DIFFERENTIATED MANUFACTURING COST ALLOCATION APPROACHES WITH RESPECT TO PRODUCTION PROCESS TYPES

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Abstract: We investigate the problem of fitting appropriate cost allocation methods to different production process types. We analyse and compare the combinations of three product costing methods versus three process types using quantitative modelling. Real data from an advanced manufacturing technology firm are used to illustrate the effects of using different types of cost allocation schemes for different processes. We propose a hybrid approach that selects the right product costing approach for each production process type. Such a hybrid approach is particularly useful in plants with different types of production processes.

Keywords: Case application, lean accounting, throughput accounting

1. INTRODUCTION

It is common that manufacturing firms use a single model for cost allocation and management accounting, and apply it to all products and all production resources. At the same time, most organizations have different types of production processes within their operations, wherefore the selection of one cost allocation model for all processes is far from trivial. Based on a simulation study, Lea and Min (2003) suggest that a management accounting system that properly can depict the production processes and map the relationships between product cost and resource consumption will lead to better performance. If we assume that there is an "optimal" cost allocation method for each type of process, the selection of only one method for a plant with multiple process types will lead to cost allocation uncertainty. This leads to the managerial problem of how to establish the "correct" costs for products that are processed in different types of production processes? In order to do so, we must first select the "best" cost allocation approach for each respective process type.

During the last decades, traditional costing methods have been discussed extensively and deemed insufficient for managing operations of today (e.g. Cooper and Kaplan, 1987, 1988; Fry and Steele, 1995; Fry et al., 1995; Åhlström and Karlsson, 1996; Bragg, 2007; Brosnahan, 2008). As a response to this and to new operations philosophies, two newer alternative approaches have been introduced: lean accounting and throughput accounting. Lean accounting is related to the developments of lean production (cf. Womack et al., 1990; Schonberger, 2008) and builds on the value streams (Maskell et al., 2012; Ruiz-de-Arbulo-Lopez et al., 2013), while throughput accounting is related to Theory of Constraints (see e.g. Goldratt and Cox, 1984; Bragg, 2007) that focusses on managing the bottleneck (Watson et al., 2007; Naor et al., 2013). These two newer approaches have led to new perspectives on cost allocation and management accounting in order to get the appropriate decision support, leading to decisions and behaviour in the organisation which are aligned with the respective strategy and production philosophy. However, if the firm has different types of processes, one accounting method will not be sufficient to create appropriate alignment between process type and cost allocation.

In this paper, we derive mathematical expressions for cost allocation approaches in different types of production processes and compare these analytically. We test and evaluate these in a case study with real data on three products and three different types of production processes. Then, we propose guidelines for the cost allocation in operations with multiple types of production processes. Finally, we discuss the implications for managers and research, as well as limitations of the study and suggestions for future research.

2. RESEARCH DESIGN AND METHODOLOGY

In this research, we are interested in what happens if the total production system is a mix of work centres and only one method is applied – which is typical in most manufacturing firms? How will traditional, lean, and throughput accounting capture the relevant costs compared to a manufacturing cost allocation approach that acknowledges the different characteristics of the various work centres and applies an appropriate accounting method to each? Based on the managerial problems discussed above, two research questions (RQ's) can be formulated:

RQ1: Which cost allocation approach is "best" for each respective process type?

RQ2: Can a differentiated and tailored approach provide "better" cost allocation than any one particular cost allocation method applied to the whole set of work centres? And if so, what differences and insights can be noted?

The paper is based on empirical data from a case company. The company is a large, advanced manufacturing technology company with many manufacturing sites globally. The investments in machining capacity are extensive and as a consequence the products are generally very expensive. The product range is broad and the demand volume per individual product is low. The data used in this study are taken from a key manufacturing site with about 2000 employees. Three products were selected to represent diversity in terms of volume and complexity, cf. Table 1. Also, all products are processed in job shops, flow shops, as well as line work centres.

