient manner (Sunder 1997). The measurement and management of opportunity costs is a key to good resource management. The ease of measuring the opportunity cost of a resource is linked in an important way to the lumpiness or granularity of the resource. Some resources can be acquired as and when needed for consumption, making it easier to measure their opportunity cost. It is economical to acquire other resources in a lump sum at one time, in anticipation of future demand, complicating the determination of opportunity costs. Some resources can be stored and used when needed; others expire with time, used or not. These differences reflect variations among resources with respect to various dimensions of granularity.

In this paper, we develop a time-based characterization of the intrinsic nature of resources. Time flows continuously and smoothly, and therefore has zero granularity. Resource flows are not necessarily continuous, smooth or uniform. They exhibit varying degrees of granularity. Three dimensions of granularity, pertaining to resource acquisition (*acquisition* granularity), the natural expiration of their usefulness (*expiration* granularity), and the consumption of their benefits (*consumption* granularity), are important to understanding the nature of costs associated with resource acquisition and use. Using examples, we illustrate how characterizing resources along these dimensions helps capture the opportunity cost of resources relevant for various decisions.

The granularity framework suggests that estimating the opportunity cost of a given resource with finite granularities may require the use of *multiple cost drivers*; in particular, a combination of time-based and count-based assignments. Note that this use of multiple drivers for a single resource, or pool of resources, is fundamentally distinct from the traditional activity-based costing (ABC). In ABC, a single cost driver is sought to be identified for each one of the many pools of resource costs, (e.g., using setup hours to assign setup costs and machine hours to assign maintenance costs to specific jobs). A second key difference is that in our framework the multiple cost drivers for a single resource are combined in a nonlinear fashion while in the traditional ABC systems, cost is a linear combination of the chosen drivers.

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while not an exact measure of opportunity costs, can be a better measure than variable costs." Also see Balakrishnan and Sivaramakrishnan 1996, 1998.

One implication of our analysis is that even the use of the “correct” count drivers prescribed by ABC can give rise to incorrect estimates of the opportunity cost of resources with finite granularities. The reason is that the time-driven decay of these resources is ignored in systems that assign costs based solely on use-counts (i.e., consumption).

Section II of the paper describes the granularity framework. Section III speaks to the relevance and valuation of resources for a decision. Examples in section IV illustrate the use of the granularity framework to capture and enrich our understanding of the opportunity cost of resources relevant for decisions. Section V has some concluding remarks.

II. GRANULARITY FRAMEWORK

Consider three dimensions of granularity: acquisition, expiration and consumption. The first is concerned with the acquisition of resources. Expiration granularity is a measure of the extent to which resources *retain* their usefulness over time. More storable the benefits are, more granular is the resource. Finally, consumption granularity deals with the “lumpiness” of resource consumption, i.e., the user's ability to control the rate at which the benefits from a resource are extracted. We introduce these concepts with the help of examples.

Acquisition Granularity

Acquisition of electrical power from the utility company for heating and lighting in households is continuous. Electrical power is bought instantaneously at the moment it is utilized. The technology for measuring this continuous flow of the resource to the customer and to implement a contract for such a transaction is available at an affordable cost. This resource is not inventoried. We place this resource at the zero end of the acquisition granularity scale. See Figure 1A.

(Place Figure 1 here)

Acquisition of groceries is more granular than the acquisition of electric power. It is not always economical to acquire sugar or vegetables in chunks as small as we use them. The technology of their acquisition is such that to implement the purchase of spoonfuls of sugar or bitefuls of vegetables is costlier that buying them few pounds at a time. Most people therefore choose to buy their groceries in quantities enough to last for a week or so (see Figure 1B). This argument underlies the basic economic order quantity model that trades off the cost of transactions with the cost of storage to determine the optimum lumpiness (batch size) of acquisition of resources.

In addition to the transaction and storage costs, some of a resource's acquisition granularity may arise from the granularity of resource supply. For example, it may not be possible (without exorbitant additional costs) to buy half a car or a 13 ounce can of Coca Cola because their suppliers have chosen, for their own economic reasons, to make them available for sale in discrete packet sizes.

These household examples can also be applied to business organizations. Inventories may be bought for a few days, weeks or months at a time, tools for a few weeks or months, machinery for a few years and the factory for some tens of years. These resources lie at increasing distance from the origin along the scale of acquisition granularity, the exact location on the scale being determined by economics of the relevant technology.

One way to quantify the acquisition granularity is to look at the time intervals between consecutive acts of acquisition.[2] Groceries are bought every week while houses are bought only once in many years. Therefore, by this measure, houses are more granular than groceries. When a resource acquisition is perfectly matched to its usage, as in our electricity or water examples, such a resource has zero acquisition granularity.

Expiration Granularity

A second dimension of granularity concerns the expiration of the benefits yielded by a resource. A highway sign, factory roof or a grain silo yields its benefits almost continuously through time. Barring renovation (which creates a new asset), over time the silo will deteriorate and fall apart, largely independent of whether it is used for storage. Employees provide another example of a resource whose benefits flow continuously and cannot be stored. If an employee is hired for a day, month or year, his services must be utilized during that time; any unutilized services are lost forever. When the expiration of the benefits of an asset is intrinsically related to the passage of time, it has zero expiration granularity. Effective use of these assets is therefore related to their capacity utilization. Indeed, capacity utilization is a meaningful metric only for resources with low expiration granularity. One speaks of the capacity utilization of a grain silo but not of the grain stored inside.

Diamonds perhaps lie near the other extreme of the scale of expiration granularity. A diamond retains its benefits for an indefinite period of time ("Diamonds are forever," we are told). These benefits are perfectly storable, and the passage of time does not necessarily cause depletion of benefits expected of the resource by its owner. A bag of grocery lies somewhere between the silo and diamond, in the sense that they become useless if not utilized within a few days or weeks. Most economic resources fall in this middle range. See Figure 2.

