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Hybrid manufacturing accounting in mixed process environments: A methodology and a case study

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ABSTRACT

When manufacturing firms are deciding which products to produce, it is of utmost importance that they correctly allocate costs to products. It is common practice for manufacturers to use a single model for cost allocation and management accounting and to apply it to all products and production resources. Since most organisations have different types of production processes within their operations, the selection of one cost allocation model can lead to incorrect cost allocation and cost uncertainty. Newer manufacturing accounting approaches, such as lean accounting and throughput accounting, have been developed for specific manufacturing situations and are ill suited for mixed and complex process environments. We therefore study the problem of how to establish correct cost allocation for products produced by a manufacturer with a variety of production process types. We compare traditional accounting, throughput accounting, and lean accounting using mathematical modelling to derive analytical expressions for cost allocation using these principles. We develop a hybrid manufacturing accounting approach — a methodology for combining accounting approaches in a mixed-process environment. We illustrate the usefulness of this methodology in a case study of a large firm characterised by high-tech complex manufacturing in multiple production units (job shops, flow shops, and line processes). We apply our hybrid approach as well as traditional accounting, lean accounting, and throughput accounting to three products of different complexity and analyse the causes for deviations between approaches.

1. Introduction

When manufacturing firms make decisions about which products to produce, it is of utmost importance that they allocate costs correctly to their products. Otherwise, the price of the product will not correspond to the expected profit margin of the product and may be set too high or too low. Alternatively, if the price of the product is market driven and not based on costs, it is important to know the cost in order to know the margin of each product. In one example, after implementing a more detailed costing system, Nestlé SA found that 30% of their 130,000 brand variations were not making money (Fisher and Krumwiede, 2012). It is common for manufacturing firms to use a single model for cost allocation, product costing, and management accounting, and to apply it to all of their products and production resources. At the same time, most organisations have different types of production processes within their operations, rendering the selection of one cost allocation model for all processes far from trivial. Tayles and Walley (1997) argued that appropriate management accounting techniques and measures should be dictated by a company's manufacturing environment. If we assume that there is a correct cost allocation method for each type of process (i.e., one that accurately captures the actual costs associated with utilising that particular set of resources), then the selection of only one method for a plant with multiple process types will lead to cost allocation uncertainty as well as errors. This leads to a managerial problem of how to establish the correct costs for products that are processed in a facility with a variety of production process types.

During the last three decades, traditional costing methods have been discussed extensively and have been deemed insufficient for managing today's manufacturing operations (see e.g., Cooper and Kaplan, 1987; Fry et al., 1995; Åhlström and Karlsson, 1996; Bragg, 2007; Brosnahan, 2008). Firms that implement lean production or theory of constraints find that other accounting principles than traditional accounting are required that better can capture responsiveness, economies of scope, and operational improvements (Cooper and Maskell, 2008). As a response, two newer alternative approaches have been introduced: lean accounting (LA) and throughput accounting (TA). LA is related to the development of lean production (see e.g., Womack et al., 1990; Schonberger, 2008) and builds on value streams (Maskell et al., 2012; Ruiz-de-Arbulo-Lopez et al., 2013), while TA is related to the theory of constraints (see e.g., Goldratt and Cox, 1984; Bragg, 2007) that focusses

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on bottleneck management (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 appropriate decision support, leading to decisions and behaviour in the organisation that are aligned with the respective strategy and production philosophy. Such decisions include product costing, process planning and the selection of routings.

However, for a manufacturing organisation with a mix of resources and production process types, a single approach may not be sufficient or even appropriate (Myrelid and Olhager, 2015). Lea and Min (2003) stated that a management accounting system that can properly depict the production processes and map the relationships between product cost and resource consumption will lead to better performance. This is the context for our current research. What happens if the total production system is a mix of production units and only one method is applied (which is typical in most manufacturing firms)? How will traditional, lean, and throughput accounting capture the costs compared to a cost allocation approach that acknowledges the different characteristics of the individual production units and applies an appropriate accounting method to each? Based on the managerial problems discussed above, two research questions (RQ's) can be formulated:

RQ1. How should management accounting principles be selected in a mixed process environment with job shops, flow shops, and lines? Should a single approach be used, or should a mix of approaches be used where each approach is matched to the respective process?

