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An Activity-Based Cost Model as a Decision-Making Tool for Continuous Improvement Projects

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Abstract Activity-based cost models, although they originally appeared as a solution to allocate indirect production costs to products, have today a much broader application and the potential to provide more complete and accurate information for decision making. In this regard, extended ABC models have been suggested in recent years as a way to assist specific decision making and improve the overall efficiency of production costs, intertwining concepts of technical and managerial optimization with cost optimization. This paper uses the theoretical roots of Time-Driven Activity-Based Costing and contributions from previous mathematical cost models, to assist Kaizen and continuous improvement projects. In order to demonstrate the applicability of the proposed model, an example is explored to demonstrate how the proposed cost model can be used for optimization purposes. The case study is related to changing chemical reactors in a production line. The proposed cost model can be developed suggested as a weighting between continuous improvements and general process / production optimizations in order to refine its performance in ensuring to the changes in production activities the minimum of technical externalities and accurate forecast of production costs in decision-making processes.

Keywords: Kaizen; Time-Driven Activity-Based Costing; Costing Systems

1 Introduction

Costing systems are important because in addition to providing an accurate and detailed cost information for financial purposes, they are an essential source of information for decision making (management information), in view also of their relevance for profit estimation.

Traditional cost systems and models although have immeasurable potential to provide managerial information on costs, they are not enough nowadays. ABC systems due to their ability to classify and allocate resources to activities and from these to products and other cost objects, offer several opportunities for decision making. But, nowadays, cost systems require approaches that go beyond traditional activity-based cost models, which has been widely discussed in the literature since Cooper and Kaplan (1991) argued about Activity-Based Costing's benefits.

Activity-Based Costing (ABC) systems are particularly relevant for improving and optimizing production since they use accounting and technical information guided by cost drivers. This enables decision making to support continuous improvement considering not only the intensity of technical changes but also their economic impacts. By directly evaluating the impacts of operational changes on the company's economic result, improvements that would be accepted or discarded only for their technical impact can be better evaluated according cost global restrictions. Furthermore, Time-Driven Activity-Based Costing (TDABC) has been also studied and applied what allow a greater use of its conceptual roots - linked to the concept of time as a cost driver - and that depart from the traditional application of ABC systems.

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Nevertheless, there are still challenges in the formulation of cost models focused on the support of effective managerial activities in companies and particularly in its operations and production processes. The literature presents some contributions in this direction. For example, Santana and Afonso (2015) state that the advantages of TDABC as a decision tool would be: flexibility in the design of its cost models, wide applicability, ease of integration with management systems - possibly due to its information generated on activities -, low cost of implementation and maintenance, particular focus on idle capacity, among others.

Nevertheless, ABC models have still their limitations namely, measurement errors, need of structured information systems and robust databases, demand of constant reviews and regular maintenance over time. All this may turn it more expensive than expected.

Some attempts and suggestions have been made to extend and improve activity-based cost models. In extended ABC models it is possible to add variables related to direct resources, activities and products to expose not only the consumption of indirect resources only (which generate indirect costs) but other cost elements as well as opportunity cost related to the installed capacity.

From these approaches, mathematical cost models are particularly interesting to deal with the complexity of production, optimization and continuous improvement issues. According to Santana *et al.* (2017), the development and implementation of more sophisticated mathematical cost models are necessary to integrate costing systems with management activities and to provide support for more consistent decision making. Santana *et al.* (2017) state that new solutions to manage costs efficiently and effectively can be achieved by more sophisticated cost models, contextualizing that when it comes to a strategic cost management approach, the "evolution" of the traditional ABC system has been carried out, most recently through TDABC models. The next frontier is the development of TDABC and its integration with other models. Moreover, extending the use of cost models to more complex approaches such as optimization problems and integrating cost models with optimization models open important routes for research and practical application.

In the context of continuous improvement and kaizen programs, it should be emphasized the need for such projects to use appropriate cost models to generate timely and adequate information linked to the changes proposed, since the interaction of economic and technical information - made possible through the definition of activities - has higher potential to privilege changes that generates really effective improvements in organizations.

