Management accounting and R&D cooperation: The case of standards for the calculation of cost-of-ownership in the semiconductor industry

Marc Wouters[a,b]
Maximilian Sandholzer[a]

[a] Karlsruhe Institute of Technology, Institute for Management (IBU), Kaiserstraße 89, 76133 Karlsruhe, Germany, marc.wouters@kit.edu, maximilian.sandholzer@imise.uni-leipzig.de

[b] Corresponding author, telephone +49 721 608 41852, fax +49 721 608 41857

Documents
Document Sharing Hub

Full document details: Management accounting and R&D cooperation: The case of standards for the calculation of cost-of-ownership in the semiconduc...

Management accounting and R&D cooperation: The case of standards for the calculation of cost-of-ownership in the semiconductor industry

Abstract

Based on a field study of the semiconductor industry, we consider the role of standards for the calculation of total cost-of-ownership that underpin R&D processes. Drawing on Robson's theory of accounting calculations as mobile, combinable, and stable inscriptions that expedite long-distance control, we examine how the standards helped to mobilize, combine, and stabilize these industry-wide calculations. The findings also suggest the standards enabled the calculations to become malleable: companies could significantly modify calculations by inserting private data, adjusting the manufacturing setting and products reflected in calculations, switching between default values and proprietary data, or using parts of the standards selectively. The combination of stability and malleability, because of the existence of standards for the calculation, strengthened the capacity of cost-of-ownership calculations to be a mediating instrument that impacted the investment decisions of integrated circuit (IC) manufactures and semiconductor equipment companies. The study demonstrates how standards created commonality and at the same time enhanced flexibility and thereby the influence of accounting.

Keywords: cost-of-ownership; interorganizational management accounting; semiconductor industry; management accounting standards; product development; R&D

1 Introduction

Sharing information on technology, operational processes, and costs with other companies is relevant in the context of R&D cooperation and supply chain management (Agndal and Nilsson, 2009; Anderson, Glenn and Sedatole, 2000; Caglio and Ditillo, 2008; Carr and Ng, 1995; Cooper and Slagmulder, 2004; Håkansson and Lind, 2004; Kulp, 2002; Munday, 1992). One particularly interesting setting for studying such cooperation and the role of interorganizational management accounting is the semiconductor industry. Miller and O'Leary (2007) and Miller, Moll, and O'Leary (2012) focused on this particular industry, and they investigated various kinds of mediating instruments that help firms in aligning their investment decisions with investments made by other firms and agencies in the same or related industries. These mediating instruments also comprise cost-of-ownership calculations. Our intention is to provide more depth to those findings by addressing the role of standards to strengthen the mediating capacity of cost-of-ownership calculations. "Standards" refers to a

Documents
Document Sharing Hub
Full document details: Management accounting and R&D cooperation: The case of standards for the calculation of cost-of-ownership in the semiconduc...

defined, “official,” but voluntary method for the calculation of cost-of-ownership of semiconductor manufacturing equipment, described in publicly available documents (SEMI 2012a, 2012b). We want to develop the ideas of Miller and O’Leary (2007) and Miller, Moll, and O’Leary (2012) further, by investigating how the mediating capacity of cost-of-ownership calculations is influenced and reinforced by the existence of these standards for the calculation of cost-of-ownership.

Understanding the mediating capacity of cost-of-ownership calculations is important, because these guide large investment decisions in R&D and capital equipment (Miller and O’Leary, 2007). The context of the semiconductor industry is important here: investments in R&D and in manufacturing equipment are enormous; the lead time for developing future technologies is very long and it is difficult to predict the outcome; moreover, many different parties are involved in creating markets and shaping technological progress. Miller and O’Leary (2007) analyzed cost-of-ownership calculations as one of the mediating instruments in this industry. Cost-of-ownership includes depreciation of the expensive capital equipment and various kinds of recurring costs, such as for tools and auxiliary materials. These calculations are used as an indicator of the attractiveness of a candidate technology and of a specific supplier offering. Only looking at the initial investments is not enough, because operational costs are also considerable, and there are interdependencies between investment costs and throughput, yield, uptime and other variables that also affect the economics of the technology. These cost-of-ownership calculations represent a form of interorganizational management accounting (Caglio and Ditillo, 2008, 2012; Fayard et al., 2012): It is the integrated circuit manufacturer who will incur the cost-of-ownership, but equipment suppliers and other firms and agencies also provide some of the data and use the results. Therefore,