RQ2. Which differences and insights can be noted from using a hybrid manufacturing accounting approach compared to using a single principle in a mixed environment?

In this paper, we first review the related literature on management accounting approaches and their potential relationships with basic manufacturing process types. Second, we derive mathematical expressions for cost allocation approaches in different types of process environments and compare these analytically. Third, we test and evaluate these in a case study with real data on three products and their respective operations sequences, which include three different types of production processes. We propose a hybrid approach and provide guidelines for cost allocation in operations with multiple types of production processes. Finally, we discuss the implications for manufacturing company managers and for future research, as well as some limitations of our study. Overall, this research contributes a quantitative comparative analysis of alternative manufacturing accounting principles, the development of a novel methodology for hybrid manufacturing accounting, and an illustration of the usefulness of the hybrid approach in a real-life case.

2. Related literature

In this section, we review the characteristics of traditional, lean and throughput accounting, and their relationships with production process types. A brief description of production process types can be found in Appendix A.

2.1. Traditional accounting

What is commonly called traditional accounting was developed during the early 20th century. In this approach, the costs of direct material, direct labour, and overhead are allocated to the products according to allocation keys. This approach was adapted for mass production and a less complex manufacturing reality than what is often the case today. Organisations that use traditional accounting identify their cost centres based on departments or groups of machines, to which they initially allocate the direct workforce costs dedicated to those centres, the depreciation of machines, the raw materials, and the semi-finished goods, and later allocate indirect costs to the centres (Johnson and Kaplan, 1987). Fry et al. (1998) noted that this traditional accounting approach seemed to be the perfect tool for the control of organisations with division-like structures. Thus, there is support in the literature that traditional accounting principles should be appropriate for job shop environments.

2.2. Throughput accounting

Throughput accounting supports the theory of constraints (TOC) presented by Goldratt (1980) and Goldratt and Cox (1984), where the bottleneck in the production is of the essence. While traditional accounting principles are concerned with the distribution of indirect costs, TA is concerned with improving material flow through the factory and optimising the entire system (Hilmola and Gupta, 2015). Where traditional accounting would conclude that it is more profitable to produce a product with a higher margin per unit, TA considers how many units it is possible to produce per time unit (Maskell, 1991). Traditional accounting principles encourage manufacturers to produce as many units as possible in order to spread the fixed cost to a larger number of units and thereby achieve a lower price per unit. In contrast, TA might instead ask resources to stop producing to avoid inventories (Bragg, 2007). The key principle of TOC states that within each system, at least one constraint exists that limits the ability of the system to achieve higher levels of performance relative to its goal (Watson et al., 2007). This constraint is then exploited to achieve the highest rate of throughput possible within the confines of the system's current resources and product demand (Kee and Schmidt, 2000; Souren et al., 2005). Maximum utilisation of the constraint should therefore lead to maximum output from the system. Thus, constraints determine the performance of a system, and Inman et al. (2009) found that effective use of bottlenecks improved organisational performance. Non-constraining resources will have extra capacity by definition (Myrelid and Olhager, 2015). Thus, the type of process which most closely relates to the use of TA is the flow shop, which typically has one specific key resource that constrains the capacity of this production unit.

2.3. Lean accounting

Lean production has been well known for three decades now (Krafcik, 1988; Schonberger, 2007), along with an awareness that traditional accounting principles can be misleading for a company that intends to apply lean principles in production (Åhlström and Karlsson, 1996). In addition to the idea that work with LA principles should be lean in itself, LA should also support organisations' initiatives to become and stay lean in their production and other processes and to focus on customer value (Maskell, 2000; Ruiz-de-Arbolo-Lopez et al., 2013). Preferably, a firm should be organised by value streams where people are assigned to value streams with no overlap and with few or no shared services (Maskell et al., 2012). Cost management in LA is done by value stream costing, where each value stream is treated separately and can be reported with separate value stream income statements (Maskell et al., 2012). Cooper and Maskell (2008) suggested that the income statement should be presented in plain English in order for everyone to be able to understand the information. When companies apply this philosophy and adopt leaner processes with value streams, operating efficiencies can improve. However, according to traditional accounting approaches, the financial measurements may well seem to be worse than before with lower profits (Cooper and Maskell, 2008). This has led to additional research on LA, including value stream costing, to further understand the performance of value streams (Ruiz-de-Arbulo-Lopez et al., 2013). Research has found a positive correlation between the implementation of lean production and the use of LA principles (Kennedy and Widener, 2008; Fullerton and Wempe, 2009; Fullerton et al., 2014), for example as demonstrated by the case in Agyapong-Kodua et al. (2012) and Fiat (Chiarini and Vagnoni, 2015).