(Place Figure 2 here)

Expiration of benefits derivable from a resource is linked to time through one or more of three reasons--weathering, obsolescence, and timeliness. Weathering refers to the progressive diminution of remaining benefits with the passage of time due to intrinsic resource characteristics. Cars rust and milk sours. Obsolescence and timeliness have more to do with the economics of the environment in which a resource is used. Changing environment, especially technology, may reduce or eliminate the demand for services of a resource. Personal computers with an 8088 processor and Visicalc (the first personal computer worksheet) have become obsolete in the nineties. Finally, the services of a resource may have value only if they are available at a specific time. A printing press that breaks down till 6 AM and fails to print the morning edition of the paper causes permanent economic loss.

The time scale of expiration granularity is a relative one. Each resource's expiration granularity is defined in relation to its own estimated life and not along an absolute time scale. It is a measure of how smoothly the benefits of the resource expire with time over its life. Fresh fruit can be preserved only for a few days, whereas a factory roof typically has a life of well over ten years. Yet, the fruit has higher expiration granularity than the roof because the freshness of the fruit is storable even if only for a few days, while the benefits from the roof cannot be stored.

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[2] This assumes that the consumption demand for the resource is uniform. If the demand itself were lumpy and infrequent, even a zero acquisition granularity resource may be acquired only periodically.

Expiration of benefits need not always be tied to the passage of time. It is more appropriate sometimes to use other measures of the benefit extracted. The life of an automobile may be defined better in terms of the number of miles driven, and the life of a die may be defined better in terms of the number of blanks it produces. As we clarify later, the role of time versus non-time based measures of benefit extraction is key to estimating the opportunity costs for a proposed use of the resource.

Figure 3 illustrates the location of several resources in the two-dimensional (acquisition and expiration) granularity space. A rental car lies close to the origin because this resource has small granularity along both the dimensions. It can be acquired in small (relative to its life of many years) units of time.[3] Its benefits are lost forever with the passage of time. Plant facilities lie in the northwest corner of the quadrant because their benefits have small expiration granularity but large acquisition granularity (it is not economical to acquire the plant for a few days or even a few months at a time). Inventories lie on the right side of the quadrant because they have large expiration granularity (can store their benefit till used) but can have their acquisition granularity vary over a large range.

(Place Figure 3 here)

There is an important distinction between the two granularity concepts. Expiration granularity is an *inherent* characteristic of the resource and its environment, and is beyond the owner's control. Acquisition granularity, on the other hand, can be a consequence of inherent characteristics of a resource, or result from an acquisition decision based on a benefit-cost analysis of alternative technologies. A plant manager may choose to lease machine time instead of buying the machine, even though it may be more economical to buy the machine outright.

Consumption Granularity

Consumption is defined as the extraction of benefits from a resource. For some resources, the rate at which the remaining benefits of the resource expire may be fixed, and for others, the owner may control it. The benefits of a stone sculpture or a factory building, both standing in open weather, expire with time, and they are not manipulable. The owner has considerable dis-

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[3] Small is a relative term. Depending on the context, a day can be as a short or long time.

cretion in extracting the benefits from an automobile. The concept of consumption granularity captures the extent of the owner's control over the timing and rate of extraction of benefits of a resource.

Machine tools and shop-floor personnel are examples of resources with zero consumption granularity. It is not possible to extract two machine hours worth of benefits from a machine in one hour even if you promise to give it a day's rest. Raw materials have infinite consumption granularity because the benefits from these resources are fully extracted when they are converted to finished goods (though the ability of a particular user to use the materials may be constrained by the available plant capacity). To the extent a driver can accelerate the rate of extraction of benefits from a car within a shorter than usual period of time, a car can be said to have an intermediate level of consumption granularity, within its technological boundaries.

Expiration and consumption granularity concepts are related, but different. Both expiration granularity and consumption granularity are intrinsic resource characteristics. Expiration granularity characterizes the time path of expiration of benefits of a resource, whereas consumption granularity characterizes the decision-maker's control over this time path of expiration. To make this distinction clear, we present a two-way classification of some resources (in their normal uses) along with the expiration and consumption granularity dimensions in Figure 4.

(Place Figure 4 here)

Salaried employees constitute a resource that has low expiration and consumption granularities. A salaried employee's time, if unused, is lost forever. That is, benefits expire with time making it a resource with low consumption granularity. Its expiration granularity is also low because with every passing minute the work potential is lost, whether used or not (because the contractual obligation expires at the end of the contact period). A sports stadium has low expiration granularity because it yields benefits continuously over time till it deteriorates and needs to be demolished or rebuilt. It has medium consumption granularity because rough usage and lack of proper maintenance affect its remaining useful life. A battery cell has low expiration granularity because it has a finite life even if unused, and its usefulness declines with time (a fresh battery cell is stronger than an unused one-year old battery cell). However, the decision-maker has considerable control over the extraction of benefits from the cell. If used sparingly, the battery cell will last longer; toy trains often stop running within an hour out of their boxes on Christmas mornings.

A software program has medium expiration granularity because it is likely to become obsolete with the advance of software and computer technology. Until such time it retains its full benefits. Its consumption granularity is low because using it once does not diminish its value for the next use. A car has medium expiration granularity under assumptions of normal use (normal speed and upkeep) because its life extends somewhat if less than expected mileage is put on it in a given year. For example, a two-year old car with 15,000 miles on it can be expected to be in a better condition than another car of the same vintage but with 45,000 miles on it. A fresh fruit has medium expiration granularity because its freshness can be preserved over a part of its useful life. Within this time period, it retains its full benefits. It has high consumption granularity because the benefits can be extracted within a very short period of time by eating them.