Table 1 Product characteristics.

Aspects	Product A	Product B	Product C
Demand volume	High	Low	Low
Number of operations	55	49	15
Number of work centres	8	11	5

The data used in this study concern a full year and has been collected by the researchers, with the assistance of managers from manufacturing, logistics, and finance. Different data sources have been used, such as the ERP system, interviews as well as documents and reports, allowing for triangulation of data. The dataset includes both financial and operations information such as material cost, labour cost, routings, setup and run times, identification of bottlenecks, and categorization of work centres.

3. PRODUCTION PROCESS TYPES

We identify three types of production processes at the case company: job shop, flow shop, and line. There are no examples of project manufacturing or continuous processing, wherefore the three types that are identified are concerned with discrete manufacturing; cf. Hayes and Wheelwright (1979), and Hill and Hill (2009). The organization of the production system is such that each work centre includes one production process type. The relevant characteristics of these three types are described below.

3.1 Job shop

A job shop consists of subgroups of resources that are functionally related, such that e.g. cutting machines are grouped together. Within the subgroup resources are similar and can perform similar types of processing. A product is sequenced through the job shop according to its routing, creating potentially irregular flows and moving bottlenecks. Thus, the work centre is not characterised by a bottleneck or smooth flow. A job shop offers sequencing flexibility and can thus manage a wide range and customization of products with variable demand. The focus is on achieving high resource utilisation, which typically leads to extensive queuing and long lead times at various resources in the work centre.

3.2 Flow shop

The resources consist of one bottleneck and some non-bottleneck resources. Thus, the capacity of the bottleneck determines the capacity of the work centre, while the other resources have over-capacity by definition. A product will visit the bottleneck and some or all of the other resources. The flow shop is dependent on the utilization of the bottleneck, while non-bottlenecks are continuously providing the bottleneck with work. The characteristics of a flow shop lies in between the characteristics of a job shop and a line, for example, in terms of lead times and average capacity utilization (cf. e.g. Hill and Hill, 2009). A flow shop is often used for the production of a product group that requires similar types of processing but with a product variety that would not allow for using a line.

3.3 Line

A balanced line of resources dedicated to the production of a particular set of similar products. The products visit all resources and pass through the line in a fixed sequence. The capacity of the work centre is related to the cycle time or "takt" time of the line. Line production is less flexible and less able to customize and adapt to variable demand, with respect to balanced and fixed sequences, than the other types of production processes. A well-balanced line is associated with high resource utilisation as well as short product lead times through the line.

4. MANUFACTURING COST ALLOCATION

We consider three types of management accounting approaches, i.e. traditional management accounting, throughput accounting, and lean accounting, and derive and compare the mathematical expressions for the corresponding cost allocation approaches.

A basic assumption is that a work centre (*k*) is made up of some individual resources (*j*). We also assume that there is a maximum of one bottleneck resource (*B*) in a work centre.

The following notation is used:

AC_j = Annual Cost in resource *j*

AC_k = Annual Cost in work centre *k*

AW_j = Annual Work hours in resource *j*

AW_k = Annual Work hours in work centre *k*

B = Bottleneck, $j = B$ is the index for a bottleneck resource in a work centre

$C_{i,j}$ = Cost for product i in resource *j*

$C_{i,k}$ = Cost for product i in work centre *k*

CUT_j = Cost per Unit Time in resource *j*

CUT_k = Cost per Unit Time in work centre *k*

$i = 1,..., I$, index for product

$j = 1,..., J$, index for resource

$j \in k$, the set of resources j that belong to work centre *k*

$k = 1,..., K$, index for work centre

q_i = Lot size for product *i*

$s_{i,j}$ = Setup time for product i in resource *j*

$t_{i,j}$ = Time for processing one unit of product *i* in resource *j*

$T_{i,j}$ = Time that product *i* spends in resource *j* for setup and processing

$T_{i,k}$ = Time that product *i* spends in work centre *k* for setup and processing