2.4. Management accounting principles and production process types

Some management accounting approaches are better suited to certain production processes than others, since different accounting approaches have been developed for different contexts (Lea and Min, 2003; Myrelid and Olhager, 2015). Specifically, the newer management accounting approaches of TA and LA were developed with particular manufacturing systems in mind: TA was explicitly developed for bottleneck-dominated systems, while LA was explicitly developed to suit lean production systems. Fisher and Krumwiede (2012) found that it can be difficult to select the right costing system for a given situation, and recommended that convenience, correctness, and implementation costs should be considered when selecting management accounting principles. In the present study, we focused on the aspect of correctness, i.e., that the accounting approach can accurately capture the costs of each production unit in an appropriate manner.

These management accounting approaches have been compared in the research literature. For example, Bakke and Hellberg (1991), Lea and Fredendall (2002), and Lea and Min (2003) provided different perspectives on the relative advantages of TA versus traditional accounting. Chiarini (2012) and Li et al. (2012) compared traditional and lean accounting, while Myrelid and Olhager (2015) compared the cost structures of traditional, lean, and throughput accounting. These studies have provided different perspectives on the relationships between these accounting systems, typically proposing that TA or LA is generally preferable to traditional accounting. However, none of these studies have investigated the relationships between accounting approaches using mathematical modelling.

3. Manufacturing cost allocation models

In this section, we focus on the distribution of manufacturing resource costs and derive mathematical expressions for cost allocations in three different process types. We consider traditional management accounting, LA, and TA, and we derive and compare the mathematical expressions for the corresponding cost allocation approaches. We use the term production unit to denote a specific type of process, and a basic assumption is that a production unit (k) is made up of some individual resources (j), that together make up a job shop, a flow shop, or a production line. We also assume that there is a maximum of one bottleneck resource (B) in a production unit. The following notation is used:

AC_j=Annual Cost in resource j
AC_k=Annual Cost in production unit k
AW_j=Annual Work hours expected in resource j
AW_k=Annual Work hours expected in production unit k
B=Bottleneck, $j = B$ is the indicator for a bottleneck resource in a production unit
$C_{i,j}$=Cost for product i in resource j
$C_{i,k}$=Cost for product i in production unit k
CUT_j=Cost per Unit Time in resource j
CUT_k=Cost per Unit Time in production unit k
$i = 1, \ldots, I$, index for product
$j = 1, \ldots, J$, index for resource
$j \in k$, the set of resources j that belong to production unit k
$k = 1, \ldots, K$, index for production unit
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 production unit k for setup and processing

3.1. 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 are then allocated to products with respect to the *time spent at each individual resource*. Thus, the overall cost at the production unit 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 production unit 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).

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

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

$$CUT_j = \frac{AC_j}{AW_j} \tag{3}$$

3.2. Lean cost allocation

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

$$C_{i,k} = T_{i,k} \cdot CUT_k \tag{4}$$

$$T_{i,k} = \sum_{j \in k} (t_{i,j} + \frac{s_{i,j}}{q_i}) \tag{5}$$

$$CUT_k = \frac{AC_k}{AW_k} \tag{6}$$

3.3. Throughput cost allocation

Fundamentally, TA only acknowledges raw material costs as variable costs, which leads to a potential danger when raw material costs are relatively low (Lea and Min, 2003). The exclusion of all costs other than raw material costs in TA may result in an incomplete and inappropriate mapping between actual resource consumption and the product cost (Souren et al., 2005). Lea and Min (2003) suggested that a variety of cost elements need to be included in the product cost determination process. Consequently, in this study we have included all relevant resource-related costs, in order to be able to derive a cost allocation scheme that captures the same set of costs as traditional and lean accounting.