Diamonds, oil fields and industrial gold are resources that have high expiration granularity because their benefits are storable for long periods of time. A diamond has low consumption granularity because wearing it does not diminish its value for subsequent use. An oil field has medium consumption granularity because there are physical limits to the rate at which oil can be extracted without seriously reducing the total amount of oil that can be extracted from the oil field over its life time. Industrial gold has high consumption granularity because they yield their full benefits when used for the intended purpose (e.g., melted to coat the terminals of a computer chip).

While the classification of specific resources may be open to debate, we hope the above discussion makes the distinction between the consumption and expiration granularity concepts clear in the context of normal and ordinary use of each resource.[4] We next discuss how these concepts may help us in decision making.

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[4] When resources are used for purposes other than what we call normal and ordinary, their granularities may change. The resultant estimates of opportunity costs may change too. After all, opportunity costs depend on the context in which resources are used.

III. RESOURCE GRANULARITY AND DECISION MAKING

Recall that the opportunity cost of a resource is definable only in the context of a decision. Therefore, wherever it is not made explicit below, we ask the reader to interpret the discussion in light of a decision whose execution requires consumption of the resources being analyzed.

If a resource can be used only for the decision being considered, measurement of its opportunity cost is straightforward. Before it is acquired, opportunity cost is equal to its acquisition cost less the post-use salvage value. This cost is considered in making the decision. After it is acquired, opportunity cost is equal to the disposal value of the unused resource (Zimmerman 1997, 28).[5]

For some resources it is not technologically feasible, or economically viable, to reduce acquisition granularity. Firms that need molten steel invest in a furnace, a lumpy resource with large acquisition granularity. For other resources, acquisition granularity is a consequence of the economics of the purchase decision. An investment decision may create a resource with large acquisition granularity, whereas a decision to lease the services of the resource when needed results in a resource that has smaller acquisition granularity. For example, bulk buying a raw material used in two or more decisions may be cheaper than buying it upon receiving a requisition from the production department. Labor hired on annual salary contract (large acquisition granularity) to perform a variety of anticipated or planned tasks can be cheaper than labor hired for specific tasks and paid by the hour (small acquisition granularity).

Acquisition granularity and the economics of resource acquisition have important implications in shaping the opportunity cost of a resource in making decisions. If the acquisition granularity of a resource is small, acquisition cost itself is its opportunity cost. However, if its acquisition granularity is large, then its opportunity cost is determined by the best alternative use of the

[5] Resources that give rise to “avoidable fixed costs,” such as unique tooling requirements, have a fine expiration granularity because their benefits erode completely within the decision horizon, and the resource does not have any use beyond the decision horizon (it has, by definition, no other use). That is, what is acquired is consumed. Other resources such as jigs and fixtures may have coarser expiration granularity (i.e., benefit expiration date lies beyond the decision horizon), implying that they have positive salvage value at the end of the decision horizon.

resource at the time of the decision. As detailed below, the cost of the best alternative use is influenced by the resource's expiration and consumption granularity.[6]

Consider the extreme case of a resource with zero expiration granularity. Such a resource yields benefits at an unchanging rate through time whether or not anyone uses these benefits. The opportunity cost of such a resource, when there is no use for it, is zero. If this resource also has large acquisition granularity, it best represents a *pure capacity resource.* Since the benefits derived from a pure capacity resource are measured conveniently as a function of time, its opportunity cost can be expressed as a function of time as well. Therefore, time is the best and the only cost driver for a pure capacity resource. Formally, let $C_0(0)$ be the initial acquisition cost of a resource with zero expiration granularity, which expires in T time units, and let $C_0(T)$ be its estimated salvage value. Assuming, for convenience, that the depreciation is constant through time, and that the factor market in which the resource was purchased is efficient, the time rate of expiration of benefits of this resource is given by $\dot{C}_0 = \frac{C_0(0) - C_0(T)}{T}$ per unit time**.** This rate is an estimate of the opportunity cost (*OC*) per unit of time that must be charged to a decision which requires the use of this resource, if it is not other wise idle. That is, $OC = Max\{0, \dot{C}_0\}$**.** Thus, a *time-based* allocation of a resource's cost to a decision (or a *duration* driver) can be justified under assumptions of factor market efficiency and full capacity utilization.

At the other extreme, consider a resource with infinite expiration granularity. This resource yields benefits only when consumed. It does not decay with time when not consumed. Its cost can therefore be assigned to a decision only through a metric of consumption, or in cost accounting parlance, through a *count* driver. Formally, let $C_\infty(0)$ be the acquisition cost of an infinite expiration granularity resource, where X is a "count" measure of the life of the resource (or use capacity), and at the end of its economic value of count X let its salvage value be $C_\infty(X)$. A decision

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[6] Surveys indicate firms using just-in-time operations management, such as Ford and GM increasingly buy, rather than make, automobile parts. For our present purposes, outsourcing a part is equivalent to "leasing" the facilities and other resources needed to make the parts in-house. This change reduces acquisition granularity of the resources used, and costing a decision becomes simpler because estimates of opportunity cost are less prone to measurement errors.

task that makes use of this resource will be charged at the rate of $C'_{\infty} = \frac{C_{\infty}(0) - C_{\infty}(X)}{X}$ per unit count. Note that the count measure could even be in units of time. For example, the useful life of jet engine parts and light bulbs are measured in hours of service provided.