> “calculations of cost-of-ownership are utilized extensively throughout the semiconductor and related industries. They are intended to compare two or more systems or technologies by relating the capital costs and operating expenses associated with each one to measures of output and operational effectiveness” (Miller and O’Leary 2007, p. 727).

Why would we expect *standards* to be important for the mediating capacity of cost-of-ownership calculations—a facet Miller and O’Leary (2007) do not consider? Organizational structures and practices in the semiconductor industry are highly networked and hybrid, and standards are generally more important as the organization of an industry is more networked and hybrid (Schilling and Steensma, 2001; Sahayn, Steensma and Schilling, 2007). Standards in the semiconductor are developed and revised through an industry organization focused just

AVA Documents Document Sharing Hub

Full document details: Management accounting and R&D cooperation: The case of standards for the calculation of cost-of-ownership in the semiconduc...

on that: SEMI (Semiconductor Equipment and Materials International) is a global industry association that provides a forum for collaboration and standard setting. These are mainly technical standards (such as for production processes, testing, or wafer size), but some standards are called "equipment metrics" and concern topics such as cost-of-ownership. In fact, the semiconductor industry seems to be the only case of having cost accounting standards for the calculation of cost-of-ownership that are voluntary, publicly available, and widely used (Geißdörfer, 2008). Thus, the networked semiconductor industry represents a setting in which standards are likely to be important, it provides an intriguing and rare example of management accounting standards, and these are left unexplored by Miller & O'Leary (2007), although the role of cost-of-ownership calculations as such has shown to be important.

This leads to the research questions for the present study: In what way does the existence of standards for the calculation of cost-of-ownership enhance the capacity of these calculations to be a mediating instrument? This does not address the accuracy or comprehensiveness of standards, but how standards help making these calculations "work," in the sense of influencing what is happening in organizations, or more specifically, in directing semiconductor companies' investment decisions.

Robson (1992) provides a powerful way for analyzing the role of standards. For the present study, drawing on Robson's (1992) notions of mobility, stability and combinability helped to develop a more nuanced understanding of the mediating capacity of cost-of-ownership calculations in the semiconductor industry. We distinguish between different situations in which cost-of-ownership calculations were mobile in the semiconductor industry. We investigate what combinability of these calculations meant in these situations. We also analyze how the existence of standards for the calculation of cost-of-ownership helped stabilizing these mobile and combinable calculations. Beyond this, we investigate how standards made the calculations of cost-of-ownership *malleable*, which went beyond aggregating, disaggregating, and rearranging numbers (i.e., combinability) and concerned more fundamental changes to the calculations, such as inserting proprietary data or changing the calculation methods. We find that standards made the meaning of the input data and calculation methods enough commonly understood, so that users could make such significant changes. The standards contributed both to the commonality of accounting calculations as well as to their flexibility. The study provides a more nuanced understanding of how accounting can be both—common and flexible—because of the existence of standards.

Documents
Document Sharing Hub
Full document details: Management accounting and R&D cooperation: The case of standards for the calculation of cost-of-ownership in the semiconduc...

This is an empirical study based various kinds of data. We consulted research papers and other publicly available documents. We have spoken with many experts on cost-of-ownership in the semiconductor industry, and several of them have been involved in these developments since more than 20 years. We also obtained documents and an example calculation based on software that incorporates the cost-of-ownership standard. Furthermore, we have created a spreadsheet-based model of cost-of-ownership calculations to verify our detailed understanding of the standards for the calculation of cost-of-ownership.