4.1 Traditional cost allocation

The key principle in traditional cost accounting is that all relevant costs for each resource are collected at the individual resource level and then allocated to products with respect to the *time spent at each individual resource*. Thus, the overall cost at the work centre level is the sum of the costs from the resources that the product uses. The annual costs and annual work hours are collected at each individual resource. Below, we establish the explicit mathematical expressions for the cost for a product *i* in work centre *k* ($C_{i,k}$), with a specification of the time spent at each individual resource ($T_{i,j}$), and the cost per unit time for each resource (CUT_j).

$$C_{i,k} = \sum_{j \in k} C_{i,j} = \sum_{j \in k} T_{i,j} \cdot CUT_j \qquad (1)$$

$$T_{i,j} = \left(t_{i,j} + \frac{s_{i,j}}{q_i} \right) \qquad (2)$$

$$CUT_j = \frac{AC_j}{AW_j} \qquad (3)$$

4.2 Throughput cost allocation

The key principle for throughput cost allocation is that all relevant costs for the work centre are allocated to the bottleneck and then allocated to products according to the *time spent in the bottleneck*. Fundamentally, throughput accounting (TA) only acknowledges raw material costs as variable costs, which leads to potential danger of using TA when raw material costs are relatively low (Lea and Min, 2003). The exclusion of all costs but raw material costs in TA may result in an incomplete and inappropriate mapping between actual resource consumption and the product cost. Lea and Min (2003) suggest that a variety of cost elements need to be included in the product cost determination process. Consequently, we include all relevant and variable resource-related costs. In line with the focus on the bottleneck resources, the costs for non-bottlenecks are transferred to the bottleneck. Then, the cost for using a bottleneck becomes high, while the cost for using a non-bottleneck is zero. Thus, a product that is processed by a non-bottleneck but not by the bottleneck received a zero cost from the corresponding work centre. Correspondingly, the time spent at a non-bottleneck is disregarded from a cost point of view. Instead, the cost for product *i* in work centre *k* is entirely related to the time spent in the bottleneck resource *B*. Below, we present the corresponding expressions for the cost for a product *i* in work centre *k* ($C_{i,k}$), with a specification of the time spent at the bottleneck resource ($T_{i,B}$), and the cost per unit time for the corresponding work centre (CUT_k).

$$C_{i,k} = T_{i,B} \cdot CUT_k \qquad (4)$$

$$T_{i,B} = \left(t_{i,B} + \frac{s_{i,B}}{q_i} \right) \qquad (5)$$

$$CUT_k = \frac{AC_k}{AW_B} \qquad (6)$$

4.3 Lean cost allocation

The key principle for lean accounting is that the work centre is considered as one coherent value stream, which can be considered as one entity from a cost allocation perspective. Consequently, all relevant costs for the work centre are collected at the work centre level and then allocated to products with respect to the *time spent in the work centre*, irrespective of the particular time used at various resources. On average, all products are expected to have similar (but not necessarily identical) capacity requirements at the various resources along the value stream; cf. a balanced line that allows some (small) variation in processing time at the work stations along the line. Consequently, all products are assumed to consume a balanced amount of resources at each work station along the value stream. Below, we show the related expressions for the cost for a product *i* in work centre *k* ($C_{i,k}$), with a specification of the time spent in the work centre ($T_{i,k}$), and the cost per unit time for the work centre (CUT_k).

$$C_{i,k} = T_{i,k} \cdot CUT_k \qquad (7)$$

$$T_{i,k} = \sum_{j \in k} \left(t_{i,j} + \frac{s_{i,j}}{q_i} \right) \qquad (8)$$

$$CUT_k = \frac{AC_k}{AW_k} \qquad (9)$$

5. MATCHING COST ALLOCATION APPROACHES WITH PRODUCTION PROCESS TYPES

We compare, evaluate and interpret the cost allocation consequences, when applying different types of cost allocation approaches to different work centre types; cf. Table 2. Traditional accounting was established for “general” production systems, such as a job shop. Lean accounting was targeted at line-type work centres that can be characterised as value streams (Huntzinger, 2007; Maskell et al., 2012). Finally, throughput accounting is targeted at work centres of the flow shop type dominated by a bottleneck (Corbett, 1999; Bragg, 2007). Thus, some combinations of cost allocation approach and production process type are expected to be aligned, while others may be poorly aligned. The combinations that are subject to a misalignment are numbered (1)-(6) in Table 1 and are discussed below.

