Managing the essential Strategic entrepreneurial Production resource for the 21st Century: Foundaries at the Interface

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Abstract

Twenty first century economies are increasingly being fueled by regional entrepreneurial and intreprepreneurial solutions to global problems such as water purity, global warming, health care, energy, and nutrition. However, the tradition al single technology or "Silo" approach to solving one of these problems while negatively affecting others are increasingly being eschewed. Multi technology solution sets, often comprised of both emerging and more established technologies, are increasingly embraced. Many utilizing these types of solution bases seek to leverage the more established management practices centered on the established technologies in order to manage their entire production process. Yet is this approach appropriazte?

One such multi technology solution set is comprised of the more emergent technology basis of nanotechnology and micromachining (MEMS) combined with the more established semiconductor microfabrication. This "Small Tech" solution base is seen by many as theb next "Shumpeterian Wave" of economic development. Yet they require costly "Foundaries at the Interface" or Multi Technology, High Product Mix, Low Volume fabrication facilities (MT-HMLV). These fabrications facilities have adopted for the most part the more established management practices of High Volume Semiconductor Faciltiy (HVSF) management proacticeses. We show that the results practice have been less than optimum. Our case study effort shows that these facilities use of taditonbal HVSF managment practices do not convey the strategic value of a MT-HMLV, nor do they adequately assist in their operational management. These facilities often funded by governmental action are essential to regional and firm based economic growth are now at risk. If this is so there is cause for concern.

Abstract Keywords
(R&D, Technology, entrepreneurship, Innovation, Nanotechnology, Metrics, MEMS, economic development, technology transfer, Government)

I. Introduction

The complexity of 21st century problems have hastened 21st century entrepreneurs and intrepreneurs to embrace solutions based on complimetary technology sets rather than the traditonal technology "silo" approach. Many seek to address regional problems concerned with water, health care, nutition, energy, and global warming that have global implications. Thesecomplementary technology sets are comprised of established technologies as well as emergent ones. These entrepreneurs and regional production facilties often seek to leverage as much knowledge centered on the established technology based operations.

One such set of technologies that are forming the basis of a great number of 21st century innovations is "Small Technology." Small Technology based innovations are those created at the interface of; Semiconductor Micro-fabrication, Micromachining (MEMS) and Nanotechnologies. Many see innovations based small technology as the harbinger of the next Schumpeter's wave critical to 21st century firm and regional economic success.

Why? Firms and other entities based on these technologies are starting to solve commercial and governmental problems in a uniquely valuable manner and without contributing to other global problems as they persue their focused solutions [59], [36], [3], [60], [12]. While these innovations are being increasing valued. This valuen is being developed b y new necessary competencies which for the basis of new industri2rfqfq es while creatively destroying others. The Schumpetarian Wave is building.

Yet the production facilities from which these innovations will spring, "Foundaries at the Interface" or more specifically in this case Multi Technology High Mix Low Volume fabrication facilities (MT-HMLV) [47], [48] are costly and under an increasing amount of operational and strategic scrutiny. The global answer to this scrutiny has been to utilize the "Best Practice" production facility management practice of the most established production base - semiconductor microfabrication. Multitechnology solution set managers often seek to leverage the most established technology basis managerial practice. Yet is this practice acceptable or do these existing practices lack managerial approaches that adequately address operation effectiveness or express value to their stakeholders?

There are factors that further complicate the use of semiconductor based managerial practices that rely heavily on a metrics management approach:

1) Semiconductor manufacturing facilities are moving from more the more developed economies of North America and Europe to the big emerging economies of Asia.
2) Money for these facilities once more freely flowing is being more harsley scruntinized during a period of recession.
3) These "Fondary at the interface" facilties are often too costly for any one firm to sustain and increasingly seeking support from various governmental bodies seeking to support economic development

4) The “Small Tech” foundaries of the future have often grown from purely research facilities with little or no operationa scrutiny.

5) The successful use of metrics management based on semiconductor microfabrication, especially those developed for the highly successful High Volume Semiconductor Fabrication (HVSF) has made the metrics management approach the methodology of choice, both operationally and strategically for any semiconductor like facility.

Many of these facilities are perceived as extensions of High Volume Semiconductor Facilities (HVSF). The “Defacto” standard for HVSF management, both operational and strategic is metrics. However, simply applying HVSF based metrics to this group of MT-HMLV facilities is proving ineffectual. MT-HMLV’s are fraught with ineffective operations and strategic management practice. Current management practices for these incubation facilities are barrowed from the metric management approach endemic of single technology high volume production facilities. The result is that these “foundaries at the interface” are iin trouble. But do they suffer from an operational and strategic mangemt practice that while greatly suited for the semiconductor microfabrication industry is not well suited for a small tech “foundary at the interface?

We focus on a groups of “Foundations at the interface,” or MT-HMLV’s. They are liken by many to semiconductor fabrication facilities as far as processes are concerned.Yet, HVSF metrics unfettered use in MT-HMLV facilities have proved inadequate. We seek to ascertain why HVSF metrics management has failed. We start this by first investigating the literature.

We initiate our investigation through a literature review on three subjects. They are the nature of MT-HMLV's, the large base of operational metrics developed for HVSF and finally the operational and the strategic value of R&D metrics. First, we expand on earlier work of Myers [47] and Naughton [48] to provide a definition of MT-HMLV facilities that meets the current reality of these facilities. Then we review global and local HSVF metrics with an eye toward their use for MT-HMLV facilities. Finally, we address the lack of strategic value in currently applied HVSF metrics to MT-HMLV facilities through the inclusion of selected R&D metrics, which focus on innovation. This value is perhaps most succinctly put by Michelin and Berg [43] in their seminal piece "ROI is not enough." This is directly opposed to the nature of HVSF metrics, which imply that, not only is ROI an important consideration, but it is indeed the only consideration.

We utilize the case study method to ferret out both the differing natures of HVSF and MT-HMLV facilities and to define the state of operational and strategic metric use in MT-HMLV facilities. We found that metrics, meant to guide the efficiency of large volume foundries were not easily applied to MT-HMLV facilities. Further, we find that even through smaller than their HVSF cousins, semiconductor like MT-HMLV facilities are defined by greater complexity. Finally, that MT-HMLV's have a more arduous pathway to demonstrate value to stakeholders and posses less well defined operational characteristics.

MT-HMLV facilities metrics usage has meet with varied operational success. Indeed some are so frustrated with their initial spans that they use none at all. Even those MT-HMLV facilities that use some subset of the established metric base developed for

HVSF's use them reluctantly. This conundrum has provided an environment where managers of MT-HMLV faculties are not able to effectively use even a minimum common set of metrics. Managers making strategic decisions to invest or disinvest see this as problematic. They seek to operate their facilities effectively and to do so with a metrics management approach. We take knowledge from literature and case studies to develop a Metric Selection Model.

If we do not have a method for effective operational management tools nor a direct method for effectively communicating their strategic value compounded occurring in a time of recession and increased globalization, then these facilities are at risk. If they are truly the harbingers of the next economy and these facilities have ineffective management practice that dissuade many to invest in them then there is cause for concern.

