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Financial and Operational Survey of 12 Major University Nanofabrication Facilities: A Benchmarking Study

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Efficiently running a major nanofabrication research user facility within the framework of a university is a daunting task. Operational costs, staffing, training, safety, and the diversity of the research, faculty, and users are but a few of the challenges facing the management team. This article reports on a subset of metrics used to characterize such user facilities, based on an extensive survey of 12 major university laboratories. Data relating to such factors as laboratory staffing, operating costs, subsidies, cost recovery, tuition, comparative tool rates, hours of use, and populations are summarized and reported on in the context of determining a reasonable measure of an efficient laboratory operation.

Keywords

Laboratory, efficiency, nanofabrication, research, finances, university, operations, benchmark

Every laboratory management team has the same problem: safely and efficiently delivering cost-effective goods and services to a highly diverse population of users with vastly divergent and conflicting needs.

In the marketplace, the price and quality of goods and services is determined, in large part, by the consumer. Consumers vote with their pocketbooks by selecting goods and services based on comparative shopping (price, perceived value, and convenience). The free market provides the consumer with a general sense of satisfaction, since consumers derive fulfillment from receiving a good deal and perceive that they have been treated fairly and with respect.

In an academic environment there can be little comparative analysis because users cannot readily "shop around." Users of academic laboratories have little recourse but to use the existing facility, leading to a general sense of vulnerability and loss of control regarding their research or business goals. The result is an uncomfortable, and mutual, state of dissatisfaction and uncertainty on the part of both the users and the staff providing the services, which can lead to hampered communications and poor performance of both the user community and the facility itself.

This general feeling of dissatisfaction may be traced to several tangible factors: (1) unreasonable or unrealistic user expectations, (2) universal access to tooling, preventing clear and relevant characterization metrics, (3) empathy mismatches between the service staff and the user base, (4) undercapitalization, (5) unsustainable tool-sets (tools that cannot pay for their operational costs), and (6) understaffing. Thus, it is clear that without data there can be no real understanding of what is reasonable and what is necessary or achievable. Properly addressing potential problems, site-to-site, is the key to a successful business and research enterprise and thus the motivation for this study.

Therefore, this survey was devised primarily to provide all interested parties (researchers, management, users, administration, and support staff) with a well-vetted set of data upon which a constructive discourse may be established regarding operational costs, tool rates, staffing, safety, and basic efficiency guidelines of a complex nanofabrication facility. The secondary intent of the survey was to establish a set of data that would enable the stakeholders to evaluate the expense side of the equation to balance the cost side of the equation, which is typically the focus of most discussions. The authors have constructed a comprehensive matrix of data that covers all aspects of the cost of doing research, from lab fees to tuition to indirect cost policies.

Presenting the full data set is impractical given its sheer size; therefore, only subsets of the data are provided in this article. Although not statistically valid due to the small number of data points [12 points at most for each metric or figure of merit (FoM)], such statistical measures as average, median, maximum, and minimum will be used to "parameterize" a subset of the entire data set to allow for a general disclosure of the results.

Motivation

The intent of conducting a national benchmarking survey of 12 major university nanofabrication research laboratories was to establish a set of financial and operational guidelines to enable a reasonable discourse among all interested parties with a stake in the success of the facility. Users, staff, and management would then have a common frame of reference on which to evaluate the value received from or delivered to their own facilities.

A further motivation was to generate a set of metrics that could be used to justify the operational costs of such complex and expensive facilities. That is, when establishing usage rates and cost structure it is critical that the expense side of the equation is well considered. Many "value" questions must be posed and answered to establish the correct balance of expense and cost. Therefore, the framework of a national benchmarking survey provides the consumer (researchers and businesses) and the supplier (staff and institutions) with a sense of fairness needed to keep the focus on the research and not the cost of the facility.