Table 2 Principle for comparing the effects of cost allocation approach on the type or work centre (CA: cost allocation; TA: throughput accounting; LA: lean accounting)

Cost allocation approach	Production process type		
	Job shop	Flow shop	Line
Traditional	Expected alignment	(1)	(2)
TA type	(3)	Expected alignment	(4)
LA type	(5)	(6)	Expected alignment

Using a traditional approach in a flow shop (case 1) will not capture the criticality of the bottleneck and will average out the resource costs, and thereby underestimate the cost if the bottleneck is actually used and overestimate the cost if only non-bottlenecks are utilized. However, the traditional approach will be able to track the correct costs in a line (case 2), but in an unnecessarily cumbersome way.

In situation (3), a bottleneck has to be defined in the job shop, even though there may be moving bottlenecks or no bottleneck at all. If a product is processed in this resource the cost allocated to the product becomes higher than otherwise would have been the case. If the product is only processed in resources that are not considered as a bottleneck, the cost will be zero. Consequently, the cost is either over- or underestimated, potentially with a gross margin. In case (4), a bottleneck has to be defined, but any resource in a well-balanced line can be selected as the bottleneck (even though all other resources along the line are equally constraining for the throughput of the line).

In cases (5, 6), the production process is assumed to have a value stream character, and allocates costs to products relative to the time spent in the work centre, irrespective of which individual resources that are actually utilized. If all resources in a job shop have the same annual costs, annual work hours, and workloads from each product, i.e. fundamentally a well-balanced job shop, the allocation of cost to products will be correct. Otherwise, the result is an over- or underestimation of actual costs, which also is the case for the flow shop. The level of over- or underestimation is dependent on whether the bottleneck is utilized or not. Only if the bottleneck and the non-bottleneck resources are utilized in a proportional way will the cost allocation be correct. Thus, the situation required for cases (5, 6) to treat cost allocation correct is that the work centre actually is a value stream (and not job shop or a flow shop!), and can then use a simpler cost allocation approach related to lean accounting.

In summary, cases (2, 4) will be able to correctly allocate costs, while cases (1, 3, 5, 6) will over- or underestimate the costs. The reason why cases (2, 4) turns out ok is that a line that is the simplest form of work centre, where all resources are balanced and all products consume the same amount of resources at each stage along the value stream. Then, cost allocation related to both traditional and throughput accounting will function correctly. However, the reverse is not true, i.e. that lean type cost allocation will work in job shop or flow shop environments. Also, the cost allocation principles in job shop versus flow shops differ significantly.

6. PROPOSING A HYBRID COST ALLOCATION APPROACH

We propose that plants with different types of production processes should select cost allocation approaches that fit each respective work centre, rather than selecting only one type of cost allocation approach. The principle is shown in Table 3. If the production system consists of only one type of production process, the choice is straightforward. But if two or more production processes are present in the production system at the plant, the issue is not trivial. In order to get a cost allocation that is suited to the type of production processes, the selection should be made at the work centre level.

Thus, a traditional approach is relevant for job shops, flow shops should allocate costs related to the bottleneck and throughput accounting, and balanced lines should allocate costs according to value stream thinking and lean accounting.

Table 3 Illustration of the principle for the hybrid approach, i.e. selecting cost allocation approach aligned to the type of production process (with respect to the product routing).