The remainder of this paper is structured as follows. A literature review follows in Section 2, including a description of the standards for the calculation of cost-of-ownership. Details on the research method are provided in Section 3. Section 4 presents research findings on the use of cost-of-ownership calculations in public and in private contexts. In Section 5, we discuss how the standards contributed to the capacity of cost-of-ownership calculations to be a mediating instrument, because these also enabled calculations to be malleable. Section 6 concludes the paper.

2 Literature review

We will quite extensively summarize Miller and O'Leary (2007) in Section 2.1, who analyzed cost-of-ownership calculations as a mediating instrument for coordinating investments across companies in that industry. Documents on the standards for the calculation are reviewed in Section 2.2. The framework of Robson (1992) will be used in this paper to analyze the role of these standards for cost-of-ownership calculations (Section 2.3).

2.1 Accounting as a mediating instrument in the semiconductor industry

Miller and O'Leary (2007, p. 702) use the term "mediating instruments" to refer to "those practices that frame the capital spending decisions of individual firms and agencies, and that help to align them with investments made by other firms and agencies in the same or related industries." This helps to better understand how investment processes are managed not only within organizations, but also among groups of organizations. When organizational structures and practices become more networked and hybrid, there is a need to better understand how accounting practices may play a role in the cooperation and sharing of expertise among firms.

> "Even competing firms engage in continuous and frequent information exchange on a much larger scale than commonly acknowledged. … Much of this information is accounting-based, albeit modified to deal with the often localized nature of the information transfers" (Miller, Kurunmäki and O'Leary, 2008, p. 962-963).

Documents
Document Sharing Hub
Full document details: Management accounting and R&D cooperation: The case of standards for the calculation of cost-of-ownership in the semiconduc...

Miller and O'Leary (2007) focus on integrated circuits (IC), and seen more widely, semiconductors also include flat-panel displays and photovoltaics. R&D requires huge investments, very long lead times, and many different parties are involved: firms that develop and manufacture final products (e.g., computers, phones, cameras), components (e.g., microprocessors, memory—such as Intel, Samsung, Texas Instruments, Toshiba, and NXP), equipment and subsystems (e.g., lithographic equipment, lenses and lasers—firms such as ASML, Canon, Nikon and Applied Materials), but also universities, government agencies, national laboratories, and science foundations. Research cooperation and knowledge sharing is partly organized through SEMATECH (Browning et al., 1995; Carayannis and Alexander, 2004; Link and Finan, 1997; Müller-Seitz, 2012).

Miller and O'Leary (2007) analyze *Moore's Law*, *technology roadmaps*, and *cost-of-ownership calculations* as mediating instruments in this industry. These help to resolve choices for alternative technologies and set benchmarks for cost reduction targets to safeguard the profitability of different parties.

Moore's Law describes an ongoing growth in the number of components per IC, as a result of miniaturization, and this leads to a reduction of the cost per component. Moore's Law predicts a doubling of the number of electronic elements per IC every two years.[1] This principle has become the fundamental expectation for technological progress and cost reduction of the entire IC industry. To some extent, this can be realized by continuous improvement of a particular technology. In parallel, development of an entirely new generation of equipment is necessary. For example, Miller and O'Leary (2007) describe how optical lithography, which involves beaming light through an "image" and lenses in order to project the pattern of the IC on the silicon wafer, was reaching its limits. Adherence to Moore's Law would at some point require making the project lines so small, that the wavelength of light could not project them anymore. Fundamentally new technology had to be developed, starting many years in advance of optical lithography becoming inadequate.

Technology roadmaps describe the required performance and technical standards of several steps in the production process of ICs for the next 15 years in detail. The roadmap

[1] For example, see Intel, *Moore's Law Inspires Intel Innovation*, http://www.intel.com/content/www/us/en/silicon-innovations/moores-law-technology.html (accessed 24 October 2012). The 2010 update to the roadmap has growth slowing at the end of 2013, after which the number doubles only every three years. See Wikipedia, *Moore's law*, http://en.wikipedia.org/wiki/Moore%27s_law (accessed 24 October 2012), and the International Technology Roadmap for Semiconductors, *2010 Overall Roadmap Technology Characteristics (ORTC) Tables*, http://www.itrs.net/Links/2010ITRS/2010Update/ToPost/2010Tables_ORTC_ITRS.xls, for example on the worksheet *Notes for ORTC-2A* (accessed 24 October 2012).