Thus, the objective of this article is to present a mathematical cost model to be used as a tool for generating economic information to evaluate continuous improvement and kaizen project's proposals. To this end, some activity-based cost models were revisited and combined in order to formulate an algorithm that makes it possible to take advantage of the potential of cost projections, in special global minimization, without the need to use complex software or technical knowledge.

The relevance of this model in terms of economic decision is based on the possibility of including several additional cost categories, opportunity cost as a counterpoint to the possibilities of using idle production capacity. The inclusion of these new variables in a set of functions generated by the relational concept of activity-based cost models what extends the contribution of the costing system and offers a deeper source of cost information. The proposed model can also include direct costs, providing the opportunity to manage and integrate all costs within the model.

Such possibility of including variables not related to indirect costs in the logic of activity-based cost models allows extensive analyses of sensitivity to predict the global impact on the result that the continuous improvement directions can provide and, for this reason such models are capable of balancing continuous qualitative improvements with the organization's use of resources' capacity from an economic point of view.

The organization of this article is as follows: first, a brief review of the literature was undertaken to point out the plausibility of the model as a complementary and auxiliary tool to the design and implementation of continuous improvement and kaizen projects. Then, the proposed Activity-Based Cost model is explained, and, subsequently, an application of the model is illustrated through a problem involving a specific kaizen proposal to replace chemical reactors. Possibilities of application and deepening this model are presented for future research at the end of the paper.

2 Activity-Based Cost Models

2.1 Extending Activity – Based Cost Models

The main words in all headings (even run-in headings) begin with a capital letter. Articles, conjunctions and prepositions are the only words which should begin with a lower case letter. Cooper and Kaplan (1992) argue that Activity-Based Costing (ABC) are able to provide economic information of past, current, and future operations, and to measure the costs of resource usage in a comprehensive manner. Lee and Monden (1996) compare Activity-Based Costing to Target Costing and Kaizen Costing showing the merits of the last two ones in strategic cost management and operational improvement and control.

It's important to notice that a Kaizen Costing Process is able to relate profit and product planning within Cost planning and Equipment Planning Process, but the objective of this costing process is improving (reduce) the global costs in function of annual budgeting and profit estimations.

ABC may offer a more accurate and detailed view of the process and activities behind cost objects compared to traditional costing systems. And, through the TDABC it is possible to study the effectiveness of the processes in terms of available capacity versus capacity used, and simulate the use of resources measured over time. The cost per unit of available capacity and the time required to complete an activity are the key parameters for estimating time equations. The time consumed by the event in the activity can be expressed as a function of different characteristics called time drivers (Afonso and Santana, 2016).

Focusing on the objective of providing management information directly from costing systems, some authors have recently used the theoretical concepts of ABC to create extended models which can be used for different purposes in view of the infinity of applications and integrations that matrix and functional mathematical models allow. For example, Santana *et al.* (2016) published a prescriptive demand model and a model linked to capacity optimization related to the used capacity and operational efficiency, Santana et al. (2017) and Duran and Afonso (2020) developed a decision-making model directly related to activity-based costing.

2.1 Opportunities to Integrate Costing Systems and Continuous Improvement

Imai (2012) defines Kaizen as a common sense, low-cost approach to management which aims help enterprises attain higher quality products and services, lower costs, and achieve timely delivery by the continuous collaborative effort of managers and their workers.

Lee and Monden (1996) explain that Kaizen Costing follows target costing in timing, providing more stringent means of cost management while standard costing systems is only on meeting standards. So, the Kaizen Costing would be able to sets a cost reduction target amount and attains it through continuous improvement activities through this process. In this case, cost reduction target amount is translated into specific actions, which allows every manager and employee to understand what to do. An Activity-Based Cost Model follow the logic of Kaizen Costing, however, in a opposite way: An Activity-Based Costing like a tool of Kaizen Project do not orient the actions, but validity it.

Working with the concept of activities becomes an advantage in relation to other costing methods in cases where there are changes in operations and production actions, since the cost linked to each activity directly involved in the action of change as well as global impacts can be observed directly in numerical values by decision makers.

Activity-Based Cost Systems can be customized to serve as a specific management tool in projects, such as continuous improvement and kaizen projects.