In line with the focus on 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. This relates to one of the key principles of TOC: "an hour lost at a bottleneck or a constrained resource is an hour lost for the whole system. In contrast, an hour saved at a non-bottleneck resource is a mirage because it does not make the whole system more productive." (Krajewski et al., 2016, p. 257). The key principle for TA cost allocation is correspondingly that all relevant costs for the process are allocated to the bottleneck, and then further allocated to products according to the *time spent in the bottleneck*. Consequently, a product that is processed by a non-bottleneck, but not by the bottleneck, receives a zero cost from the corresponding production unit. Thus, the time spent at a non-bottleneck is disregarded from a cost point of view. Instead, the cost for product i in production unit k is entirely related to the time spent in the bottleneck resource B. Below, we develop the corresponding expressions for the cost for a product j in production unit 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 production unit (CUT_k).

$$C_{i,k} = T_{i,B} \cdot CUT_k \tag{7}$$

$$T_{i,B} = (t_{i,B} + \frac{s_{i,B}}{q_i}) \tag{8}$$

$$CUT_k = \frac{AC_k}{AW_B} \tag{9}$$

3.4. Comparisons

In comparing the key principles of the three cost allocation approaches, we found that there are fundamental differences between them. Crucially, the cost allocation focus differs (as highlighted in italics above): the individual resource is the focus in traditional accounting, the production unit as a value stream is the focus in LA, and the bottleneck is the focus in TA. For the comparison of the mathematical expressions for cost allocation in the three approaches, we introduced an index that identifies the cost allocation approach, $l = 1,2,3$, where 1 = traditional accounting–related, 2 = LA-related, and 3 = TA-related. This index is added to the variable name, such as: $C2_{i,k}$= Cost for product i in production unit k for method 2, i.e., for LA cost allocation. It is notable that all three types of expression differ between all three types of cost allocation methods. When we included the two latter equations in the first for each method, we obtained the following expanded expression for the cost for product i in production unit k:

$$C1_{i,k} = \sum_{j \in k} ((t_{i,j} + \frac{s_{i,j}}{q_i})\frac{AC_j}{AW_j}), \text{ for traditional cost allocation} \tag{10}$$

$$C2_{i,k} = \sum_{j \in k} (t_{i,j} + \frac{s_{i,j}}{q_i})\frac{AC_k}{AW_k}, \text{ for LA cost allocation} \tag{11}$$

$$C3_{i,k} = (t_{i,B} + \frac{s_{i,B}}{q_i})\frac{AC_k}{AW_B}, \text{ for TA cost allocation} \tag{12}$$

Equations (10) through (12) clearly display that both the time and cost elements differ between the three approaches.

We then analysed whether there can be special cases where two methods become identical. First, we know that $AC_k = \sum_{j \in k} AC_j$, i.e., the annual cost for the production unit is the sum of the annual costs for the individual resources. Correspondingly, the expected annual work hours for the production unit are the sum of the annual work hours at the individual resources, i.e., $AW_k = \sum_{j \in k} AW_j$. When comparing equations (10) and (11), we found that the traditional and LA cost allocation approaches coincide if the cost per unit time (CUT) is the same for each resource, or if the workload ($t_{i,j} + \frac{s_{i,j}}{q_i}$) is identical for all resources in the production unit; i.e., a balanced production unit.

Equations (11) and (12) are identical if all resources along the line are considered as bottlenecks and all workloads are identical. In such a scenario, it does not matter if all of the costs in the production unit are allocated to the bottleneck or to the production unit level and later distributed to the product. However, in such a case, the production unit should in principle be considered a value-stream line, and not a flow shop, since there is no dominant bottleneck.

Similarly, equations (10) and (12) are identical if the workloads at all resources in the job shop are the same. Consequently, all resources can be regarded as bottlenecks. Again, the production unit should in principle be considered a value-stream line, and not a job shop or a flow shop, since there is no diversity in terms of workload or a dominant bottleneck.

Thus, a detailed comparison of the mathematical expressions for the three cost-allocation approaches shows that there are indeed differences, but also that the approaches can lead to the same result in some special cases.