Documents
Document Sharing Hub
Full document details: Management accounting and R&D cooperation: The case of standards for the calculation of cost-of-ownership in the semiconduc...

coordinates by making sure that the overall expected technical progress according to Moore's Law is achieved, and it also coordinates by detailing what different technologies need to accomplish. For example, the roadmap lays out the number of electronic elements per chip (in billions of transistors), and the size of lines. For new technology generations, the roadmap also shows which choices for alternative new technologies are still open. Roadmaps bundle knowledge and facilitate decision making in the industry. They help companies to understand which choices are likely be become dominant, so they can make more informed choices about R&D and equipment investments. The roadmap documents are produced and published by an organization called "International Technology Roadmap for Semiconductors" (ITRS) (www.itrs.net), which is sponsored by the five large semiconductor industry associations in the world.[2] Meetings organized by ITRS have the aim to identify barriers for achieving technological progress as defined on the industry roadmap. Information sharing in these meetings is subject to rules about what may be discussed and exchanged as to not violate antitrust legislation (Miller, Moll and O'Leary, 2012). Figure 1 provides an overview of some of the actors in the semiconductor industry.

(Insert Figure 1 around here.)

Cost-of-ownership calculations are a key element for making technology decisions. Apart from the technology question "will it work?" there is the question of whether a particular new technology will be acceptable from a cost point-of-view. Calculations of cost-of-ownership are used to compare the economic attractiveness of technologies and supplier offerings. These results are compared to overall expectations for cost reduction, based on the roadmap, and competing offerings are compared against each other. Cost-of-ownership can be defined as

> "the total lifetime cost associated with acquisition, installation, and operation of fabrication equipment,"[3] or as the "full cost of embedding, operating, and decommissioning in a factory environment equipment needed to accommodate the required volume of units actually processed through the equipment" (SEMI, 2012a, p. 4).

Miller and O'Leary (2007) describe that in the 1990s several alternative technologies to follow-up optical lithography were considered on the technology roadmap (X-ray, electron-beam, and extreme ultraviolet). Immersion lithography entered on the roadmap in 2003,

[2] The European Semiconductor Industry Association (ESIA), the Japan Electronics and Information Technology Industries Association (JEITA), the Korean Semiconductor Industry Association (KSIA), the Taiwan Semiconductor Industry Association (TSIA), and the United States Semiconductor Industry Association (SIA).
[3] See SEMATECH, *SEMATECH Dictionary of Semiconductor Terms*, http://www.sematech.org/publications/dictionary/con_to_cz.htm (accessed on 29 August 2012).

Documents
Document Sharing Hub
Full document details: Management accounting and R&D cooperation: The case of standards for the calculation of cost-of-ownership in the semiconduc...

which would make smaller lines possible with optical lithography than ever imagined, and so it could extend the life of optical lithography as a suitable technology for pattering ICs. Around 2004, the fundamental technical problems of extreme ultraviolet (EUV) were considered solvable and cost-of-ownership comparisons between EUV and immersion lithography became relevant. Miller and O'Leary (2007) describe a study by Silverman (2005) evaluating these alternative technologies based on cost-of-ownership, and which estimated that the cost-of-ownership of both technologies would be quite similar.

In sum, Miller and O'Leary (2007) and Miller, Moll, and O'Leary (2012) investigated cost-of-ownership and other mediating instruments in the semiconductor industry. Underexposed in these studies, though, is the role of standards for the calculation of cost-of-ownership, although standards are likely to be important in such as networked and hybrid sector (Schilling and Steensma, 2001). We want to nuance their observations, which leads to the research question introduced above: In what way does the existence of standards for the calculation of cost-of-ownership enhance the capacity of these calculations to be a mediating instrument?