Operation no.	Work centre type	Cost allocation approach		
		Trad. CA	TA type CA	LA type CA
1-5	Line			X
6-8	Job shop	X		
9-12	Flow shop		X	

7. CASE APPLICATION

We compare cost allocation approaches across different production process types using real data from a manufacturing plant, having job shops, flow shops, as well as lines. We tested all combinations of cost allocation approaches for the three case products for each work centre along their routings. In addition, we tested the hybrid approach and compared it with the situations where only one cost allocation approach was used for a product, i.e. a single approach for all work centres along the routing of a product, irrespective of the type of production process. The results are displayed in Table 4. The numbers in Table 4 have been rescaled with respect to confidentiality. However, the relative differences are indicative of the real data.

Table 4 A comparison of cost allocation approaches for three case products with real data from a large manufacturing plant (costs in Euros, and deviations from the hybrid approach).

Product	Hybrid approach (proposed here)	Uniform (single) approach		
		Traditional CA	TA type CA	LA type CA
A	90 451	86 799 (-4.0%)	63 104 (-30.2%)	99 665 (+10.2%)
B	102 685	101 250 (-1.4%)	64 012 (-37.7%)	125 399 (+22.1%)
C	43 443	56 923 (+31.0%)	40 528 (-6.7%)	53 587 (+23.4%)

A few observations can be made. The product cost when using the hybrid approach will always stay between the minimum and the maximum numbers of the other three. Thus, the other approaches either over- or underestimate the cost according to the hybrid approach.

The cost for the hybrid approach is reasonably close to the cost for the cost allocation approach that fits the dominant work centre type for each respective product. Product A is primarily processed in job shops and lines, wherefore the cost for product A according to the hybrid approach (90 451) is close to the traditional approach (86 799, i.e. -4.0%) and lean type cost allocation (99 665, i.e. +10.2%). Product B is dominated by job shops, wherefore the hybrid cost (102 685) is close to the traditional approach (101 250, i.e. -1.4%). Finally, product C is primarily processed in some flow shops, wherefore the hybrid cost (43 443) is close to the throughput type cost allocation (40 528, i.e. -6.7%).

LA type cost allocation yields higher product costs in all three cases than TA type cost allocation. The reason is that these products are processed relatively less at the bottleneck and relatively more in non-bottlenecks in the flow shops.

8. DISCUSSION, IMPLICATIONS, LIMITATIONS AND FURTHER RESEARCH

We advocate that the right cost allocation method should be selected for each type of production process, such that (i) value stream related cost allocation is used for lines, (ii) bottleneck related cost allocation is used for flow shops, and (iii) traditional cost allocation is used for job shops. The fundamental idea of the hybrid approach is that the costing system should be applied at the work center level (and not at the plant level), which should be a straightforward process of allocating the right costs to products.

Fitting the appropriate cost allocation method to the process type does not necessarily imply that the company should adopt more than one accounting model. Using different methods for allocation of resource costs to products does not automatically mean that different accounting models need to be applied fully. However, some kind of upper level accounting methods is required to ensure that the relevant non-variable costs are included in the product cost, and not only the variable costs that can be related to the individual work center. But this does not mean that traditional, lean and throughput accounting have to be used concurrently. A traditional accounting approach or activity-based costing (ABC) could be used for this purpose, while lean accounting and throughput accounting would not be able to account for the non-variable costs as ABC or traditional accounting would.

Although we have tested the hybrid approach using real data for three representative products from an advanced manufacturing technology firm, we have only tested the procedure in one company and for complex products, which is a limitation of this study. Further research can test the hybrid approach for other types of products and for other types of firms.

9. CONCLUDING REMARKS

In this paper, we investigated the problem of selecting appropriate cost allocation methods for different types of production processes. Numerical results from a real case study using real case data were used to illustrate the effects of using different types of cost allocation schemes for different situations. In conclusion, we advocate that a hybrid approach should be used for proper cost allocation in plants with different types of production processes.

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