A resource with finite expiration granularity may be viewed as a convex combination of the two extremes. As an example, consider the case of a rental car. Let us assume that a car-renting company maintains an attractive fleet by replacing its cars after every two years, or 60,000 miles. Consider a car purchased for $35,000. The salvage value at the time of disposal is $11,000. If the car is leased out to a customer for a day, the expected usage for the day is 100 miles (60,000 miles / 600 days). Of course, the customer may or may not drive the car for 100 miles. Even if the customer drives the car for less than this distance, the rental car incurs a day's worth of time decay on the car. This resource expiration is valued at

$\dot{C}_0 = \frac{(\$35{,}000 - \$11{,}000)}{600\ days} = \$40$ per day, which is equivalent to 100 miles in distance. The decay rate in miles is $C'_{\infty} = \frac{(\$35{,}000 - \$11{,}000)}{60{,}000\ \text{miles}} = \$0.40$ per mile. It makes sense for the car rental company to charge the customer a rental rate of $40 /day plus $0.40 / mile for miles in excess of 100 miles per day.

In essence, we are using a non-linear combination of two cost drivers to estimate the opportunity cost of renting the car for a day. The fixed daily rate of $40 per day is computed using a time driver, which reflects the fact that the car has to be replaced in two years' time even if not used. However, if the customer uses the car for more than a 100 miles, more than $(1/600)^{th}$ of the lifetime benefit of the car has been extracted from the car. The additional deterioration of its future use from the additional miles is accounted for by using the count driver (miles driven) at the rate of $0.40 per mile. This example is representative of many assets with finite expiration granularity in typical manufacturing and service facilities.

Formally, let *T* be the expiration age of a finite granularity resource and let *X* be the count measure of its productive life. Let $C_E(0)$ be its acquisition cost and $C_E(T)$ $(C_E(X))$ be its estimated salvage value at the end of its useful life. When not in use, we assume a linear depreciation of its value at the rate of $\dot{C}_E = \frac{C_E(0) - C_E(T)}{T}$. When in use, its rate of expiration is given by

$C_E' = \frac{C_E(0) - C_E(X)}{X}$. Let a decision require *x* units of the count driver and let the resource be dedicated to the decision for *t* time units.[7] Then, assuming that resource is in demand otherwise (as per original expectations), the opportunity cost of the resource for this decision can be estimated as $\mathrm{OC} = Max\left\{\dot{C}_E * t, C_E' x\right\}$.

The above discussion is presented as a decision tree in Figure 5. To estimate the opportunity cost of resources associated with a given decision, we begin with a list of resources. Each of these resources is characterized by their acquisition, expiration and consumption granularities. Referring to Figure 5, if acquisition granularity of a resource is low, then its opportunity cost is its acquisition cost. The opportunity cost for electric power is its acquisition cost. If a resource has high acquisition granularity, we classify the resource based on its expiration and consumption granularities.

(Place Figure 5 here)

If the resource has low expiration and low consumption granularity, its opportunity cost is zero if there is no other use for the resource. It will exhibit time-decay whether used for the decision under consideration or not. If there are other uses for the resource, then a time-based allocation provides an appropriate estimate of its opportunity cost. This is because its decay is determined primarily by the passage of time. For a pure capacity resource such as a grain silo, opportunity cost is best measured with a time-based or duration driver.

If the resource has low expiration granularity but high consumption granularity, its opportunity cost is best estimated by comparing how much of the resource is required for the decision (consumption) with attrition in benefits during the time period spanned by the decision (time

[7] The relation between the number of count driver units and time required may be subject to technological constraints. For example, traveling 100 miles requires that a car be used for more than an hour, but the reverse may not be true.

attrition). If loss of benefits due to consumption exceeds time attrition, some of the resource's future use is lost. In this case, opportunity cost is the excess of the consumption over the time attrition. If consumption is less than time attrition, then the opportunity cost is zero if no other use exists. If there are other uses for the resource, then the consumption or the time attrition determines the opportunity cost depending on which is higher. The intuition for this rule, which requires the use of time and count drivers, was discussed earlier in the context of the rental car.

Cost basis is not suitable for estimating the opportunity cost of a resource that has high expiration granularity but low consumption granularity. The benefits from such a resource does not expire with time, neither does the owner have any measure of control over the rate at which the benefits are extracted. The opportunity cost for a diamond is the *value* attached by the decision-maker to the "road not taken."

Finally, if the resource has high expiration granularity and high consumption granularity, then a consumption-based assignment provides an appropriate estimate of its opportunity cost. Opportunity cost for inventory is best measured with a consumption or count-based driver.

One important implication of the above discussion is that assigning the cost of a resource with finite expiration granularity to a decision requires the use of *multiple drivers*; in particular, a combination of time-based and count-based assignments. In extant cost systems, the focus has been on the identification of the "correct" count driver (e.g., setup hours to assign setup cost instead of direct labor hours), and on the assessment of specification errors associated with using the wrong count driver (number of setups versus number of setup hours). Our analysis suggests that even the use of the "right" count driver can give rise to incorrect assignments of the cost of resources with finite expiration granularity because the time-driven decay of these resources is ignored in systems based on use-counts. Fortunately, the magnitude of this error is bounded by technological considerations that often cause use-counts to be correlated with time.

When cost systems use a single driver to allocate the costs of resources with intermediate expiration granularity, *expiration specification error* (ESE) results. This error is minimal for resources at the extremes of the expiration granularity spectrum. Time-based assignments entail no ESE for resources with zero expiration granularity, and count-based assignments entail no ESE for resources with infinite expiration granularity. The magnitude of ESE depends also on the resource's consumption granularity. If the resource has high enough consumption granularity and expected use, its useful life may end well before the sheer passage of time results in a loss of value. A police patrol car needs to be replaced every other year or so because of the severe conditions of its use, and the mileage it accumulates. Thus, using number of miles as a cost driver would lead to small expiration specification error. The same driver can lead to substantially greater error, if the same model car is used for local commuting. In the latter case, benefit expiration due to passage of time is likely to be as significant, if not more, than the expiration due to the miles driven.