4. Matching accounting principles to process types

4.1. Level of alignment between accounting principles and process types

For the present study, we compared, evaluated, and interpreted the impact of using different accounting approaches for different process types. In particular, we investigated the level of alignment between these two entities. Traditional accounting was established for general production systems, such as a job shop. LA was developed for line-type production units that can be characterised as value streams (Huntzinger, 2007; Maskell et al., 2012). Finally, TA targets production units of the flow shop type dominated by a bottleneck (Corbett, 1999; Bragg, 2007). These three specific combinations are expected to align, but the level of alignment between other combinations can vary substantially. Table 1 shows the cases where alignment is expected, while the other case combinations are numbered (1–6) and are discussed below.

Using a traditional approach in a flow shop (case 1) will not capture the criticality of the bottleneck and the high costs associated with utilising a bottleneck resource; it also ignores that the cost of non-bottlenecks is zero. Instead, the traditional approach will assign costs to each individual resource based on the annual costs for each respective resource. Consequently, the costs will be underestimated if the bottleneck is actually used and overestimated if only non-bottlenecks are utilised.

A traditional accounting approach will be able to track the correct costs in a line (case 2), albeit in an unnecessarily cumbersome way. Even if the workloads differ slightly between work stations along the line, traditional accounting will be able to identify the correct use of resources at each work stations. As shown above, equations (10) and

Table 1
Level of alignment for different combinations of manufacturing accounting approaches and the type of production unit (TA: throughput accounting; LA: lean accounting).

Manufacturing	Production unit		
accounting approach	Job shop	Flow shop	Line
Traditional	Expected alignment	(1)	(2)
TA	(3)	Expected alignment	(4)
LA	(5)	(6)	Expected alignment

(11) yield the same result if the workload is balanced in the production unit.

In situation (3), a TA 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 bottlenecks, the cost will be zero. Consequently, the cost is either over- or underestimated, potentially with a gross margin.

In case (4), a TA bottleneck also 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). As shown above, equations (11) and (12) yield the same result in such a case. If the line is poorly balanced, the selection of a bottleneck for TA becomes crucial. If the resource that is selected as the bottleneck corresponds to an "average" resource, the cost allocation will be correct, but if the designated bottleneck is utilised to a higher or lower degree, the level of alignment will be reduced.

In cases (5) and (6), the production process is assumed to have a value stream character and allocates costs to products relative to the time spent in the production unit, irrespective of which individual resources are actually utilised. If all resources in a job shop have the same annual costs, annual work hours, and workloads from each product (i.e., similar to a well-balanced job shop), then 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 utilised or not. Only if the bottleneck and the non-bottleneck resources are utilised in a proportional way will the cost allocation be correct. Thus, in order for cases (5) and (6) to treat cost allocation accurately, the production unit must be a value stream (and not job shop or a flow shop), and a simpler cost allocation approach related to LA can then be used. In such a scenario, however, the production unit should more appropriately be categorised as a line (and not as a job shop or flow shop).

In summary, cases (2) and (4) will be able to correctly allocate costs, while cases (1), (3), (5), and (6) will over- or underestimate the costs. The reason why cases (2) and (4) allocate costs accurately is that a line is the simplest form of production unit, where all resources are balanced and all products consume the same amount of resources at each stage along the value stream. In these situations, both traditional and throughput cost allocation will function correctly. However, the reverse is not true, in that LA will not accurately allocate costs in job shop or flow shop environments. It can therefore be concluded that none of the manufacturing accounting approaches work well in all types of production processes. Thus, the accounting approach should be matched to the process type in the production unit, in order to avoid under- and/or overestimation of costs.

4.2. Hybrid manufacturing accounting approach

Since different cost allocation approaches are aligned with different production processes and not with the overall production system, the selection of cost allocation approaches should be dealt with at the production process level. Consequently, we propose that manufacturing plants with different types of production processes should select cost allocation approaches that fit each respective production unit, rather than selecting only one cost allocation approach. This principle is illustrated in Table 2; a product routing consists of 15 operations through 5 different production units, of which 2 are job shops, 2 are flow shops, and 1 is a line. Table 2 also outlines the type of cost allocation approach that is used for the hybrid approach. If the entire production system consists of only one type of production process, the choice of accounting approach is straightforward (traditional accounting for job shops, TA for flow shops, and LA for line processes). However, if two or more production processes of different types are present in the production system at the plant, such that products visit production units with different characteristics along their operations sequences, the corresponding choice is not trivial. In order to get a cost allocation that is suited to the type of production processes in use, the selection should be made at the production unit level. Thus, (i) a traditional approach is relevant for job shops, (ii) flow shops should allocate costs according to bottlenecks and TA, and (iii) balanced lines should allocate costs according to value stream thinking and LA (see Table 2). The product that is illustrated in Table 2 will thus be charged with job shop costs according to traditional accounting for operations 1–2 and 7–8, with flow shop costs according to TA for operations 3–6 and 9–11, and with line process costs according to LA for operations 12–15.