The reduction of time or isolated costs in sectors and departments does not always guarantee an overall reduction in working time or costs for organizations. Subsequent impacts can sometimes neutralize process and production improvements, or even cause marginal decreases in time and cost. When, for example, in chemical leaching, solid caustic soda is exchanged for liquid caustic soda in order to reduce the danger of feeding and discharging the reactors, the costs of activities related to the heating control required by the liquid reaction must be previously calculated. Not only raw material costs should be projected, since the activities will be significantly different and impact on previous and subsequent stages of leaching. It should be estimated the global time and need of workers and equipment, for example.

Considering that a process of any kind is inherently unique - although it may present partitioned production for the operationalization of the plant - and the possible deviations explained in the isolated application of a kaizen project, a proper Activity Based Cost Model presents itself as an important auxiliary tool in decision making about continuous improvement actions, mitigating global cost distortions, and increasing the likelihood that continuous improvement actions are indeed contributory to the company.

As changes in production structures and processes, even if reduced and gradual, can impact the time of activities and / or their costs, it is important to evaluate these qualitative impacts in terms of the overall quantitative impact on the company's results and this can be done concomitantly. The relation of perceived value to the company's profit can be used to verify the general efficiency of the application of the kaizen system in organizations due to their global contribution to the company's strategy.

It is important to develop cost model that ensure that tactical decisions do not overlap with the company's overall strategy, using mathematical considerations to suggest and ensure that each continuous improvement is evaluated by an Added Value index given by the improvement / profit provided by the model, while still allowing quantification of targets for the kaizen project.

In this way, organizations could create targets for kaizen-Activity-Based Cost Model indexes given the expected perceived value of continuous improvement achieved and the impact on the expected result and, later, evaluate the perceived value and the real profit realized to assess the overall efficiency of the organization's Kaizen system. It should be noticed that the additional value perceived by customers can be measured in different ways - through satisfaction surveys with loyal customers and new customers, and even by increasing sales globally or focused, according to the type of improvement implemented.

Such models allow management issues and managerial implications to be disregarded - it it is not necessary to add sectoral productivity calculations for an improvement action to be accepted - since the total estimated cost is studied as a direct function of time. That is, it provides a direct relationship between time and the cost of labor and, thus, the total time of labor is already a function of the overall cost of the organization.

3 Proposed Activity-Based Cost Model

The basic concept of this model is to structure costs in a set of mathematical functions that follows the rational and theory of Activity-Based Cost Models. In this context, we should consider the general and original structure of an Activity-Based Cost Model that beacon itself in two types of production relationship which can be established between Resources-Activities-Products in the two ways: from resources to products and reversely from the later to the former.

In the model proposed here, costs are estimated from the level of use of activities and the is computed considering products' characteristics and the demand. This allows to perform cost minimization objectives, what directly assist managers to decide about changes proposed in kaizen projects.

In this model, the cost of products (P_k) is obtained as a function of the activity time spent in the production of all products in a given period. Given that, the cost of products (k) and of activities (i) are considered as variables - P_k and A_i respectively - in function of the consumption of resources. There is functional relation between these variables, and so, we can derive (and minimize) the cost function using only inputs from activities because these are estimated for a certain set of products and also because activities explain the consumption of resources - considering variable or fixed resource prices - which gives the possibility of sensitivity analysis based on activity changes.

$$A_i = f_A(R_j) \qquad (1)$$

$$P_k = f_P(A_i) \qquad (2)$$

In view of the relevance of cause and effect (causal relationship) between the variables R_J (Resource consumption) and performed A_i (activities), we can consider that the cost of products can be given by a composite function of R_J.

$$P_k = f_P(f_A(R_j)) \qquad (3)$$

$$P_k = f_{P'}(R_j) \qquad (4)$$

Thus, fP' is a new function that relates the cost of product k to the consumption of resources.