In order to use the "Small Tech" solution set effectively one resource intensive asset is required – a fabrication facility. Many agree that innovations created at the interface of micro-technology semiconductor micro-fabrication and nanotechnologies are critical to 21st century firm and regional economic success. We provide the model, which is designed to meet the strategic and operational requirements of a MT-HMLV facility. This model allows a metrics approach designed to meet the needs of the diversified group that is MT-HMLV facilities stakeholder group. Finally, we suggest future research to test the findings to other MT-HMLV manufacturing facilities.

II. Literature Review

We developed a literature review to ascertain the state of knowledge of operational and strategic metrics for MT-HMLV facilities. Furthermore, we focus on metrics as a management tool. Finally, we find gaps in the literature and practices that need to be included in this investigation and form the basis for our model.

We initiate our literature review with a discussion of metrics categorization. Many researchers have noted the differences between product and process metrics [21]. Others have noted the differences between continuous processes (i.e. semiconductors) and more job shop like operations like Micro and nanotechnologies [13]. These two concepts provide great value to our discussion of effective metrics for MT-HMLV facilities and help build a connection to our metric selection model. MT-HMLV managerial practices suffer from the direct application of metrics developed for facilities with are intrinsically different in nature and provide radically different outcomes. We address this inequality with use of Hayes and Wheelwright [24] process product metrics approach, which helps to explain the correlation between product and processes. To date these ideas have not been applied to the MT-HMLV facility.

Metrics developed for commercial high volume semiconductor facilities are efficient centric whereas MT-HMLV's are job shop intensive. Using this model, we see MT-HMLV facilities are job shop intensive, whereas HSVF are categorized as commercial. Trying to apply metrics from one extreme, transferring to the other has not proved effective. For example in HSVF, research has shown that wafer starts and yield proves to be the universal metrics and added to that is the push towards automation [21].

MT-HMLV facilities are characterized by high product mix and low volume. Their products and processes are unique in nature. This creates the need of a more flexible factory environment. Hence, high volume, low mix metrics cease to be an effective measure of operational and strategic success. Moreover, when innovation is emphasized in semiconductor like facilities, lot moves become the more defining metric [21]. No wonder the unfettered application of HVSF metrics to MT-HMLV facilities is so problematic.

Understanding the fundamental differences between MT-HMLV and HSVF provides a starting point for effective management. We focus on three literature streams to assist us in developing our model. We seek first to derive value from metrics developed for traditional MT-HMLV facilities, then continue with: HVSF metrics and finally analyze relevant R&D Metrics literature.

II.1 Multi Technology High Mix Low Volume Facilities (MT-HMLV)

Myers introduced the term Multi-Technology High Mix Low Volume in 2000 [47]. Others have expanded this semiconductor centric original use to include the research and development aspects of facilities that emphasize not only semiconductor micro fabrication, but also Nanotechnologies [48]. Still others suggest that MEMS and Nanotechnology facilities differ greatly in operation and strategic value to a firm when compared to HVSF facilities [64].

Here Naughton demonstrated the difference in tool alignment between HSVF and MT-HMLV facilities [48]. Naughton provides evidence that shows provides that that the nature of the MT-HMLV facility workflow differs from HVSF and these tools must mimic these needs. Naughton also suggested than any product produced in quantities of less than 1 million should be consider low volume. However in today's MT-HMLV facilities, even the LV portion of this acronym has changed greatly. Now LV or low volume can mean tens of thousand of parts, but for the large majority of their MT-HMLV product efforts, they are more likely to be at the 1000 quantity range and for a R&D intensive environment an order of magnitude less than that [66].

This work together with Walsh's earlier effort, which focuses on the operational and strategic management problems firms endure when converting older semiconductor fabrication facilities for MEMS and Nanotechnology utility [66]. These efforts provide the confirmation for the inclusiveness of MEMS and Nanotechnology in MT-HMLV. Furthermore, the investigations illustrate even more greatly the differences between HVSF and MT-HMLV facilities.

Further, we use the High Mix (HM) portion of the acronym to mean not only many differing semiconductor products, but also tasks of product and process maturation, innovation, design validation and many other types of efforts that are not centered on a product production utilizing a matured process [51]. Is it any wonder that HVSF based metrics that did not fit the earlier form of MT-HMLV facilities would now even be further off the mark? Another basic difference in our uses of the term MT-HMLV is found in the MT portion of this acronym. Earlier works for the most part used the MT portion to mean differing semiconductor technologies, whereas we use this portion to mean three distinctly differing technology bases. They are semiconductor micro fabrication, nanotechnologies and MEMS. Here Nano and MEMS technologies are technology platform on their own and not necessarily simply extensions to semiconductor micro fabrication [29]. There is a much larger difference between these base technologies and differing forms of Semiconductor micro fabrication than just the material usage and processes.

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II.2 HVSF Metrics

Metrics have become the "defacto" operations management performance standard for HVSF facilities. The era of metrics management in semiconductor micro fabrication was introduced during the semiconductor micro fabrication industry transition from grown junction semiconductor technology of the 1940's to semiconductor surface technologies in the late 1950's [55], [30], [44]. Today, most semiconductor chips are silicon based and fall into well-defined product areas. The ITRS roadmap has broadly categorized these into four categories: microprocessors/microcontrollers, memory devices (RAM, ROM EPROM), power and smart power [26]. The semiconductor industry produces well over $261.2 billion in commercial products and is found in nearly every aspect of our life [56]. Counterintuitive too many, despite this success, the number of semiconductor micro fabrication facilities worldwide is shrinking. This is due to processing convergence, the advent of huge facilities, the exceptionally large facility investments required to build modern fabrication facilities and the resultant volume requirements for its efficient production. These facilities are simply out of the resource scope and product quantity requirements of most firms.

These capital intensive, large diameter silicon based semiconductor micro fabrication facilities, are managed through metrics designed to maintain both cost effectiveness and yield efficiency. The modern production of semiconductors follows a two-step process: front end and back end and are customarily performed in separate facilities [26]. But even here, there is more influence of back end than front end processing for metrics. We will investigate the HVSF metrics usefulness to operation and strategic management of MT-HMLV's. We then build on Sattlers' [52] and others semiconductor metrics classification schemes. We do this by bifurcating these metrics into those focused on an entire process or "global" metrics and those more focused on specific process steps or tools or "local" metrics [37].

II.2.1 HVSF Global Metrics

Many global HVSF metrics focus on productivity and yield, but not all. For example, Goldrat in "The Goal" discussed metrics dealing with throughput and lot moves [23]. Some measure of lot moves due to the high mix and low volume nature of MT-HMLV facilities are essential metric. We provide a selected list of global metrics in Table 1 below. First we will discuss the utility of HVSF yield and wafer start metrics in a MT-HMLV environment. Next, we will address the utility of Cycle Time (CT) and Work in Process (WIP) measures [52]. Finally, we discuss the information, simulation automation, clustering and facilities upgrade project targets in the landscape of MT-HMLV facilities.