2.2 Standards for the calculation of cost-of-ownership

We firstly describe the SEMI E35 standard that defines the calculation method of cost-of-ownership, and then the SEMI E10 standard, which defines operational parameters that are key inputs to the calculation according to the E35 standard. We need a few pages for providing enough background information and to illuminate the following aspects, which will be important for the analysis: Each calculation of a cost-of-ownership result requires a lot of data for describing the manufacturing situation. This makes data collection (and exchange) an important issue, but it also means that each calculation reflects only a very particular setting. The calculations are complex, and therefore the interpretation requires a detailed explanation of how it has been conducted. The standards provide such an explanation. The relevant standards E10 and E35 address different aspects, whereby E10 provides data on utilization as key input for the costing calculations according to E35. The standard contains default values.

SEMI E35, guide to calculate cost-of-ownership metrics

The standard SEMI E35-0312 can be purchased for US$100 from SEMI (www.semi.org). The document is called a "guide" and its purpose is "to provide standard metrics for evaluating unit production cost effectiveness of manufacturing equipment in the semiconductor related industries" (SEMI, 2012a, p. 1). The guide is applicable to any type of equipment for processing semiconductor units, such as IC wafers and devices.

Documents
Document Sharing Hub
Full document details: Management accounting and R&D cooperation: The case of standards for the calculation of cost-of-ownership in the semiconduc...

The often-mentioned "basic equation" for cost-of-ownership in semiconductors proposed by Carnes and Su (1991) and Dance, DiFloria and Jimenez (1996) provides an intuitive introduction to the general idea:

$$COO = \frac{CF + CV + CY}{TPT * Y * U}$$

COO is the cost-of-ownership, *CF* is the total fixed cost, *CV* the total variable cost, and *CY* the total cost due to yield loss. In the denominator, *TPT* stands for throughput, *Y* is composite yield, and *U* is utilization of equipment. By multiplying throughput with utilization, we get the total amount of produced units, which is reduced to the total amount of *good* units by the multiplication with the yield figure.

SEMI E35 splits the cost-of-ownership into the cost of equipment ownership (*CEO*) and the cost of yield loss (*CYL*) (SEMI, 2012a). *CEO* is a factor in cost-of-ownership that includes all costs not associated with yield loss. *CYL* is based on the idea that a unit lost at the end of a given manufacturing process step represents the loss of the cost of the starting unit and the manufacturing costs to that point. The basic equation can be rewritten by splitting the nominator into two parts, which are described below.

$$COO = \frac{CF + CV}{TPT * Y * U} + \frac{CY}{TPT * Y * U} \triangleq CEO + CYL$$

Cost of equipment ownership: 20 cost elements

CEO represents the fixed and variable cost in relation to the good amount of units produced, and the *CEO* equation is formulated as follows (SEMI, 2012a):[4]

$$CEO = \frac{(FC + RC) * ER}{TPT * Y * U} = \frac{(\sum_{ij} F_{ij} + \sum_{km} R_{km}) * ER}{TPT * Y * U}$$

The fixed costs per unit of equipment (*FC*) and the recurring costs per unit of equipment (*RC*) are multiplied with the amount of equipment required (*ER*), since the fixed costs and recurring costs are measured per piece of equipment. The indices "*i*" and "*j*" for the fixed costs refer to a table in the standard that defines cost categories *i* and within those the cost elements *j*. These include the cost categories equipment (with 5 cost elements, such as installation) and facilities. Similarly, the indices "*k*" and "*m*" for the recurring costs refer to a table that defines cost categories *k* and within those cost elements *m*. These include consumables (with 5 cost elements, e.g., utilities), maintenance (with 4 cost elements, such as spare parts), and labor (with 4 cost elements, for example, engineering).

[4] In the standard document SEMI E35, the term "*GUE* per year" is used. *GUE* stands for "good unit equivalents", and *GUE per year* is equal to *TPT* × *U* × *Y*. In the equation, "Recurring costs" are what the basic formula considers "variable costs".

Documents
Document Sharing Hub
Full document details: Management accounting and R&D cooperation: The case of standards for the calculation of cost-of-ownership in the semiconduc...