Based on the time spent on resources in each activity - and on the optimization of these consumption relations - the model allows the global minimization of the cost of products. The model allow minimization of products acts globally - not focused in each product separately - in order to produce simple and relevant information to support decision making about changes in the production process. If the company has a cost target, the minimization model will show the global impact of changes in the search for such target. Since all costs are pondered in the model, evince the minimum of cost that could be aimed with changes broadens the horizon of the decision spectrum, that means, the decision-maker can decide pondering medium and long-term company's goals.

$$\min_0 \sum_k^K P_k \qquad (5)$$

Note that basic algebraic understanding is necessary to suggest a set of interrelationships between activities, resources and products which appear in the model through their coefficients. For each new independent variable (activity, resource) in a specific relation (function) it is a specific set of new coefficients.

$$P_k = \sum_j^J x_{kj} R_j \qquad (6)$$

So, if we consider that $A_I = f_A(R_j, \dots, R_J)$ and $P_K = f_P(f_A(R_j, \dots, R_J))$, x_{kj} is the generic denotation of the coefficients of $P_k = f_{P'}(R_j, \dots, R_J)$.

Note that while K is the number of products, I is the number of activities and J is the number of resources. For each product there is a function directly related to the consumption of resources that is specified by its coefficients x_{kj}. Such coefficients will be as many as the resources consumed in the production of a product unit multiplied by the number of products. Product costs are obtained multiplying the activities' coefficients by the resource function and the products' coefficients by the activity function, according to the algebraic logic of the composite functions.

All coefficients of the cost function of the products $P_k = f_{P'}(R_j)$ must sum one, due to the fact that such coefficients are normalized. The normality's resizing allows dimension lessness of the coefficients of all functions in this model, so that it has validity and mathematical coherence.

Nevertheless, in view of the objectives of this model, the above-mentioned restrictive logic can be relaxed. The compensation between different resources in this model can be acceptable. Thus, one resource will ponder another that exacerbates normalized values, since the sum of the total coefficients equals the number of resources used in the model. Thus, there are only two restrictions, one global (7) and another one that specifies the first restriction for some resources only (8).

$$\sum_k^K \sum_j^J x_{kj} = J \qquad (7)$$

$$\sum_k^K x_{kj} = 1 \qquad \forall j \qquad (8)$$

Thus, within the concept of Activity-Based Cost Models, activities consume resources, so, we state that coefficients of $P_k = f_{P'}(R_j)$ are in function of the of coefficients that relates Products and Activities (a_{ki}) and Activities and Resources(r_{ij}).

$$x_{kj} = \sum_{i}^{I} a_{ki}\ r_{ij} \qquad (9)$$

Note that for x_{kj} with two products, two activities and two resources, k, i, j = 1, 2: $x_{22} = a_{21}r_{12} + a_{22}r_{22}$.

The coefficients of these functional relationships can be a function of the amount of time needed by each product in each activity. The time required in each activity will give the need of the different resources that support such activity.

$$a_{ki} = f_k(Q) = \frac{Q_{ki}}{\sum_k^K Q_{ki}} \qquad (10)$$

$$r_{ij} = f_i(Q) = \frac{Q_{ri}}{\sum_i^I Q_{ri}} \qquad (11)$$

Finally, the amount of time required by the activity (i) to produce a unit of product (k), q_{ki},, if multiplied by the amount to be produced of a given product, K_t, directly generates the time required in Ai to produce all units of a given product (Q_{ki}).

$$Q_{ki} = q_{ki} * K_k \qquad (12)$$

The last relevant consideration in this model is related to the association of how the activity time is quantified, depending on machine hours or man hours. Considering the fact that the machine hour is already directly and objectively related to the indirect costs of maintenance and energy, the time for a machine to perform a given activity varies very little depending on human activity and, therefore, the machine time would be less related to actions of continuous improvement in kaizen projects.

Thus, considering man hours as the measure of the activity, the machine time will always be calculated proportionally to labor hours. The need of resources which are not labor will be defined according to a factor that allows to relate all resources to labor. In the application of the model presented here, it was considered a 1: 1 ratio between labor time and the use of the other resources.

4 Application, Results and Discussion

The economic impact of a reactor exchange in a production process was simulated and the data obtained analyzed using the proposed model.

The improvement to be evaluated comes from the extension / modification of the example presented by Schmal (2010) and demonstrates how decisions that encompass complex process parameters, can be properly evaluated and related to the consumption of resources and activities.