An intermediate level of consumption granularity characterizes most resources. Thus, determining the cost associated with their use suggests the use of multiple cost drivers. However, most cost systems employ a single cost driver for each resource, giving rise to expiration specification error. The granularity framework alerts us to the error, and gives a mechanism for assessing its magnitude. The aggregation and measurement error framework in Lim and Sunder (1990, 1991) suggests that while adding more drivers can cut the expiration specification error, it may add measurement errors of their own. Therefore, it is important to keep in mind that using single-driver cost systems for finite expiration granularity resources is not necessarily the wrong thing to do.

IV. EXAMPLES

The examples in this section apply the granularity framework to specific contexts. Example 1 shows how this framework is useful in understanding the construction of cost pools. Example 2 shows how multiple drivers may better capture the opportunity cost of resources whose benefits decrease with time and with use. The final example uses the framework to explain observed pricing practices in situations with bundled resources.

Example 1 – Resources using single cost drivers

Consider production of wheat cereal, which requires processing commodity raw materials such as wheat and sugar in a continuously operating, capital-intensive environment. From the plant's perspective, the central office determines input prices and quantities. What information (performance measure) would aid (motivate) the plant manager in effectively utilizing plant resources?

A traditional cost perspective would calculate the cost per case as a key indicator. This indicator is subject to short-run volume fluctuations because a large proportion of total cost is fixed in the short-run. A refined system would avoid this problem by calculating separately the cost of materials used, and the cost of capacity resources. This approach implicitly recognizes that there are two broad categories of resources. For the plant, measuring the length of time for the various uses for the plant (e.g., standard time for actual production, time gained or lost due to efficiency, changeovers, preventable downtime, scheduled downtime) recognizes its zero expiration granularity. This information is also the key to increasing plant productivity. For raw materials, a standard input-output relation (e.g., standard for actual production and amount gained or lost due to efficiency) recognizes raw materials' large expiration and consumption granularity. In this case, the two major resource classes lie at the extreme ends of the scales of expiration and consumption granularities. Thus, a single driver for each resource suffices.

Example 2: Resources with multiple drivers

The cost of a punching press can be allocated to products using duration (machine hours) or count (number of punches) drivers. Either approach is subject to error. The benefits of some parts of the machine (machine frame, foundations and basic wiring) expire over time, and therefor these parts have low expiration granularity. The benefits of other parts (e.g., the die and the battering ram) expire with the number of punches, and therefore these parts have high consumption granularity. Thus, ideally, we should segregate the cost of the machine into two pools -- one with the cost of resources whose benefits expire with time, and the other containing the cost of resources whose benefits expire with use. Such a classification, of course, would correspond to classifying the resources by their expiration granularity. For additional accuracy one could use the multiple driver approach outlined in the previous section, which recognizes that the benefits expire both with time and with use for each of the two classes.

Example 3: Bundled resources

This two-part example illustrates errors that can arise, and opportunities that can be overlooked, if decision-makers ignore the differing granularities of resources that are typically bundled.

Pricing: A cab owner hires a driver at fixed wage to operate the cab for an eight-hour shift. A typical tariff may have a start-up charge plus a mileage related charge (say, $3.00 for the first 1/9th of a mile, and $0.50 per 1/4th mile thereafter.) In addition, there may be a charge for waiting time. Consider the three major resources used in providing the cab ride:

- The driver. The acquisition granularity is defined by the eight-hour shift for which the driver is hired. The expiration granularity is zero because the service potential of the driver winds down with the clock. The consumption granularity is also zero.
- Fuel. The acquisition granularity is defined by the size of the fuel tank, and the time cost of stopping to refuel. Ignoring losses due to evaporation, fuel is a resource with large expiration granularity but it has a medium level of consumption granularity (the driver can use up the fuel by driving more, but cannot use it all up in an arbitrarily short period of time).
- The car. In the previous section, we discussed how pricing a rental car requires the use of multiple drivers. Using a similar rule to price a cab ride, the opportunity cost of the car may be determined as:

$$\text{Opportunity cost of the car} = Max\left\{\dot{C}_E * t, C'_E * x\right\},$$

where x is the number of miles covered during the ride, t is the time it will take to reach the destination, and $\dot{C}_E$ and C'_E are time-based and count-based rates as defined in the previous section.

The start up charge is then justified as the compensation for the driver's average waiting time between rides and the car's time decay during this time. A similar justification applies when the cab is caught in a traffic jam, only in this case the charge must also include the cost of fuel consumed as the car idles waiting for the traffic to clear.[8]

Cost management: A time-based perspective allows for more efficient extraction of resource use. Consider, for example, a circular truck route that originates from an assembly plant,

[8] The pricing for a luxury limousine (pricing by the hour or day only) provides a useful contrast. The time-based loss of benefits for the limo likely exceeds the loss from the number of miles traveled.

and stops at three different supplier factories before returning to its home base with a full load. Such a system is wasteful because the driver spends most of the time waiting while the truck is being loaded and unloaded by others. Recognizing that the truck and the driver are resources with differing expiration granularity, however, suggests a solution to increase the efficiency of the driver. Acquiring more trucks (or, trailers which can hitched to cabs) which can be loaded or unloaded during the transit time between factories may better exploit both resources. If the cost of saved time of the driver exceeds the cost of the additional equipment, such an action might be worthwhile. Suzaki (1987, p 193) claims that such an unbundling of resources with differing expiration granularities saved money for a Japanese automaker.

V. DISCUSSION AND CONCLUSION

To fulfill its role in decision making and contracting, accounting data must capture the economics of resource acquisition and consumption. We develop a time-based granularity framework to capture the economics of resource acquisition and use. This framework recognizes three characteristics of resources:

- acquisition granularity which represents the lumpiness in resource acquisition
- expiration granularity which represents the lumpiness in expiration of benefits associated with the resource over time, and
- consumption granularity which captures the user's ability to vary the rate at which benefits of the resource are extracted.