The definitions of these cost categories and cost elements include many specific issues. For example, differences between the costs of consumable parts, spare parts, and repair parts are defined within the recurring costs. Also, the definitions avoid double counting, such as counting a part that has been purchased initially together with equipment acquisition cost later again as a spare part. Furthermore, for each cost element, the document includes a description of the method for measuring the particular cost element.[5]

The E35 guide also includes "default values" such as for the cost of space in a wafer fab. These values can be used if actual data are not available.

Cost of yield loss: three cost elements

The cost of yield loss (*CYL*) expresses the costs incurred by yield losses (*CY*) per good unit ($TPT \times U \times Y$). This represents that a unit lost at the end of a particular manufacturing process step causes a cost equal to the cost of the starting unit plus the manufacturing cost of the step at which it was lost. This requires knowledge of the accumulated manufacturing costs before the unit is lost. So, if a unit is damaged during this process step, the cost of yield loss incurred includes the cost-of-ownership of the equipment in this process step. This means that the cost-of-ownership of a piece of equipment is an input value for the cost of yield loss, and thereby also input for the calculation of the cost-of-ownership. This circular relation is solved by performing iterations to approach the cost-of-ownership value.

The cost of yield loss equation is further specified into 3 cost elements: equipment yield loss, defect limited yield loss, and parametric limited yield loss. Measuring these various yield losses requires further assumptions, input values, and measurement models.

The SEMI E35 does not include all elements for the cost-of-ownership calculations. Several of the input parameters and calculations are defined in other SEMI standards, particularly in the SEMI E10 standard. Those standardized parameters and calculations are also needed for other purposes, such as for exchanging technical data among different machines connected in a production line.

SEMI E10, reliability, availability, maintainability, and utilization

The SEMI E10 standard is called "Specification for definition and measurement of equipment reliability, availability, and maintainability (RAM) and utilization". We used the

[5] For example, for the cost element Labor within the cost category of Maintenance, the method is formulated as follows (SEMI, 2012a, p. 14): "Calculate the number of maintenance labor hours required for scheduled and unscheduled downtime based on using SEMI E10 metric inputs. Multiply the actual burdened costs for labor-hours of effort multiplied by the number of hours for each equipment purchaser's personnel type. Equipment user may need to adjust actual hours required due to warranty and service contract coverage. Note that operation labor hours are not included in this category."

Documents
Document Sharing Hub
Full document details: Management accounting and R&D cooperation: The case of standards for the calculation of cost-of-ownership in the semiconduc...

SEMI E10-0312 version, available through www.semi.org at a price of US$ 200. This standard provides the detailed explanation of the definitions and calculations that underlie *total utilization* and *operational uptime*, which are key parameters in the cost-of-ownership calculation. Furthermore, the E10 standard includes the definition and calculation of the costs of consumable material, nonconsumable parts, and maintenance, which are also part of the cost-of-ownership calculation. The importance of standardization for effective information exchange is mentioned in this standard:

> "This Document establishes a common basis for communication between users and suppliers of semiconductor manufacturing equipment by providing a standardized methodology for measuring reliability, availability, and maintainability (RAM) and utilization performance of equipment in a manufacturing environment." (SEMI, 2012b, p. 1).

The core of the SEMI E10 standard is the definition of various operating states of equipment that cover all equipment conditions and periods of time:

1. Non-scheduled state: time when the equipment system is not scheduled to be utilized in production (for example, holidays out of the production schedule).
2. Unscheduled downtime state: time when the equipment system has experienced a failure until equipment is restored to a condition where it may perform its intended function (for example, replacing a broken component).
3. Scheduled downtime state: time when the equipment system is not available to perform its intended function due to planned downtime events (for example a setup activity for converting the equipment to another process).
4. Engineering state: time when the equipment system is in a condition to perform its intended function, but it is operated to conduct engineering experiments.
5. Standby state: the time other than nonscheduled time, when the equipment system is in a condition to perform its intended function and consumable materials and facilities are available, but the equipment system is not operated (e.g., no operator is available).
6. Productive state: the time in which the equipment system is performing its intended function.[6]