Methodology

The study was conducted twice (in FY 2010 with FY 2008 data, and FY 2012 with FY 2011 data). Results of the two studies were comparable. The data reported in this article (Tables 1-8) are from FY 2011, except where noted.

There are two basic challenges with this type of survey: (1) relevance of the conclusions, and (2) fidelity of the data.

Relevance is an issue because of the immense diversity of laboratories, laboratory users, and the research performed. Answers to specific metrics may not be available or comparable due to local methodologies or accounting practices, depending on the facility.

Fidelity is an issue because of the highly subjective nature of the source data itself (the data produced by each site). In addition, the benchmark data are dependent on an accurate accounting of, and response to, the definition of the metrics.

To address these two issues, a methodology was created based on direct contact with the individuals responsible for the source data. That is, the appropriate people and skill sets (financial, technical, and operational) were identified at each facility via direct interviews at each of the sites. Follow-up conference calls and e-mails provided the authors with comprehensive and high-fidelity data that are believed to serve the intent of the benchmarking survey.

Following is a description of the overall methodology and boundary conditions under which the authors operated. The methodology was divided into the following categories: (1) Metrics, (2) Site Selection, (3) Iteration and Feedback, (4) Openness, (5) Statistics, and (6) Data Gathering and Dissemination.

Metrics

The first step was to select a series of metrics that would represent the operational and financial baselines of a range of laboratories serving similar constituencies. Such items as operational costs, staffing, and cost recovery seemed fairly clear at first but in actuality required extensive discussion to ensure accuracy. In the end, more than 120 metrics and 20 FoMs were selected to characterize each facility and site comprehensively.

Metrics were grouped logically: (1) Facilities, (2) Cost Recovery, (3) Expenses, (4) Lab Usage, (5) Typical Tool Costs, (6) Cost of Research, (7) Demographics, and (8) Policies.

FoMs were also grouped to enhance clarity: (1) Support, (2) Financial, (3) Ratios, (4) Users, and (5) Salary.

To minimize ambiguity, each metric and FoM was precisely defined and integral to the data. Jargon and the vernacular of each site were eliminated or defined in uniformly used terminology.

Site Selection

Selection of the laboratories was based on several criteria: (1) physical size, (2) geography, (3) reputation, (4) peer stance, (5) National Nanotechnology Infrastructure Network (NNIN) participant, (6) faculty exposure, and (7) core research and technical competences.

The laboratories selected were located at the following universities: Massachusetts Institute of Technology (MIT); University of Michigan (UM); Cornell; Purdue; Harvard; Georgia Institute of Technology (GIT); University of Minnesota (UMN); Stanford; University of Washington (UW); University of Illinois at Urbana-Champaign (UIUC); University of California, Berkeley (UCB); and University of California, Santa Barbara (UCSB).

Iteration and Feedback

The key to optimizing the fidelity and relevance of the data was to iterate continuously on the responses provided by the individual sites. That is, the data were not gathered, entered into the database, and then forgotten. As the data set took shape the authors would analyze and compare the data, then go back to sites already interviewed to obtain better clarity on previous responses. The metrics themselves also went through this process. If it was clear that a metric would better represent the entire data set (based on new data), the data set would be altered and the previous sites would be re-interviewed to update their responses. In addition, as new sites were visited, additional metrics were added to improve the relevance of each site to the overall relevance of the entire data set.

Openness

The key to getting all the sites to divulge what could be considered sensitive data was to be open. Revealing the complete workings of the University of Michigan Lurie Nanofabrication Facility (LNF) encouraged other sites to disclose their information. For all sites, it was stressed that the data would be openly available upon request for those with a reasonable need. Such requests could come from faculty, users, or administrators. While participating sites would not be anonymous, the site-specific data would be redacted to conceal the affiliation with any given data set.