Our analysis suggests that estimating the opportunity cost of a resource with finite granularities may require the use of multiple cost drivers; in particular, a non-linear combination of time-based and count-based assignments. The argument for non-linear cost assignment is fundamentally distinct from ABC in which a single cost driver is sought to be identified for each cost pool. The need for multiple drivers arises because time-driven decay of resources is ignored in systems that assign costs based solely on use-counts (i.e., consumption). The resultant error may be small when the time-driven decay is small relative to the decay from usage.

Whether the benefits from using the granularity framework are worth the costs remains to be determined. An avenue for future research would be to develop an implementable rule for partitioning an organization's resource set into a manageable number of granularity classes. Characterizing the granularity of each individual resource in an organization may be no more practical than using a separate cost pool for each resource in the traditional ABC systems. Classifying resources into a small number of granularity classes will give rise to intra-group heterogeneity, and errors of measurement. These errors must be weighed against thecosts 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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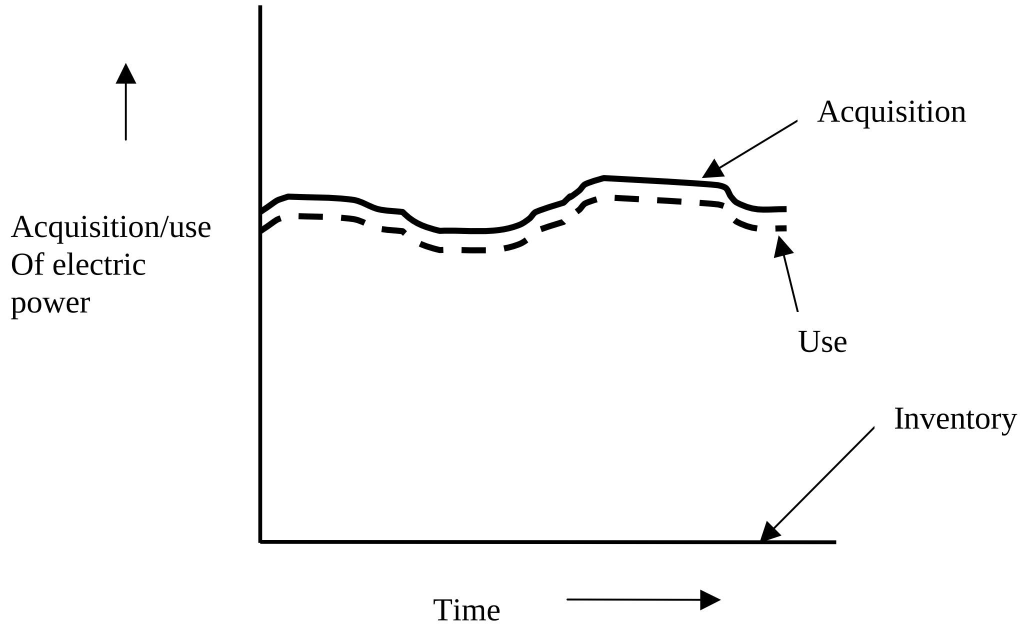

Figure 1A: Acquisition granularity of electric power (Low)

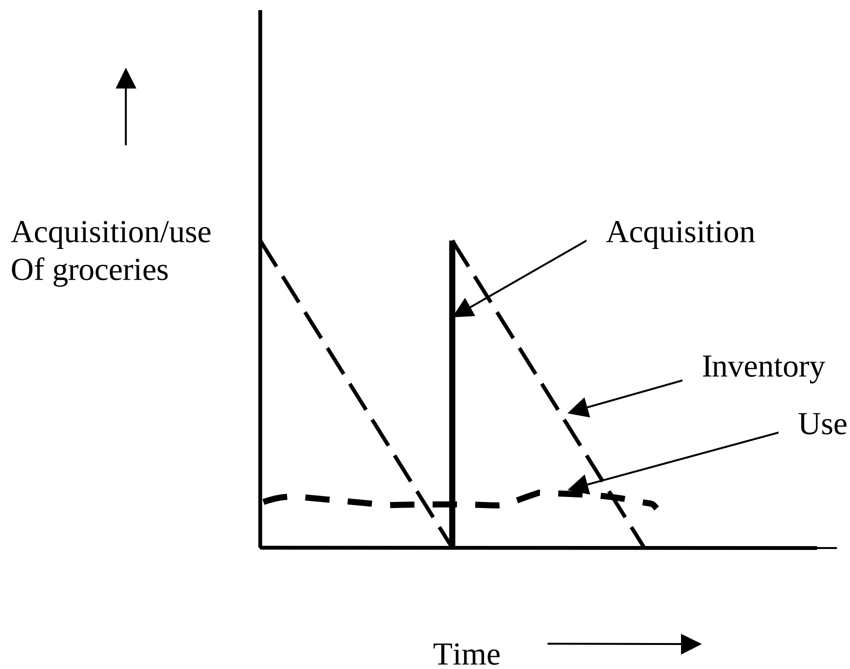

Figure 1B: Acquisition granularity of groceries (Medium)