Table 2
Illustration of the hybrid approach, for a product with 15 operations in 5 production units.

Operation no.	Production unit type	Manufacturing cost allocation approach		
		Traditional accounting	Throughput accounting	Lean accounting
1–2	Job shop #1	X		
3–6	Flow shop #1		X	
7–8	Job shop #2	X		
9–11	Flow shop #2		X	
12–15	Line			X

5. Case application

We tested the hybrid approach using empirical data from a case company. The company is a large, advanced manufacturing technology company with many manufacturing sites globally. Their investments in machining capacity are extensive and their products are generally very expensive. The company uses all three production process types for discrete manufacturing (i.e., job shop, flow shop, and line), and organises the total production system into a number of production units, where each production unit includes only one production process type. Each of the 30 production units contain five to 15 machine resources, organised as a job shop, flow shop or line. There are no examples of project manufacturing or continuous processing. The product range is broad (more than 100 end products, with extensive customisation) and the demand volume per individual product is low, i.e. a high-mix – low-volume environment. 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. In addition, all products are processed in all three types of process types (i.e., job shops, flow shops, and line). Table 3 shows the number of operations and the distribution of production units for the three case products. The data for product C along its five production units are used in the illustration of the hybrid approach in Table 2.

The data used in this study cover a full year and were collected by the researchers, with the assistance of company managers from manufacturing, logistics, and finance. One of the authors held a logistics development position at the company at the time of data collection and analysis. Different data sources have been used, such as the enterprise

Table 3
Product characteristics related to production processes.

Aspects	Product		
	A	B	C
Number of operations	55	49	15
Number of production units	8	11	5
Number of job shops	4	7	2
Number of flow shops	3	3	2
Number of lines	1	1	1

resource planning (ERP) system, interviews, and documents and reports, allowing for triangulation of data. The datasets include both financial and operations information, such as material and conversion costs, routings, setup and run times, identification of bottlenecks, and categorisation of production units. The conversion costs concern employees, machines, tooling, rework, and production support, i.e. all manufacturing-related costs that can be assigned to a process. This includes the allocation of fixed and indirect cost if these can be assigned to a specific resource. There may be other cost elements that can be included in the total product cost, such as costs of marketing, supply chain relationships, and after sales service, but these cost elements fall outside the plant focus of this study.

We tested all combinations of cost allocation approaches for the three case products for each production unit along their routings. An assumption had to be made concerning bottlenecks in job shops and line systems, since TA is dependent upon the utilisation of the bottleneck and distributes all costs of the process to the bottleneck. Thus, a bottleneck had to be identified for each process. Such an anticipated bottleneck was identified for each job shop and line process with the aid of the production managers for each respective process.

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 production units 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. The numbers in italics are those that represent the associated relationship between management accounting principle and process type and were used in the hybrid manufacturing accounting approach. For example, the hybrid approach for product A states that €62,122 should be allocated to the product for the operations that are performed in job shops (evaluated according to traditional accounting), €3903 should be allocated for the operations carried out in flow shops (evaluated according to TA), and €24,426 should be allocated for the line operations (evaluated according to LA), for a total of €90,451. In comparison, traditional accounting applied to all process types would allocate €62,122 + €1690 + €22,986 = €86,798 to product A, which is 4% lower than the total cost according to the hybrid approach. Assuming that the hybrid approach identifies the true costs for manufacturing product A, the company has historically underestimated costs by 4%, since they have been using traditional accounting only. Correspondingly, using TA as the only accounting approach irrespective of process type would lead to a total cost estimate of only €63,104 for product A (the sum of €45,299 from the processing in job shops, €3903 from flow shops, and €13,902 from the line process). Finally, the corresponding cost when applying LA to all process types is €99,665 (€73,107 from job shops, €2133 from flow shops, and €24,426 from the line process).