Statistics

Despite the best efforts of the authors, there remains some subjectivity. Apples-to-apples comparisons are difficult at best. To aid in the comparison process, the authors selected and calculated four statistics: (1) maximum, (2) minimum, (3) average, and (4) median. The selection of the maximum and minimum are obvious. Since there are so few data points, the median is a better measure of the data than the average in some cases. In addition, the median prevents outlier points from adversely impacting the result. By reviewing the average and the median, readers may reasonably compare their own data to that of the survey sample.

Data Gathering and Dissemination

Completing the survey at each site was a non-trivial undertaking. Site personnel spent considerable time researching their data and working with the authors to assure that the data generated were consistent with the overall benchmarking data. The primary incentive for each site's participation was access to the completed survey and the un-redacted data set. All participating sites would receive the raw data (as a spreadsheet) if requested. Non-participating sites requesting data would receive a PDF file with redacted data to eliminate site association. The value of that incentive to participate became apparent as the survey progressed.

Data

The complete survey results are too numerous to include in this article. Therefore, a small sampling of each major category, with data from the 2011 survey, is provided (Tables 1-8). Since some of the data collected in the 2008 survey was not collected in the 2011 survey (due to workload and time constraints) the 2008 data are used as noted. The 2008 data primarily involve the demographics of the particular institution rather than the operational and financial data from any of the sites. The entire data set with the institution names redacted is available by contacting one of the authors. Any participating sites may request the raw data directly. The data of particular interest are highlighted in red and represent the diversity of each site and its user base as well as its funding model. In addition, the University of Michigan (LNF) numbers are presented as a reference to aid in evaluating the data from the other institutions.

Table 1. General Facilities.

Metric	Facilities				
	Max	***Min***	***LNF***	***Median***	***Average***
Gross (ft^2)[a]	25,000	8,184	18,000	15,000	15,556
Staffed Hours (h)[b]	105	40	60	60	63
Hours of Operation	168	62	168	–[c]	156
Number of Major Tools	**167**	**40**	120	120	115

a. Entire footprint of cleanroom [under filter (the cleanroom proper) and service aisles (not including subfabs)].
b. Number of hours per week the laboratory is staffed. Maximum possible is 168 hours/week.
c. All labs but one are at 168 hours of operation — median of no meaningful value.

Table 2. Cost Recovery.

Metric	Cost Recovery (K)				
	Max	***Min***	***LNF***	***Median***	***Average***
Internal CR ($)[a]	3,278	659	1,339	1,658	1,761
External CR ($)[b]	**3,500**	**102**	624	624	899
Subsidy ($)[c]	**3,210**	**600**	1,800	700	1,001
NNIN ($)[d,e]	1,200	150	348	348	538
Total ($)	**7,130**	**2,477**	4,415	4,784	4,846

a. Cost recovery from all internal academic users.
b. Cost recovery from external non-academic users.
c. Revenue or support from non-user-based sources (state, college, industrial affiliates).
d. NNIN statistics are from NNIN sites only.
e. NNIN funds directed to user support — salaries only.

Table 3. Operating Expenses.

Metric	Expenses (K)				
	Max	***Min***	***LNF***	***Median***	***Average***
Operations ($)[a]	3,956	660	1,726	1,706	1,903
Salaries and FB ($)[b]	2,036	248	1,872	1,476	1,413
NNIN ($)[c]	1,400	450	652	652	803
Ancillary ($)[d]	3,210	0	43	170	477
Service Contracts ($)[e]	675	0	329	100	285
Total ($)[f]	**7,010**	**2,425**	4,428	4,739	4,788

a. All user-related expenses.
b. Staff and fringe benefits salaries paid directly from user fees.
c. NNIN funds directed to user support — salaries and equipment.
d. Staff salaries that are not funded by user revenue but support laboratory.
e. Facilities and tool support provided by external suppliers (represents labor and material).
f. Operations, salaries, NNIN, and indirect cost (IDC) recovery from externals.

Table 4. Staffing – Headcount and Full-time Employees (FTE).