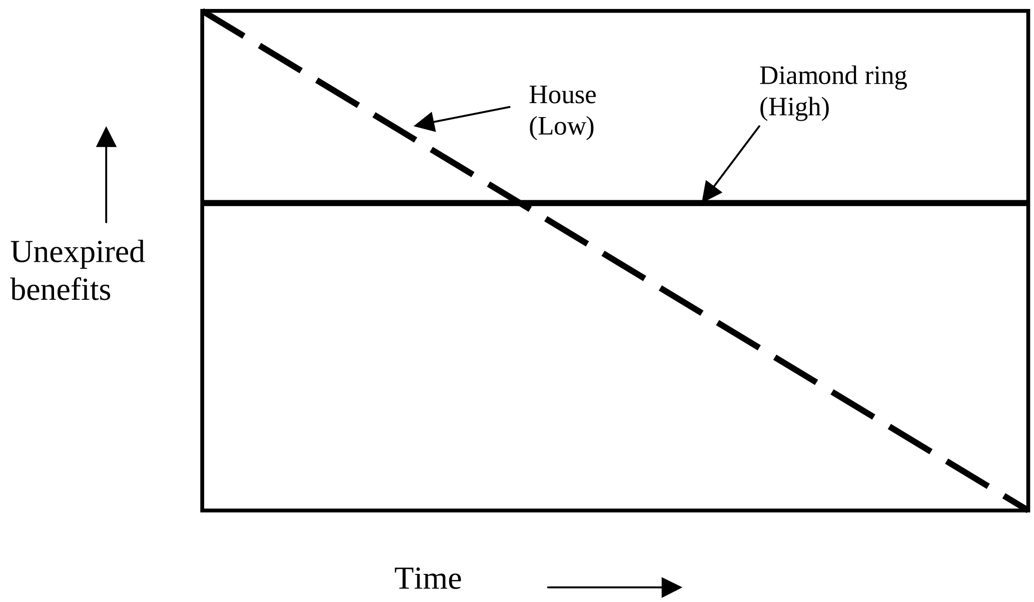

Figure 2: Expiration granularity

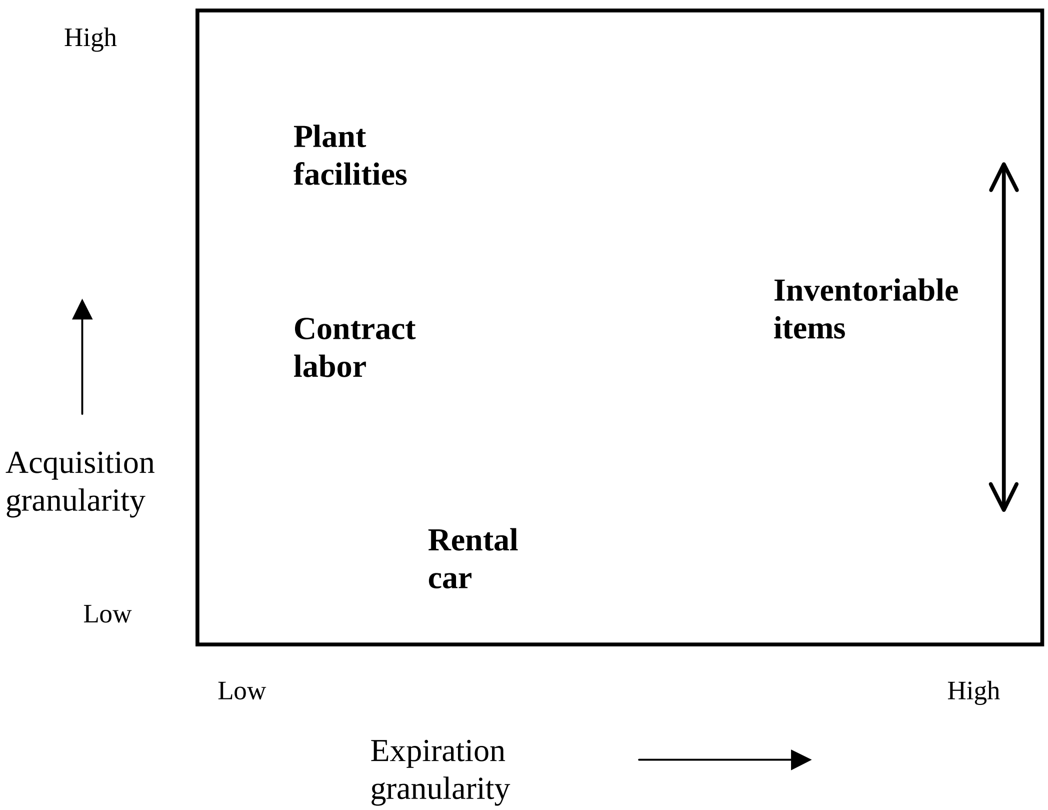

Figure 3: Acquisition versus Expiration granularity