The operating states 2-6 are called *operations time*, consisting of *downtime* (2 and 3) and *uptime* (4-6). Semiconductor manufacturing equipment registers the operation states,

[6] Just to illustrate the level of detail required for defining these states, note that the standard describes, for example, that "times for heating, cooling, purging, pump down, cleaning, etc., that are specified as part of production recipes shall be specifically included in productive time. However, similar times that are not specified as part of production recipes shall be specifically excluded from productive time" (SEMI, 2012b, p. 8)

Documents
Document Sharing Hub
Full document details: Management accounting and R&D cooperation: The case of standards for the calculation of cost-of-ownership in the semiconduc...

either automatically, or the operator needs to enter information about equipment status that cannot be monitored automatically.[7]

Transitions between different states define events. For example, a *downtime event* is a state transition event either into a scheduled downtime state from a state other than a scheduled downtime state, or into an unscheduled downtime state from a state other than an unscheduled downtime state. The latter is also called a *failure*, and failures are further classified into six different types of failures.

Twenty-six performance measures for reliability, availability, and maintainability (RAM) and utilization are defined based on the states and the events. For example, *mean uptime between failures* ($MTBF_u$) is uptime ÷ number of failures during uptime; and *total utilization* is productive time ÷ total time.

The SEMI standards for cost-of-ownership calculations are incorporated in the commercially available software sold by WWK, called TWO COOL. This software has been purchased by about 3000 companies in the semiconductor industry.[8]

2.3 Mobility, stability, and combinability of calculations.

Robson (1992) provides a compelling way to analyze how standards impacted the capacity of cost-of-ownership calculations to be a mediating instrument. We will draw on Robson's (1992) notions on accounting numbers as "inscriptions" and the mobility, stability and combinability of these. Inscriptions "refer to the various techniques of 'marking' an object or event that is to be known—writing, recording, drawing, tabulating" (p. 689). Such "technologies for *inscribing* the world" (p. 689, emphasis in original) lead to information and knowledge. In other words, information and knowledge is usually obtained from inscriptions rather than through direct interaction with the original objects and events. "It is arguably the case that most of our knowledge does not come to us directly from our own experience of the world: books, newspapers, etc., all supply our 'information'" (p. 689).

Accounting numbers are analyzed by Robson (1992) as inscriptions, which are explained not in terms of how accurately they correspond to the original objects or events (i.e., represent reality), but in terms of their impact on the world. Inscriptions can travel

[7] Furthermore, the guideline describes several activities included in each state, and both the scheduled downtime state and the unscheduled downtime state are formally broken down into eight more detailed substates each. For example, two substates of scheduled downtime are *preventative maintenance* (which consists of the time for preventative action, equipment test, and verification run as specified by the supplier) and *maintenance delay, supplier* (which is the time during which the equipment cannot perform its intended function because it is waiting for supplier personnel, supplier-controlled parts, supplier-controlled consumable materials, or supplier-controlled information such as test results).

[8] Interview notes 2012-06-01 J

Documents
Document Sharing Hub
Full document details: Management accounting and R&D cooperation: The case of standards for the calculation of cost-of-ownership in the semiconduc...

between a context of action and an actor who is remote from that context and who wants to influence it. Accounting numbers as inscriptions can influence action at a distance, such as headquarters of a company prescribing certain types of reporting from divisions to represent local activities, formulating targets in terms of those reported numbers, which may lead to taking actions (e.g., replacing local management). Robson (1992) discusses several powerful characteristics of accounting numbers that enhance their capacity to influence action at a distance: mobility, stability and combinability. These characteristics of accounting numbers allow them the impact action at distance, almost independent from their representational qualities. We will discuss these characteristics in more detail below when analyzing the findings.