Two major observations can be made. First, the hybrid approach does not necessarily lead to the highest or lowest product costs; the other approaches either over- or underestimate the cost according to the hybrid approach. The hybrid approach could in theory lead to the lowest or highest costs. For example, if for a particular product traditional accounting allocates the lowest costs in job shops, TA the lowest costs in flow shops, and LA the lowest costs in a line process, then the hybrid approach will add up the lowest costs for each respective process type, and consequently will yield the lowest overall costs. The circumstances under which this will occur are (i) the product avoids expensive resources in the job shop (so traditional accounting allocates lower costs than LA) and utilises the designated bottleneck extensively (so traditional accounting allocates lower costs than TA); (ii) the product avoids the bottleneck in flow shops (so TA allocates lower costs than traditional and LA); and (iii) the product utilises expensive resources in the line (so LA allocates lower costs than traditional accounting) and utilises the designated bottleneck extensively (so LA allocates lower costs than TA). Correspondingly, the reverse is true for the highest costs. However, the hybrid approach yields neither the highest nor the lowest overall costs for any product in the real-life cases in Table 4.

Second, the cost for the hybrid approach is reasonably close to the cost for the cost allocation approach that fits the dominant production unit 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 (€86,798, i.e., −4.0%) and LA-type cost allocation (€99,665, i.e., +10.2%). Product B is dominated by job shops, therefore the hybrid cost (€102,685) is close to the traditional approach (€101,250, i.e., −1.4%). Finally, product C is primarily processed in flow shops, therefore the hybrid cost (€43,444) is close to the TA-type cost allocation (€40,962, i.e., −5.7%). Of the three single approaches, 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 bottlenecks and relatively more at non-bottlenecks in the various production units.

The hybrid approach data have implications for the case company. One such implication is that products that seemingly have been produced with low profit or even at a loss have actually been produced with acceptable profits. This is particularly true for product C, for which the manufacturing costs have previously been overestimated by no less than 30%. If the true manufacturing cost is €43,444 rather than €56,293, then this product's role in the company's overall product offering changes, since the actual costs are much lower than previous estimates.

A few years prior to our research study, the company outsourced some products partially or even completely due to lack of profit. In the preparation for incoming products, the calculation of production costs

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

Product	Manufacturing cost allocation approaches	Process type in production unit			Total cost	Deviation from hybrid
		Job shop	Flow shop	Line		
A	Traditional	*62,122*	1690	22,986	86,798	−4%
	TA	45,299	*3903*	13,902	63,104	−30%
	LA	73,107	2133	*24,426*	99,665	+10%
	Hybrid approach	*62,122*	*3903*	*24,426*	90,451	–
B	Traditional	*96,459*	2601	2190	101,250	−1%
	TA	60,740	*3271*	802	64,814	−37%
	LA	119,163	3281	*2955*	125,399	+22%
	Hybrid approach	*96,459*	*3271*	*2955*	102,685	–
C	Traditional	*5908*	31,597	18,788	56,293	+30%
	TA	2371	*19,083*	19,507	40,962	−6%
	LA	3629	31,506	*18,452*	53,587	+23%
	Hybrid approach	*5908*	*19,083*	*18,452*	43,444	–

differed depending upon the planned routing and the set of production units that are selected to be used (if there were multiple alternatives). There have been cases at this company where products have been scheduled to use highly utilised production units in favour of similar and less utilised production units. This led to greater sensitivity to production disturbances, resulting in longer queues, more work-in-process, longer lead times, and larger inventories.

The company strategy has since turned towards more in-house manufacturing. New insights into the issue of cost allocation, together with other factors such as business development with new customers and products coming in and others going out, have contributed to this change in strategy. Overall, the hybrid approach has highlighted the importance of aligning accounting approaches with processes and has led to insights concerning the selection of processes and resources as well as the calculations of product costs.

6. Conclusions

In this paper, we investigated the problem of selecting appropriate cost allocation principles for different types of production processes. We derived comparable mathematical expressions for the cost allocation schemes for traditional, lean, and throughput accounting. We found that there are significant differences among the three approaches, but also that the approaches can lead to the same result in some special cases.