Aiming an operational improvement of the process, most of the employees suggested to exchange the batch reactor that operates at 77 º C by a continuous reactor that would operate at lower temperatures. Operators say that the reactor thermal device that maintains the temperature at 77º C requires dangerous handling operations to removing the product at high temperatures, and during its operation when it is necessary to carry out any intervention in the process. Employees also complain about the heat generated by the reactor which impacts the entire production plant.

The production engineer suggests the use of a different reactor to improve production conditions: a CSTR - continuous stirred-tank reactor model - which would operate at 0 ° C or a PRF - Plug Flow Reactor - which would operate at 27 ° C.

Knowing that both reactors are owned by the company, disregarding investment for the reactors relocation and considering that the exchange would not affect the other processes in terms of efficiency and process conditions, the engineer said that there are no technical problems to carry out this change, stressing, however , that the time and the conversion of inputs into products could be affected, providing a Table of parameters to the decision-maker in this kaizen project, that relate process parameters and data needed to perform and economic evaluation using the proposed Activity-Based Cost Model. In a simplified way, activities and resource consumption of reaction (A+B→R) are presented in Table 1.

Table 1 Activities related to reactors

Molar Mass of A = 50 g/mol	Molar Mass of B = 50 g/mol	Molar Mass of R = 100 g/mol	Feed of A and B = 5 mols/min $A + B \rightarrow R$			Technical Coefficients of Production (Labor time by Kg)		
Reactor	Temperature of Reactor	Spacial Time	Conversion of A	R Production (g/min)	R Production (kg/day)	A1 - Normal Operation	A2 - Control of Feed	APRF- Especific Control of PRF
Batch Reactor	77º C	0,65 min	0,9	450	648	1,2	8	0
CSTR	0º C	20 min	0,1	50	72	0,6	4	0
PRF	27º C	80 min	0,9	450	648	0,6	1	0,09

In this application it was considered that for each 100 kg of production in continuous reactors it is necessary 1 hour of handling time - Activity 1 (A1). This need for the batch reactor is 1 hour of handling for 50 kg of production. The PRF requires an additional activity to control the operational conditions which are to be carried out by qualified labor and is 4 times bigger than normal labor value. This activity (A_{PRF}) requires 1 hour of attention per day. The batch reactor has an automated system of valves for its loading and unloading, although it needs more attention in its feeding. An optimistic perspective is considered: that the normal working time required during its operation is 8 times greater than in a PRF and 4 times greater than in a CSTR.

It is important to note that the resources R1 and R2 are associated with the consumption of common / basic production work, while the R_{PRF} is related to qualified work, expressed in the mathematical model as a function of ordinary work. The simulations were carried out for each reactor separately, applying the coefficients of technical activity of each reactor as input, keeping labor and the installed capacity depending on the working time (labor), product price and expected production.

Thus, the coefficients of the set of functions are generated from the technical production coefficients for each reactor and define the total cost of operations.

Table 2 Coefficients generated by the model

Variables		R1	R2	R_{PRF}		R1	R2	R_{PRF}		R1	R2	R_{PRF}
A1	PRF Reactor	0,38	0,35	0,00	CSTR Reactor	0,13	0,35	0,00	Batch Reactor	0,13	0,71	0,00
A2		0,63	0,59	0,00		0,87	2,36	0,00		0,87	4,71	0,00
A_{PRF}		0,00	0,00	1,00		0,00	0,00	1,00		0,00	0,00	1,00
CAO		0,00	0,06	0,00		0,00	-1,71	0,00		0,00	-4,42	0,00
R Product		1,00	0,94	1,00		1,00	2,71	0,00		1,00	5,42	0,00
OC Production		0,00	0,06	0,00		0,00	-1,71	0,00		0,00	-4,42	0,00

Activities	A1	A2	A_{PRF}	CAO	A1	A2	A_{PRF}	CAO	A1	A2	A_{PRF}	CAO
R Product	1	1	1	0	1	1	0	0	1	1	0	0
OC Production	0	0	0	1	0	0	0	1	0	0	0	1

The production of a single product (R) was considered. The opportunity cost of the unused installed capacity was computed to generate the results obtained with each reactor. Thus, when minimizing the set of functions through Solver in Excel, the opportunities that the company would have in using the idle capacity available for each reactor are revealed. Note that the activity called Activity Opportunity in the model generates an Activity Opportunity Cost - CAO - that denotes the amount of available capacity that could be used in production acting as a vector opposite to the other activities that are consuming resources.