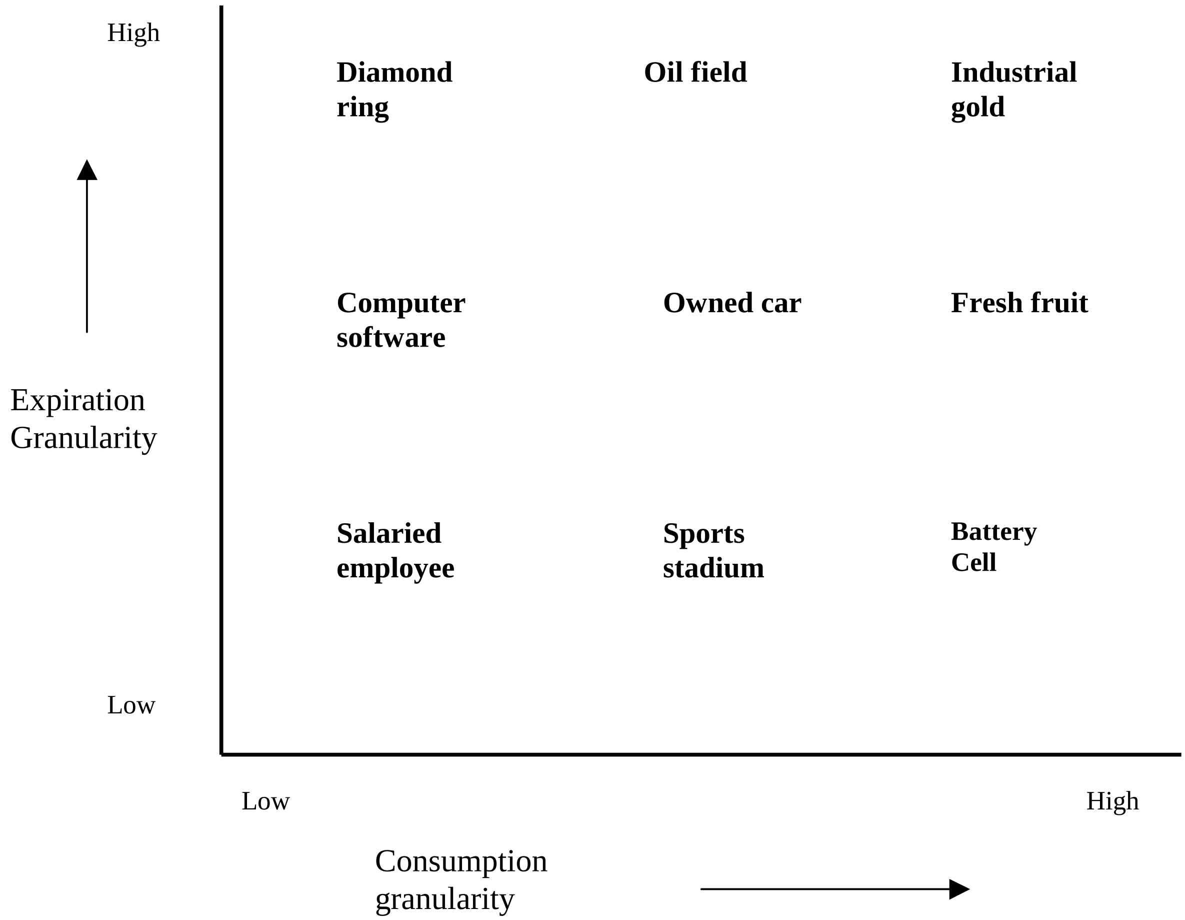

Figure 4: Expiration versus Consumption granularity

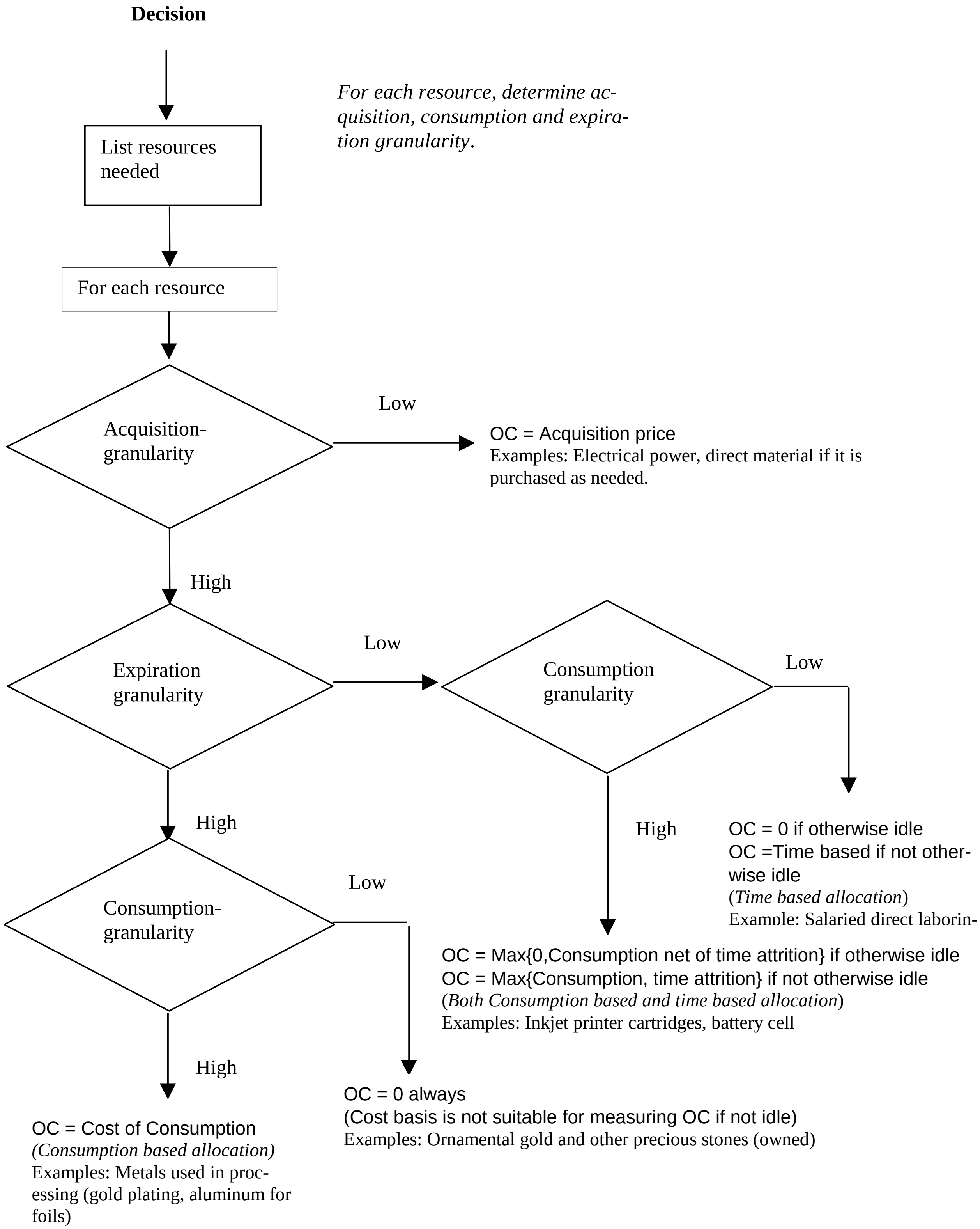

Figure 5: Decision tree based on the Granularity Framework