We then introduced the hybrid approach. A key aspect in the hybrid approach is that as soon as a product visits different types of production units along its operations sequence, cost allocation to the product should be made with the accounting approach that best matches the characteristics of each respective production unit.

Numerical results from a case study using real data were used to illustrate the effects of using different types of cost allocation schemes for different situations. Based on our data, we advocate that the cost allocation method should be selected with respect to the characteristics of each production process type, 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 production unit level, and not at the plant level, in order to allocate the right costs to products (i.e., matching the appropriate manufacturing accounting approach to the particular process type in the production unit). As the product moves along its operations sequence, the right accounting approach should – at each successive operations stage – be selected and applied, that matches the process type of that particular operations stage. Only then will the costs accumulate accurately along the operations sequence for the product.

The hybrid approach has implications for managers of mixed process environments, where products visit production units of different types. Rather than selecting one accounting approach, the results of this study strongly indicates that it is better to use the accounting approach that best matches the characteristics of the production unit – at each respective stage along the operations sequence of the product.

However, this study has some limitations. First, we have assumed that there is only one bottleneck in a flow shop, and that it is stable, which are desirable characteristics of a flow shop. We did not account for the possibility of temporary and moving bottlenecks, i.e., that the bottleneck moves from one period or resource to another. Second, we restricted the analysis to one production site, and did not consider larger production networks where a product requires manufacturing at two or more sites. Nevertheless, the key principles of applying the right accounting approach to each respective production unit (with respect to their process type) is still valid across all manufacturing sites in such a network. Third, we tested the hybrid approach using real data for three complex products from only one advanced manufacturing technology firm. Further research is needed to test the hybrid approach for other types of products and for firms in other types of industries, to evaluate the relative relevance of the hybrid approach in other manufacturing environments.

Appendix A. Fundamentals of job shop, flow shop, and line processes

This section briefly describes three production process types that are related to discrete manufacturing: job shop, flow shops, and line (see e.g., Hill and Hill, 2009; Krajewski et al., 2016). All three process types are used by the case company, which organises the total production system such that each production unit includes only one production process type. There are no examples of project manufacturing or continuous processing.

The layout of a *job shop* is such that similar equipment is organised by function (APICS, 2010). The facility configuration is based on departmental specialty, for example heat treat, lathe, mill, press, and saw. Within the department, resources are similar and can perform similar types of processing. A product is sequenced through the functional shop according to its routing, with considerable divergence among products in the steps performed. The operations necessary to complete a product are therefore decoupled, not linked (Hill and Hill, 2009). A job shop offers sequencing flexibility and can thus manage a wide range and high customisation of products with variable demand (Krajewski et al., 2016). The focus is on achieving high resource utilisation, which typically leads to extensive queuing and long lead times at various resources in the production unit.

A *flow shop* consists of dissimilar machines grouped together into a production unit to produce a family of parts having similar routings (APICS, 2010), and is related to the concepts manufacturing cell and work cell. The resources typically consist of one bottleneck and several non-bottleneck resources. Thus, the capacity of the bottleneck determines the capacity of the production unit, while the other resources have over-capacity by definition. A product will typically visit the bottleneck and some of the other resources. While the process allows for some flexibility, more dominant paths emerge than at a job shop (Krajewski et al., 2016). The production unit is dependent on the utilisation of the bottleneck, while non-bottlenecks are continuously providing the bottleneck with work. The characteristics of this process type fall in between those of a job shop and a line, for example in terms of lead times and average capacity utilisation (Hill and Hill, 2009). A flow shop is often used for the production of a product group or product family that requires similar types of processing but with a product variety that would not allow for using a line.

A *line process* is characterised by repetitive manufacturing performed by specialised equipment in a fixed sequence (APICS, 2010). Volumes are high and products are standardised, which allow resources to be organised around particular products (Krajewski et al., 2016). The resources are therefore dedicated to the production of a particular set of similar products. The layout is designed sequentially around the steps necessary to make a product, with each step of the process being completed at a particular workstation (Hill and Hill, 2009). The products visit all resources and pass through the line in a fixed sequence, and little inventory is kept between the processing steps. The capacity of the line is related to the cycle time or "takt" time of the line. Line production is less flexible, less able to customise products, and less able to adapt to variable demand than the other process types. A well-balanced line is associated with high resource utilisation as well as short product lead times through the line.

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