One of the first set of metrics utilized by HVSF facilities leveraged the concept of benchmarking HVSF stated capacity versus actual wafer starts and focused their efforts by the year, month, week and day [7]. This was furthered investigated by Leachman, who linked yield to actual wafer starts as a facility approached capacity [34]. Sattler improved this concept by adding product mix and the required number of process steps [52]. In order for these types of measures to be useful in MT-HMLV facilities, the product mix effect would have to be modified with the addition of differing types of efforts in the fab and differing types of technologies. This would lead to a greatly modify model that would recognize lower wafer capacity.

CT measures are essential to HVSF operation management and many of these focuses on traditional bottleneck processes. A common methodology for this type of global metrics is found in lithography layers per stepper per day [26]. Jacobs stated that by reducing bottleneck processes, stagnation time's leads to the reduction of cycle time [28]. Both Dietrich and Maynard further this concept by stating the solution of a bottleneck is not simply tool redundancy, but rather lies in tool and facility understanding [14], [38].

These metrics are based on a deep understanding of HVSF facilities and simply do not translate well to the realities of MT-HMLV facilities. The related WIP papers of first Sattler, Fallon and then Bonal are exceptional measures for very low mix facilities. The idea of streamlining processes for a singular product does not meet the realties of MT-HMLV facilities where flexible high mix and large process scope is essential [52], [17], [8].

We next discuss metrics developed around computer-aided efforts. Many of these applications hold promise for MT-HMLV facilities due to the nature of parameters or bound shifts. For example, modeling is used to define bottlenecks for HVSF and modifications to this process might make it applicable to MT-HMLV facilities [22]. Wu discussed the focus change in a re-facilitation effort. He described a transitioning from 300mm efforts to 450mm [68]. Tool clustering metrics must be developed along scope of process than one process. Many of the MT-HMLV facilities are older semiconductor facilities, which have been refocused. Given this fact, Goodall along similar lines discussed tool re-clustering for high volume facilities [24]. If the switch from a narrow to a more open production environment, then in order to use this concept in MT-HMLV facilities, we must switch the discussion from a narrow to more open production environment. Finally, the exploration of limiting information flow in order to streamline efforts was accomplished and was shown to be effective for HVSF [27]. This type of metric is exceptional for HVSF, but proves less than useful on efforts that are not well defined.

Table 1. Global

Metrics

Author	Characteristic	Analytical technique
Sattler, Glassey and Saeed [53] Benson, Cunningham and Leachman [7] Leachman and Hodges [33], [34]	Yield and wafer starts vs. capacity Wafer starts versus stated wafer start capacity Product mix, Wafer starts vs. capacity	Ranking Factory Performance Benchmarking
Sattler and Schluter [52] Fallon et al [17] Bonal et al [8]	WIP and Wafer starts Work in Process Work in Process	Case Study Case Study Equipment Efficiency
Ishii and Watanabe [27] Wu [68] Goodall and Fandel [24]	Control Information 300/450 Fabs comparison Fab tool cluster Setup	Case Study Case Study Manufacturing Costs
Maynard, Kerr and Whiteside [38]	Overall Yield	Project Costs
Jacobs et al [28] Dietrich [14]	Cycle Time Management Cycle Time Management	Case Study Case Study
Wagner [61]	Failure Analysis	Case Analysis
Herrmann and Conaghan [22] Guidi and Paradis [25] Mozumder and Lowenstien [46]	Simulation Automation Simulation	Modeling Modeling Modeling

II.2.2 HVSF Local Metrics

Modern HVSF facilities produce products that routinely exceed 500 individual process steps. Yield and efficiency originate at the tool base or local metrics level. HVSF routinely achieve overall yields of over 90%. This means the process steps must yield perfectly [4], [5]. We provide a selected group of HVSF local metrics in Table 2 below.

We have provided four distinct groupings that are representative of the local metrics used in HVSF. The first group is focused on labor contribution. The second group's concentration is local tool temporal contribution to Work in Process and Cycle Time. The third group focal point is a group of metrics that focuses degree of tool base process's latitude over the diameter of a wafer or uniformity. Finally, the fourth group is a set of metrics that focus on a tools contribution to the capital structure of the fab based on reinvestment, tool lifetime measures and contribution to maintenance.

One of the labor contributions metrics is driven by automation versus a more labor-intensive fabrication and was discussed by Appleyard and Brown [4]. Even though less than 10% of the production cost of any fab based product is found in labor contribution, the cost is of concern for HVSF facilities [5]. The crossover point holds great significance for HVSF, but is not very attractive to the more labor-intensive MT-HMLV facilities. Croft furthers this discussion by suggesting that production facilities should all embrace automation at some level [11]. This again provides limits on insights for the production nature of the MT-HMLV facilities.

Another important local metric for HVSF's is for a given tool, temporal contribution to work in process cycle time. Meyersdorf and Taho [40] showed that individual tools temporal performance could be improved by use of the proper metrics. Carrying forward this notion was Konopka and Trybula [32] through the use of Work in Progress (WIP) based metrics. Finally, Foster and Nugent [18] linked individual tools temporal metrics to overall HVSF profitability. While these measures are exceptionally useful for a HVSF, the temporal performance measures must be modified to be applicable to MT-HMV facilities. Here, the transference of wafer starts to lot moves would provide value to the MT-HMLV facility.

Next, metrics are used to provide overall wafer process uniformity often focusing on the process latitude of a particular tool over the diameter of the wafer. Mozumder, Saxena and Taylor [45] found process uniformity across the diameter of a wafer in a particular tool setting had profound overall yield implications. Smith [57] repeated the study on larger diameter wafers finding similar results. The scope of tool processes in MT-HMLV facilites creates problems for the user of this metric. Here we suggest a lot yield metric.

The final group of HVSF local metrics focuses on a tool contribution to the capital structure of the fab based on reinvestment, tool lifetime measures and contribution to maintenance. Hallas [19] discusses the tool contribution to overall cost of the fab while Miller [42] analyses tool performance and reinvestment. Limanond [35] and Kim [31] focus their investigations on specific tool processing such as etching, metallization and lithographic tools and then discuss the overall contribution to cost of a HVSF. However, HVSF tool selection is focused not on design performance factors such as flexibility of processing, but on their effectiveness of one single process or product platform. The result is a tool of limited with a process capability. Here again a tool for MT-HMLV should be chosen for scope capability. Unfortunately due to the extreme nature of MT-HMLV fabs these measures often lead to poor tool choices whereas flexibility of a particular tool is a critical dimension.