In the semiconductor industry, numbers, graphs, tables, and explanatory text that compose a cost-ownership calculation can be seen as inscriptions of the processes, products, and costs of IC manufacturers. These inscriptions influence investment decisions across the boundaries of individual organizations, such as IC manufacturing companies' investment decisions regarding capital equipment, and equipment suppliers' investment decisions on R&D projects (Miller and O'Leary, 2007). We will draw on Robson's theory to analyze our research question introduced in the previous section on how the existence of standards for the calculation of cost-of-ownership in the semiconductor industry has strengthened the capacity of such calculations to be a mediating instrument.

3 Research method

This empirical study is based several kinds of data. We used information that is publicly available as papers published in academic and professional journals, internet pages, and documents that can be downloaded for free (such as several SEMATECH reports and presentations) or at a moderate price (such as SEMI standard documents). These sources are included in the list of references at the end of this paper, and internet pages are referred to in footnotes.

Furthermore, we consulted 17 different experts on standards for the calculation of cost-of-ownership in the semiconductor industry, who work or have worked at industry organizations (SEMI, SEMATECH, ITRS), software companies (WWK, IC Knowledge), semiconductor equipment companies (ASML, Centrotherm, RENA), IC manufacturing companies (Texas Instruments, Infineon, NXP, Intel, AMD, Global Foundries, and others), engineering consulting firms, and other companies in the semiconductor industry, such as material suppliers. Many of them had been involved in standard setting for cost-of-ownership

Documents
Document Sharing Hub
Full document details: Management accounting and R&D cooperation: The case of standards for the calculation of cost-of-ownership in the semiconduc...

calculations and conducting cost-of-ownership analyses for at least ten years, and sometimes even twenty or thirty years.[9] From April 2012 to June 2014 we exchanged numerous emails with these people. Forty-one emails contained specific data used for this study, such as detailed explanations of particular events that occurred in the history of developing the SEMI standard, or descriptions of cost-of-ownership information exchanges between companies and its use within companies. We also conducted twelve interviews (in person, over the telephone, or via Skype) and received several documents that are not publicly available.[10]

Thirdly, we created a spreadsheet-based model of comprehensive cost-of-ownership calculations to verify our detailed understanding of the standards. We used a particular set of input values obtained from the cost-of-ownership software and services firm WWK, as well as the cost-of-ownership results generated by their software that is in accordance with the standards. Thus, in the process of studying the standards and programming our model, we could compare those cost-of-ownership results. We consulted experts in this process, and our experience with reconstructing the results and creating a consistent model was not only helpful for verifying our comprehension of the standards, but also insightful towards the complexities of these cost-of-ownership calculations and the many different ways in which these could potentially be developed. We also visited a university cleanroom to better understand semiconductor manufacturing processes.

Analysis of the data was focused on the main themes of the study: use of the standard and the reasons for the development and existence of it. At a general level, these themes were clear from the beginning of the study. We knew from prior literature about the role of cost-of-ownership in the semiconductor industry, we know from other sources about the existence of a detailed, influential standard for these calculations, and we believed that the role of this standard for the capacity of cost-of-ownership calculations to be a mediating instrument was not yet well understood. So, we set out to better understand why it existed and how it was used. The qualitative data analysis was a process of connecting the different pieces of information we had obtained, as well as discovering gaps and inconsistencies, which sparked new questions about the themes that were guiding the research. These led to revisiting our

[9] For example, one of these experts received the SEMI International Standards Excellence Award in July 2014. As co-chair of the North America Metrics Technical Committee Chapter since 1996, he has participated in the improvement and development of several key equipment maintenance standards and multiple cost-of-ownership metrics. See: SEMI, *Standards Industry Leaders Honored at SEMICON West 2014*, http://www.semi.org/en/node/50446 (accessed 18 July 2014). More information on the background of each of these experts is provided in an appendix.

[10] Wright, Williams & Kelly, 2011. *A Guide to Using Two Cool*; Wright, Williams & Kelly, 2004. *Rapid Implementation of Cost of Ownership Using TWO COOL*; an ASML presentation on cost targets in logic markets.

Documents
Document Sharing Hub
Full document details: Management accounting and R&D cooperation: The case of standards for the calculation of cost-of-ownership in the semiconduc...