Table 3 Results of each reactor by activity performance

Production = 648 Kg/day	Price of Product R = 100$ /kg	IC (labor time/day)	Labor Time Cost = 0,6$ /time unit	Activities ($/day)				Resources ($/day) R1 = R2 = R_{PRF}/4		
Reactor	Revenue by day	Costs by day	Profit by day	A1	_A2	A_{PRF}	CAO	R1	R2	R_{PRF}
Batch Reactor	64800,00	4016,96	60783,04	777,60	5184,00	0,00	-1944,64	3576,96	440,00	0,00
CSTR	64800,00	2228,48	62571,52	388,80	2592,00	0,00	-752,32	1788,48	440,00	0,00
PRF	64800,00	1295,36	**63504,64**	388,80	648,00	233,28	25,28	622,08	440,00	233,28

The results show that the PRF reactor would generate greater profit if the daily production remained at 648 Kg of product R. The cost of production when using the PRF, in addition to meeting the requirements of employees, would be reduced by 78% in relation to the operating costs of the batch reactor, largely due to the high need for attention in the loading and unloading activities of the batch operation.

5 Conclusions

Integrating the proposed activity-based model with kaizen projects aims to ensure that the process and production improvements made by the Kaizen strategy are better considered within the general objectives of the company. Mainly because the concept of continuous improvement asks for the involvement of all departments and individuals in the organization, it is important to have a tool that makes explicit the global "cost-benefit" of applying specific continuous improvement projects, as in some cases these can impact the entire company.

The proposed Activity-Based Cost Model gives a full understanding of the global impact of such improvements, as well as allowing control of kaizen in general. It is noteworthy that when conceptualizing indirect resources in fixed and variable and also adding “manipulated” variables that would simulate the consumption of direct resources and the use of installed capacity, such restrictions allow varied analyzes that may exceed the Kaizen objectives.

The proposed cost model can be developed suggested as a weighting between continuous improvements and general process / production optimizations in order to refine its performance in ensuring to the changes in production activities the minimum of technical externalities and accurate forecast of production costs in decision-making processes.

6 References

Afonso, P. and Santana, A. (2016) ‘Application of the TDABC model in the logistics process using different capacity cost rates’, Journal of Industrial Engineering and Management, 9(5), pp. 1003–1019. doi: 10.3926/jiem.2086.

Cooper, R. and Kaplan, R. (1991) The design of cost management systems. Englewood Cliffs: Prentice-Hall.

Cooper, R. and Kaplan, R. (1992) ‘Activity-Based Systems: measuring the costs of resource usage’, Accounting Horizons, Sep, pp. 1–13.

Duran, O. and Afonso, P. S. L. P. (2020) ‘An activity-based costing decision model for life cycle economic assessment in spare parts logistic management’, International Journal of Production Economics, 222, p. 107499. doi: 10.1016/j.ijpe.2019.09.020.

Imai, M. (2012) Gemba Kaizen:A Commonsense Approach to a Continuous Improvement.2nd ed. New York: McGraw-Hill.

Lee, J. Y. and Monden, Y. (1996) ‘An International Comparison of Manufacturing-Friendly Cost Management Systems’, The International Journal of Accounting, 31(2), pp. 197–212.

Santana, A. et al. (2016) ‘a Prescriptive Cost Model for Demand Shaping: an Application for Target Costing’, Proceedings of the 3rd International Conference on Project Evaluation (Icopev 2016), pp. 1–8.

Santana, A. et al. (2017) ‘Costing models for capacity optimization in Industry 4.0: Trade-off between used capacity and Operational efficiency’, Procedia Manufacturing, 13(June), pp. 1183–1190.

Santana, A. and Afonso, P. (2015) ‘Activity-Based Cost Equations Systems: Extending the Predictive Power of TDABC’, 9th International Conference on Industrial Engineering and Industrial Management XXI International Conference on Industrial Engineering and Operations Management International IIE Conference 2015, pp. 1–8.

Schmal, M. (2010) Cinética e Reatores. 1st edn. Rio de Janeiro: Synergia.