Table 2: HVSF Local Metrics

Author	Characteristic	Analytical Technique
Appleyard and Brown [4], [5] Croft, Toente and Baker [11]	Labor Usage Labor	Case Study Case study
Meyersdorf and Taho [40] Foster and Nugent [18] Konopka and Trybula [32]	Tool Usage Tool Usage WIP	Temporal Temporal Temporal
Smith et.al. [57] Mozumder, Saxena and Taylor [45]	Wafer Uniformity Wafer Uniformity	Yield Yield
Hallas, Kim and Mosier [19]	Tools	Manufacturing Cost
Miller [42]	Tool Utility	Cost
Liamnond et.al. [35]	Tool Utility	Cost
Kim and Lee [31]	Tool Utility	Cost

II.3 Research and Development Metrics

MT-HMLV facilities act as engines of innovation, centers of new product and process creation, developers of proof of concept and innovation and invention centers at the interface of converging technologies [65]. These tasks diverge greatly from the modern HVSF facility and are much more in line with the strategic and tactical roles found in R&D and commercialization organizations. HVSF facilities provide no metrics focused on this core aspect of MT-HMLV facilities. Here the authors investigate the plethora of R&D and innovation based metrics as to their potential application to these facilities.

We provide in Table 3 a review of potentially interesting innovation metrics. We categorize them by decision-making, product and applications, process focused and a discussion of metrics on metrics evaluation. We begin with the review of R&D metrics focused on decision-making. Secondly, metrics focused on products and the applications are examined. Thirdly, the R&D process and metrics is scrutinized. Next, R&D

performance versus value literature is reviewed and finally, the evaluation of metrics by using metrics in a R&D setting.

Innovation management has utilized metrics for decision making for many years [1]. The potential of metrics to condition data and information in a manner that provides knowledge in a very useful and compact nature was studied by Pich [50]. Pich stated that metrics proves easily assimilated knowledge, that easily provides assimilated knowledge, which is useful. Drongelen [15] further suggests that metric selection for maximum utility is paramount to their effective use. Adams introduced a framework for innovation based decision-making processes using metrics [2]. While this basic knowledge is important, the sufficiency of data and the correct application of information are essential to the managerial supervision of a MT-HMLV facility.

The focus of a R&D based innovation center is to transfer knowledge, re-invent the corporation, provide new technology product paradigm platforms and make existing technology product lines better faster and cheaper [65]. Yet all MT-HMLV facilities have differing focuses. Meyer suggests tailoring metric use to innovation and R&D facilities activities [39]. He suggests differing metrics for those facilities that revolve around basic research versus core technology exploration and finally applied market research. Chen and Chen evolved this concept by further investigation into the parallel use of metrics in both R&D and marketing efforts [10]. The multi-faceted nature of MT-HMLV facilities suggests a specialized set of metrics that encompasses their mission scope.

Metrics utility in managing a firm's innovation modus operadi has been extensively investigated. Szakonyi [58] proved the necessity of metrics for the effective management of a R&D process. Schumann duplicated this work [54]. Multiple objective and subjective methods for applied metrics in R&D situations was explored by Werner and Souder [67] and directly correlates too many of the MT-HMLV facilities. Hauser [23] for example, suggested differing metrics sets for facilities focused on research, development or engineering. The efficacy of R&D activities by firm industrial leaders showed by increasing funding in R&D for these facilities increased their market dominance [49]. When there are different mixtures of R&D, primarily in the private sector, it is extremely difficult to choose one or a set of metrics for a MT-HMLV facility due the ever-evolving product lines. Projects may be shelved for a period of time or even extended, which makes the use of applied metrics that much more challenging.

The use of metrics can also be used to convey a performance attribute for a firm and Bagieri [6] surveyed this concept. Using stakeholders instead of shareholders the fundamental contribution of R&D in a firm was examined. While metrics are a necessary managerial decision-making tool to operate a facility efficiently, the use of metrics to provide a framework of information to stakeholders is extremely difficult at best. External stakeholders tend to lack the specific knowledge about MT-HMLV facilities to understand their importance. Internal stakeholders are predisposed to their prejudices, which affect the interpretation of those chosen metrics.

The last section that the authors investigated encompasses using metrics to examine the metrics of a firm. Mihm [41] investigated this idea by examining system design metrics and by using local metrics. He found by using local metrics as an integrated knowledge base, a complex system could be devised and improved. Another concept of looking at metrics was investigated by Chen [9]. Here, they used a data framework, Data Evaluation Analysis (DEA), to evaluate R&D performance and found that a semiconductor R&D performance can be improved. Since the understanding of metrics and their applications are under investigation, the use of another metric upon a metric seems redundant. . The investigation of metrics based literature and the nature of MT-HMLV facilities, provides us with the foundation to build the Metric Selection Model (MSM)

Table 3: R&D Metrics

Author	Characteristic	Analytical Technique
Drongelen and Bilderbeek [15] Pich et. al. [50] Adams et. al. [2] Abby and Dickson [1] Hauser [23]	Choosing Metrics Decision making Metric Application Metric Application R&D and Engineering Metrics	Operational Operational Operational Operational Core Competence
Meyer et. al. [39] Chen and Chen [10]	R&D Parallel R&D Projects	Core Competence Strategic
Szakonyi [58] Schumann [54] Werner et. al. [67] Ofek and Sarvary [49]	Metrics Evaluation Metrics Evaluation Combining Metrics R&D Investment	Process Evaluation Process Evaluation Case study Cost Analysis
Bagliersi et. al. [6]	R&D performance	Stakeholder Value Creation
Mihm et. al. [41] Chen et. al. [9]	System Design Data Envelopment Analysis	Manufacturing Throughput R&D Performance

III Methodology

We employ a case analysis methodology to generate an understanding of the differing imperatives, nature and metric utilization of MT-HMLV ad HVSF facilities. . We utilize the case method to investigate potentials of the case study depict differences not only between HVSF and MT xx but also between differing MTHMLV facilities. We have utilized Yin [69] and Eisenhardt [15] case study techniques to interview and analyze our four MT-HMLV facilities and one HSVF facility.

We provide the finding from our case study analysis section table 4. IN figure we discuss the Section 3.1. We further our case study by administrating a structured survey to all five firms. The survey probes the firm's metric utilization and we provide results in table 5 Section 3.2 detailing

III.1 Initial Case study Results

Our case study analysis focused on 21 characteristics of fabrication facilities. The range of these characteristics range from basic technologies to more specific subjects such as the degree of automation in the facility. We segments our characteristics into four groups The first group is the number and nature of technologies in use in a particular fab The second group deal with the relative mix of products at high mix facilities. Included in this is measure is the number of products, processes developed, innovation efforts embraced and research efforts taken at a specific fab. The third group speaks directly to facility utilization and includes measures such as number of wafer starts and use of tool capacity. Finally the fourth group was developed during our case study data gather and is far more specific in nature and include measures such as metric usage, tool availability, engineering holds, changes in tool setup, tool scope and amount of automation in a particular facility..

We initial the discussion with group 1 found in Table 4. Here we focus on three technologies platforms; semiconductor fabrication, MEMS and Nanotechnology.
A fabrication facility is said to have a semiconductor micro fabrication capability if it has a Bipolar or CMOS front-end process. A foundry having MEMS capability has a full

front-end process for one of the three types of MEMS Process basis (sacrificial surface, bulk silicon micro-machining or high aspect ratio MEMS. A facility is said to have a nanotechnology capability if they have a bottom up or top down nanotechnology capability. We examined four MT-HMLV facilities and one HVSF in order to develop an understanding of their differing nature of HSVF and MT-HMLV. Further this allows us to illustrate the differences within MT-HMLV facility community and their respective differences. The results of our investigation are found in the first three rows of Table 4

Next we looked at the High Mix portion of the MT-xxx definition. We operationalized through the number of different products produced at a single facility , the amount of research versus product production lot starts, the number of processes run, the number projects completed, the inclusion of an innovation mission and the inclusion of a research mission. They are found in rows 4 through 9 in table 4. We also defined volume in rows ten and 11 by the categories of number of wafer starts and tool capacity. The final nine characteristics are in group 4 and are much more specific and found under in table 4.

There are major differences between our 5 case study facilities. When looking at group 1 characteristics, for example, all of the MT-HMLV facilities have three major technology platforms whereas HVSF's have only one product platform. When examining group 2 characteristics the difference between HVSF and MTHMLV facilities are stark. Yet the number of products produced by these facilities range from hundreds to 50. Further there exists a slight but significant difference in relative use of the facility for production versus research.

	MTHMLV1	MTHMLV2	MTHMLV3	MTHMLV4	HVSF1
Group 1					
Nanotechnology	Yes	Yes	Yes	Yes	No
Semiconductor	Yes	Yes	Yes	Yes	Yes
Microsystems	Yes	Yes	Yes	Yes	No
Group 2					
Number of Products	Hundreds	50-100	20-70	50	2
Research vs. Production lots	Unknown	30% to 70%	50%	40% to 60%	0%
Innovation Mission	High	High	High	High	Low
Research Mission	Yes	Yes	Yes	Yes	No
Processes	Yes	Yes	Yes	Yes	Yes
Project Completion	Yes	Yes	Yes	Yes	No
Group 3					
# of Wafer Starts/Yr.	<10000	<1000	<2000	<5000	>50000
Capacity use	Low	Low	Low	Low	High
Group 4					
Tool Availability	Yes	Yes	Yes	Yes	No
Engineering Holds	Yes	Yes	Yes	Yes	No
Metrics	Yes	Yes	Yes	Yes	Yes
Global Metrics	0 to 2	0 to 2	1	2	5+
Local Metrics	5	16	5	3	16 +
Lot Moves	Yes	Yes	Yes	Yes	No
Changes in Tool Setup	High	High	High	High	Low
Tool Redundancy	Low	Low	Low	Low	Yes
Tool Scope	High	High	High	High	Low
Automation	Low	Low	Low	Low	High

Table 4: Case Study Results

Again when we examine group three characteristics we see dramatic difference between HVSF and the MTHMLV facilities. Yet here again there are significant difference between the MTHMLV facilities. These facilities run from 10,000 to less than 1,000 wafer starts. Finally in group 4 we see again an extreme difference between MTHMLV facilities and the HVSF facility. Further there are significant differences within the MTHMLV community of facilities.

We see visually that multiple root technologies greatly increase production line complexity and generate huge tool compatibility and flexibility issues. This creates a work environment where tool scope rather than tool efficiency when used in any single technology process becomes the dominant characteristic for tool selection. Further, all HVSF firms use some form of metrics, including many that are tool based or local metrics. Moreover a recurring theme in all the MT-HMLV facilities was the view that a global wafer starts metric so important for HVSF facilities provided them no or little value. Finally, lot moves usually not seen as exceptionally important for HVSF facilities were seen as providing exceptional value to the operation of MTHMLV facilities.

The MT-HMLV facilities focused on flexibility, rather than standard product manufacturing efficiency like their HVSF counterparts. MT-HMLV individual processing steps are just as critical as those in HVSF but their integration measures take on new dimensions. For example, MEMS process times are often longer due to their use of silicon and other materials in both a structural and electrical manner rather than just electrically as in HVSF. Finally, the vary nature of structural material changes in bottom up nanotechnology provide process complexity issue never encountered in a HVSF facility.

The case study analysis showed us that the very nature of MTHMLV facilities were so far afield from HVSF that the simple transference of metrics utilized to operate HVSF were not going to be effective in MTHMLV facilities. More interestingly we found a great diversity of mission, scope and process activities within the MTHMLV facility. A characteristic we did not expect to find. We decided to further our understanding MTHMLV facilities through a directed questionnaire. We developed the questionnaire using Fowler [CC] questionnaire protocol in order to more deeply understand their utilization of metrics.

III.2 Questionnaire development and results

We developed a metrics based questionnaire with 16 quires and sent them to selected individuals at all four pre screened MT-HMLV and one HVSF facilities. We sent them to the HVSF facility as a matter of completeness. All of the respondents remain anonymous due to the sensitivity of their work assignments. We provide our survey results in Table 5.

The first question acted as a general introductory inquiry into the subject of metrics in a MT-HMLV and HVSF facilities. Four out of the five interviewees responded that they strongly agree with the use of metrics is an enormous benefit to the management of the facility. The lone stand out was neutral in the subject area and came from a MTHMLV facility. The second question asked if MT-HMLV metrics are highly borrowed from the HSVF industry. All of the respondents agreed or strongly agreed to the question. The third question inquired into the percentage of HVSF metrics that apply to their particular situation. Two MTHMLV respondents stated that the percentage of useful to them HVSF metrics were from 0 to 25%. The other two MTHMLV respondents answered with 26% to 50% and 51% to 75% and 100% respectively.

The next question concerned actual metric use and their effectiveness for the efficient operation of their MT-HMLV and HVSF facilities. Three MTHMLV respondents stated that they strongly believed little value was gained from their use, one MTHMLV responded with a statement that any metrics were better than no metrics at all and of course the HVSF was quite pleased with their use.. The next question is a sidebar of the previous in that it relates the application of metrics to establish value to the stakeholders of the facility. Again, the results mirrored the previous question with one disagree.

The next set of questions was designed to introduce the concept of global and local metrics. Question number six asked if HVSF metrics emphasized wafer movers. Four individuals strongly agreed with the statement, with one individual disagreeing. Question seven asked about lot moves and it was agreed and strongly agreed to that lot moves were used as a better performing metric than wafer moves in MT-HMLV facilities. Questions eight and nine dealt with HVSF's and the how the metrics stifle technology experimentation and how the HVSF's focus is metrics on single processes. In both cases, all five respondents agreed and strongly agreed to the proposed question.

The next two questions inquire about MT-HMLV's strategic intent and the need for new metrics when dealing with these facilities. All respondents agreed strongly to the strategic intent of a MT-HMLV are a multi-technology, multi-product, low wafer start facility. In respect to the need of new operational and strategic metrics, three out of the four agreed strongly to question, with the fourth individual also agreeing.

The next question was a departure from the previous style of inquiry. Each individual was asked to pick from a list or provide examples of their metrics that are non-traditional and used in their facility. Each respondent provided a different of answers to the question. The first individual reported that lot moves and the number of multi-technology based products were how their MT-HMLV measured performance. This is in correlation to the next respondent whom also mentioned lot moves, but added that process steps metrics were also important. The third respondent placed fab utility as a metric, whereas fab utility is the percentage of the facility that is being utilized to full capacity. The fourth respondent answered that patents and the number of research papers produced was a principal metric for the organization. The HSVF response was that wafer starts and yield is the most important metric.

Table 5: Metrics Comparison

Metrics	Innovation	R&D	Prototyping	HVSF
Job Completion	X	X		
Wafer Starts			X	X
Line Yield				X
Die Yield				X
ROI				X
Cost/ function				X
Labor	X			
Queue	X	X		
Cycle Times			X	X
Lot Moves	X	X		
Tool Usage			X	X
Patents	X			
Tool Alignment			X	X
Bibliometrics	X			

The next array of questions asked for a numerical value for the global and local metrics that each MT-HMLV used. For global (integrated) metrics, one individual answered 0 to 2 metrics were used; one had a response of 3 to 5 metrics. Very few global or integrated process metrics are being used by those interviewed with the exception of the HVSF, yet they all state a necessity for one that is accurate. Most suggested a metric move from wafer starts to lot moves. All five stated once more that they employ local or tool based metrics. Two of the fabrication facilities stated they utilized 16 or greater local metrics.

One of the individuals interviewed, listed the number of papers that are published and the patents that are applied for as their global metric. Some facilities still use these metrics over local or global style metrics. It is apparent that some MT-HMLV facilities still prefer this method of a performance metric. With patent or bibliometrics style measures, they do count for global or local metric measures and are difficult to place a value on for stakeholders. This is in direct contrast to the last question of whether or not global metrics would benefit the MT-HMLV and the stakeholders.

We have shown that MT-HMLV's and HVSF's are different by nature and require different metrics to operate efficiently. Further, we have shown that a great variety of metrics exists in the nature of the MT-HMLV facilities. The leads us to the development of not the right set of metrics for an MTHMLV facility but rather a model where a set of metrics are presented to MT-HMLV facilities managers from which they can select the metrics the meet the mission an operational realities of their facility. A model we name the MTHMLV facility Metric Selection Model.

IV. Model Development

All of the MTHMLV respondents recognize the importance of a metrics based management system for their facilities but stressed the need for a new and fresh approach. A metrics approach designed to both assess the strategic and operational effectiveness of a MT-HMLV facility and convey that assessment to others. We start this approach with the knowledge that metrics follow the nature of a fabrication facility and that fabrication facilities can be thought of in terms of capacity and capabilities. It is exactly in the capabilities and capacity realm that HVSF and MTHMLV facilities are so vastly different.

The misalignment of facilities based capacity and capabilities are at the crux of the problem of simply transferring HVSF metrics to MTHMLV facilities. MT-HMLV respondents recognize that direct application of HVSF to their facilities did not assist in improved operational effectiveness. Nor did they effectively convey their strategic value to their stakeholders. In fact, in many cases, the use of HVSF metrics at MTHMLV facilities actually hampered their ability to obtain resources from stakeholders as well as run their "shop" effectively. Further due to the wide variety in mission and operational capability in MTHMLV facilities it seemed doubtful that one set of metrics would be the varied needs of these facilities.

Indeed, MTHMLV success cannot be measured by the HVSF rubric of yield. Yet yield is always important in these facilities and often getting any yield might be considered a success. Yield must be seen in the light of the mission, capabilities and capacity of the facility. The value of MT-HMLV facilities lies in their ability to produce new products and processes, critical products, provide a facility that embraces iterative lot runs utilizing nontraditional process technologies and becoming the cradle of innovation at the convergence of technologies. Their ability to prove out product design through design iterations based on real manufacturing feedback and their ability to take an embryonic technological process and create a stable manufacturing platform. Indeed ROI is not enough.

Throughput measures are important for any manufacturing facility. Wafer starts are the "Defacto" throughput standard for HVSF yet the more effective throughput measure for the vast majority of MTHMLV facilities is Lot moves. Lots are the true unit of analysis in the MTHMLV facility where each lot will require tool recalibration and differing WIP routing. Lots in these facilities can be comprised of a little as a single wafer fragment. Yet to say that wafer starts are not valuable to MTHMLV facilities would be in error.

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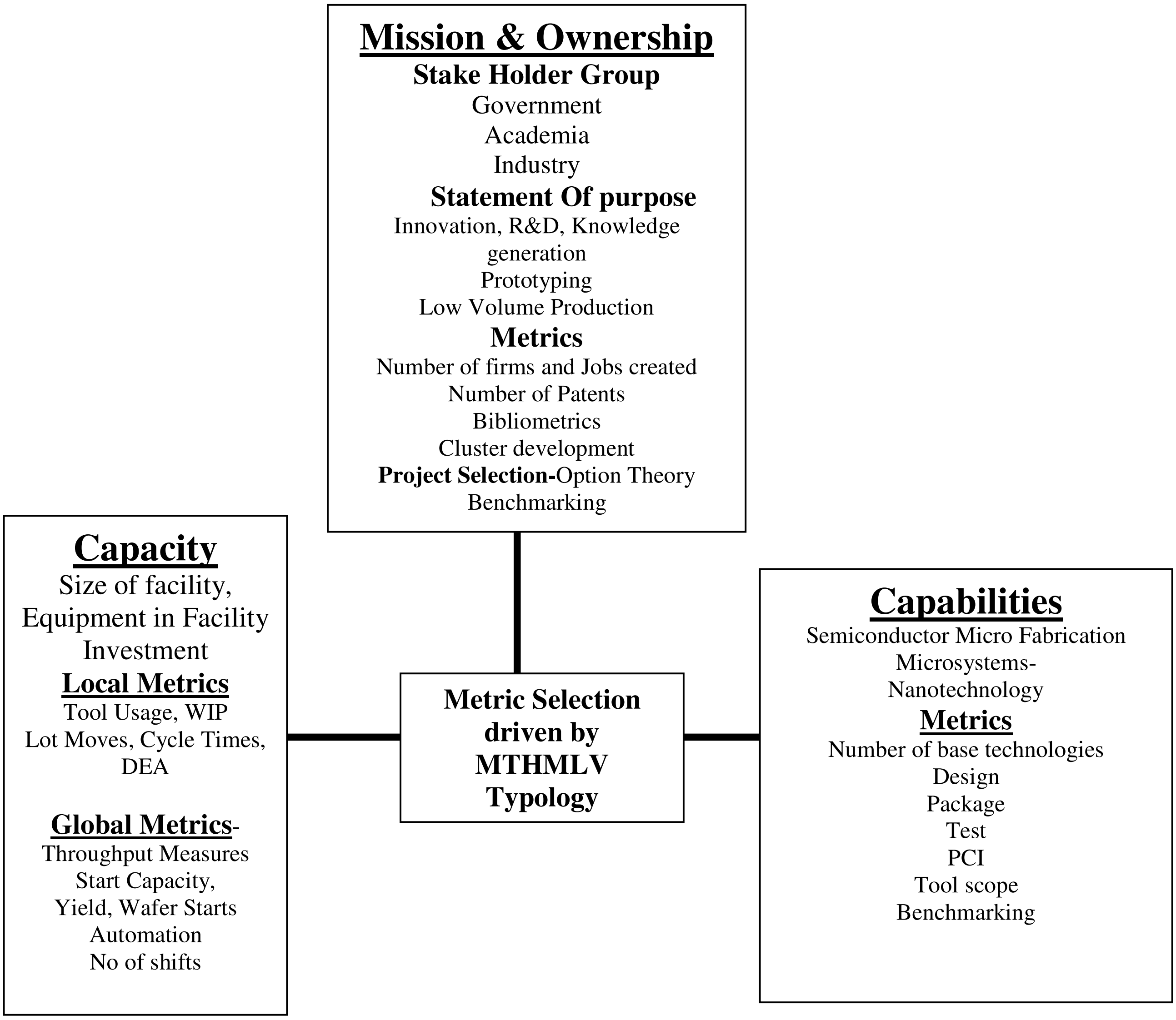
These realities suggest the development of a number of metrics from which a subset can be utilized for the specific needs of a particular MTHMLV facility. MTHMLV specific metrics designed to directly support the managerial requirements generated by the desperate missions and capabilities of MTHMLV facilities. We have developed a model, the MTHMLV Metrics Selection Model, which is designed to assist these facilities to accurately assess their operational and strategic effectiveness and value based on the mission and capabilities inhering in their facility.   Our model builds on Hayes and Wheelwright separation of manufacturing facilities into 4 distinct categories.

The realties in the MT-HMLV world is that these facilities are not distinctly in any of these categories. Rather MT-HMLV facilities occupy more of a continuum role where they provide value in all of these sectors. They require a metrics management approach that is flexible enough to meet the needs of all 4 types of facilities.

We have developed a 3 factor approach for a firm's investment and operation of a MT-HMLV facility. Those factors are mission focus, capability scope, and capacity. We operationalize each of the factors in accordance with the nature of MT-HMLV facilities.

Figure 6 MT-HMLV Metric Selection Model



We depict our HT-HMLV Metric Selection Model (HT-HMLV MSM) framework designed to be more relevant for MTHMLV metric selection. We began by developing a 3 factor derived from our literature review and case study analysis. These factors are (1) Mission and Purpose, (2) Capacity and (3) capabilities.

Mission and Ownership. We operationalized mission and ownership as follows. First we agree with Hayes and Wheelwright (***)_ that the nature of the firm dictates the type of managerial metrics required Then, we define these facilities nature through its mission and ownership. Next we develop a set of metrics that might be selected to demonstrate strategic value of the facility through a variety of metrics that meet the stated mission and speaks to the ownership group.

Our MTHM:LV facility are tasked with a variety of mission including; increased innovation, job and regional wealth creation, R&D, Prototyping, and low volume production. We individually operationalize these factors. We use bibleometirc measures as the metric for R&D, knowledge generation and innovation. The bibleometric units are Innovation awards, journal articles, citation rates and licenses as their metrics. Further some MTHMLV facilities are tasked with the necessity to produce low volume products usually tied to a specific stakeholder group. Here we utilize capacity measures. Fineally most ownership is focused on regional development, jpob and wealth creation. Here metrics are numbers. Number of employees, firm attraction and spinouts.

Capacity

We considered and cataloged the different types of business units into three distinct, but separate groups in the model. The first group is industry partners. They include commercial, for- profit research and development labs. The group also includes R&D division of a firm. The focus of both entities is to create innovative products for the commercialization in a timely and cost effective manner. Next are governmental partnership faculties. These include federally fund national labs, NASA and Department of Defense Research Labs. Their ambition is to seek new approaches to challenging technical issues and produce a product using nonstandard methods in extremely low volumes. Last, are those labs, which are in academic situation. Each of these units requires a distinct managerial style, which influences the outcome of the HT-HMLV MSM. The management approach of a federal funded national lab is quite different than a profit research and development MT-HMLV facility. Thus internal corresponding variables must be taken into consideration.

The inclusive mission of each group is unique also. Government relies on the number of patents, job formation and strategically, a firm and stable foundation on which to base new applications of gain knowledge. Academia is different in the fact that it revolves around knowledge creation and education of future engineers and technologists. In this situation, patents are a primary metric for them, with economic outcomes being secondary. Industry is different from both previous entities in that fact that business units seek stable processes in order to generate products. Examples of such metrics would include project selection and lot moves.

Next is the block containing the term Statement of Purpose. The use of the expression Statement of Purpose is linked to the modified Hayes and Wheelwright model. The model shows the relationship between type of inquiry and the production of products or services. As the progression from pure research to applications to product takes place, there are divergent methodologies that are used in HT-HMLV facilities and thus differing metrics. For example, an applications element differs from a R&D unit. Moving diagonally down the line, a different approach is used in prototyping and entirely different tactic in low volume production. Each of the four steps in the modified Hayes/Wheelwright model requires an individual structure of metrics in order to achieve the desired outcome and success.

The area of Strategic Metrics is perhaps the best known and also the most studied. As MT-HMLV facilities act as engines of innovation centers of new product and process creation, these centers are at the forefront of cutting edge technology. To provide support for the decision making process that are occurring in these centers, the proper use of metrics are needed. We have identified three core metrics for the block. They are decision-making processes, application of metrics and metric evaluation. The first step here is the decision-making processes. Project selection permits both a macro view of the venture into manageable part quantities and a temporal value placed on the project. The use of option theory can be used to an advantage in R&D operations. Options provide not only a monetary value, but a temporal assignment to objectives, which must be meet or the project is terminated. If the objectives are met, then the project continues to the next phase. Using option theory also provides additional value since the approach attempts to provide a technological outlook for the future, thus projects can be accelerated or slowed to fit the outlook. Once a project is selected, specific global and local metrics can be chosen and adopted to fit the requirements of the each individual endeavor. Intertwined with project selection is the choice and evaluation of metrics. As the project evolves, the metrics must evolve also. Metric selection and evaluation should be consistent and diligent during the process.

The block adjacent to strategic metrics is Operational Metrics. These are the best known, but least understood classification of metrics. Operational metrics are bifurcated into the Global and Local metrics portions of the model. Starting with the Global portion, the approach for MT-HMLV is founded on the Lot Move concept rather than the Wafer Start Concept. Cycle times and the subset metric of Lot Moves are best used in MT-

HMLV faculties. These metrics best describe the performance nature of the project. Trying to predict a schedule in an unpredictable situation is difficult at best. With numerous incidences as engineering holds, hot lots and project termination accounts for temporal disturbances. Lot Moves provide information in numerous methods. Completion of a particular section of a project, time to complete and holds are all accounted for in lot moves, as well as tool breakdowns. Cycle times can be used, however they provided less information as they describe only the temporal added value input to an output to an individual process.

One of the universally used metrics in HVSF's is start capacity. Start capacity is the measurement of wafers that can be started in a particular time, usually at the beginning of a tool operation. This metrics helps locate bottlenecks in tool operation, while increasing throughput. However in HT-HMLV operations, nothing is standardized and each operation is different. The use of this metric is not suitable for HT-HMLV due to the lack of standardization of products, lack of automation and re-tooling after specific operations.

The Local Metrics portion of Operational Metrics is the management approach is based on tool scope rather that tool efficiency. We must trade efficiency for scope, which provides an efficient low volume production facility with metrics, whereas high volume foundries metrics are so inefficient. The difficult portion is not the identification of metrics, however the correct metric for the application. A common approach is the use of one single metric. One metric for the entire operation is not practical and provides information to operations. The single metric approach is by human nature the one that provides the greatest self-satisfaction with the least amount of input. Countering this is the diligence use of numerous metrics, which tend to cloud the purpose of metrics and does not convey information in a distinct and clear way.

The Local Metric approach we have chosen for MT-HMLV's are founded on tool usage and tool capacity. The ability to use one tool for different operations is imperative to the operation. Flexibility is the underlying principle and effects key metrics. In MT-HMLV facilities the flexibility of tools is crucial to the operation stability. The ability to change or re-tool for explicit operation is a normal in day-to-day operations. The metric thus chosen here is tool usage. Even though tools have to be flexible in the environment, the operational throughput for each tool has to be recognized and account for. Tool Usage allows flexibility, but there still a need for whether or not a tool is operating at peak efficiency. Here the metric chosen is tool capacity. Tool capacity allows operations management to view if the processes that are required are meeting expectations

Yield is a critical dimension in HVSF's. The operations that are performed must achieve a particular yield in order for the HVSF to remain competitive in today's market place. With large capital investment and the decreasing price for standard semiconductors chips, the need for yield is critical in high volume situations. However, the use of yield is problematic in MT-HMLV facilities. With the design of new products, comes an engineering challenge that must be overcome. The use of yield in such a situation would be misleading to the stakeholders involved. Perhaps a better measurement of outcome is the application of a Process Capability Index. Process Capability Index (PCI). PCI is best described as using a sigma style process. Using the desired specifications as a norm, the project can be mapped using three or six sigma for yield and/ or quality control. Once the mapping takes place, outliers can be identified and if the situation warrants, corrections made.

Both the operation and strategic metrics can make use simple statistics. Choosing of what works and what does not, is the foundation of metrics and their applications. However, there still is a requirement to compare individual processes and their outcomes. The Metric Selection Model is based on a Data Envelope Analysis methodology. The use of Data Envelope Analysis (DEA) was conceived for business applications, but can be adapted to other applications. The basic premise for DEA is to create a framework of Decision-Making Units that are benchmarked either internally or externally. In metrics and the use of statistics in those metrics, a statistical approach is characterized as a central tendency approach and it evaluates producers relative to an average producer. In contrast, DEA is an extreme point method and compares each producer with only the "best" producers. Those above the limit are efficient and those below the parameter line are losing efficiency.

The strengths of DEA include that it can handle a multitudes if inputs and outputs and doesn't require an assumption of functional form relating inputs to outputs. Also, with input and output variables, they do not have to be necessary related in function. This provides a simple weighted formula to measure parameters. In regard to MT-HMLV facilities, both internal and external practices can be examined and reviewed. The limitations of DEA are an extreme point technique and "noise" can cause fluctuations in measurement. DEA is able to estimate the relative efficiency of a DMU, but converges slowly to an absolute. Lastly large problems are difficult without specific software and statistical hypothesis tests are difficult.

With a DEA analysis, both the maximum and minimum performance parameters are identified and plotted. Once this is occurs, then that metric can be intergraded into a larger model for each process or tool use. The idea is to keep the system simple and clear. All three categories of metrics: Operational and Strategic metrics can be measured and placed into the framework of the model. Once each tier is measured they can be compared to others. The beauty of DEA is that it can be used internally or externally for measurement.

The HT-HMLV facilities block deal with three core areas: investment, size of the facility and number of personal involved or more specifically the number of shifts. The term investment deals with the amount of financial resources that were allocated. The more allocations that are made toward a facility usually means that more advanced processes that can be achieved. More importantly, than just square footage is the capital investment of the current lineage of tools and equipment to perform the needed work involve. As the search for technology advance, there must be a continuous investment in those tools. Size of facility was another factor that was considered. With larger facilities comes the convenience of more tools and the duplication of tools. This allows the practice of parallel procedures that reduce WIP times greatly. The last item involved is the number of personal that are employed at the MT-HMLV facility. As the number of personal grows, which include engineers and technicians, the capability of the business unit also grows.

Competencies are the principal areas in which the business unit is involved. We listed three areas' of which MT-HMLV facilities are involved with. Those areas are semiconductors fabrication, micro mechanical electrical systems (MEMS) manufacturing and nano technology development. Each business unit requires a different approach to the subject of metrics. A semiconductor R&D facility and its process are going to be different that those that are involved with nano technology. Whereas, semiconductor and MEMS fabrication have similar attributes, although the MEMS creation takes multiple of steps that the semiconductor process does not have to perform.

Using the Metric Selection Model is simple and forward. By knowing the organization, how it operates and the mission of the institution, the model provides a foundation on which to build a managed approach to the problem of metrics in MT-HMLV facilities. For example, innovation and design centers are focused on creation of processes. By using advanced materials and techniques, these centers are attempting to solve tomorrow's problems. However, by holding these centers to the same metrics as HVSF or even prototyping MT-HMLV facilities are consistent with the model. Innovation and design centers require tool flexibility and the metric lot moves. Research and development overlays the innovation centers in the fact that lot moves and tool flexibility remains the chosen metrics. However, the search for a stable process is on going, which leads to prototyping. While lot moves is metric that is used here, consideration must be made to breath of capacity. Low production facilities are going to use lot moves and tool usage, since the transition has been made though innovation to production. Each stage of the process and facility, must realize their own managed approach to metrics.

VI. Conclusions

Building upon the current literature, we examined the differences in metrics for Multi Technology, High Mix, Low Volume (MT-HMLV) and High Volume Silicon Fab (HVSF) facilities. Most of the metrics in place now in MT-HMLV facilities are based upon those of their counterparts. While these metrics work well under the automated processes that are universally used in semiconductor facilities, they don't fit the essential needs for MT-HMLV facilities. Given the information that was proved by the questionnaire, MT-HMLV's prefer to use lot moves as the primary metric in their fabs. All respondents also mentioned that given the current set of metrics under use today that innovation is stifled and this subject is critical to the continuing improvement of technology.

Using the questionnaire as a foundation for our research, we constructed a framework of a managerial systemic approach to the use of metrics in MT-HMLV facilities. The model known as the Metric Selection Model (MSM) provides a framework for a systemic approach to metrics. By classifying the competencies, organizational type and purpose of each business unit, different metrics and their subsequent structure and methodology can be utilized. By separating the uses of metrics in three classifications: R&D, Local and Global, different metrics can be used for the situation. Option theory for project selection, tool usage and lot moves are considered the best metrics to use. With the use of DEA and PCI, individual operations can also be scrutinized. We also looked at the use of some common metrics for HVSF's such as wafer start and yield and showed the ineffectiveness in R&D settings. It is the hope of this report that further investigation is undertaken into the area of metrics for MT-HMLV facilities.

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