Metric	Staffing Headcount (FTE)				
	Max	***Min***	***LNF***	***Median***	***Average***
Technical[a]	21 (21)	8 (8)	16 (13.8)	14 (12.3)	14 (11.7)
Administrative[a]	8 (4.9)	0 (0)	8 (4.9)	3.5 (1.3)	3.2 (2.1)
IT[a]	3 (2.5)	0 (0)	1 (0.4)	1.5 (0.7)	1.4 (0.9)
Total[b]	**66 (37)**	**15 (14.5)**	42 (27.3)	32 (24.8)	34.3 (24.5)

a. FTE based on funding derived from user fees only.
b. Based on all sources of funding (NNIN, ancillary, and subsidy).

Table 5. Lab Usage.

Metric	Lab Usage				
	Max	***Min***	***LNF***	***Median***	***Average***
Users[a]	801	242	444	508	529
Faculty[b]	130	52	72	72	78
Lab and Tool Use (h)[c]	**160,640**	**34,400**	125,200	121000	104,576

a. Internal and external academics and non-academics.
b. Internal faculty at local institution.
c. Internal and external.

Table 6. Tool Costs.

Metric	Tool Costs				
	Max	***Min***	***LNF***	***Median***	***Average***
A DRIE ($)[a]	1,472	360	800	800	889
NA DRIE ($)[b]	5,182	1,048	1,048	2,400	2,557
A EBL ($)[c]	2,777	476	768	971	1,178
NA EBL ($)[d]	**13,654**	**992**	992	4,080	4,383

a. Academic (A) rate for deep reactive ion etcher (DRIE); 4 entrances and 16 hours tool time.
b. Non-academic (NA) rate for DRIE; 4 entrances and 16 hours tool time.
c. Academic rate for electron beam lithography (EBL) tool; 4 entrances and 8 hours of tool time.
d. Non-academic rate for EBL; 4 entrances and 8 hours of tool time.

Table 7. Subset of Cost of Research Metrics (FY08 / FY11).

Metric	Cost of Research				
	Max	***Min***	***LNF***	***Median***	***Average***
Tuition (K$)[a]	29.5	7.0	16.0	14.1	17.1
GSA Stipend (K$)[b]	2.9	1.6	2.0	2.2	2.2
Total for GSA (K$)[c]	**88.9**	**37.4**	60.8	62.7	64.1
MEMS Fabrication (K$)[d]	6.6	2.3	2.3	3.3	4.1
Hourly Lab Cost ($/h)[e]	**82**	**35**	35	44	52

a. Tuition charged to a sponsored research grant or contract (FY08).
b. Monthly stipend for a Graduate Student Assistant (FY08).
c. Total costs for a Graduate Student Assistant charged to a sponsored research grant or contract (FY08).
d. Purdue study evaluating the cost of making a pressure sensor[1]. Stanford study (UGIM 2012) disputes these numbers [2]. References 1 and 2 illustrate the difficulty of estimating actual costs.
e. Total lab expenses divided by total lab and tool time (FY11).

Table 8. Figures of Merit (FoM).

Metric	Figures of Merit (FoM)				
	Max	***Min***	***LNF***	***Median***	***Average***
Tools / Staff [a]	8.3	2.81	4.4	4.4	5.03
ICR / Faculty (K$)[b]	39,967	10,138	18,597	18,597	22,351
ICR / TCR (%)[c]	**70.4**	**26.8**	35.6	38.7	45.1
ECR / TCR (%)[d]	**68.4**	**10.0**	16.6	22.6	27.8
S / TCR (%)[e]	**61.0**	**0.0**	47.8	19.7	27.2
SFbUF / TOC ($)[f]	44.9	5.3	42.3	35.7	31.9

a. Major tools divided by all support staff (regardless of funding source).
b. Internal cost recovery per internal faculty member.
c. Ratio of internal cost recovery to total cost recovery.
d. Ratio of external cost recovery to total cost recovery.
e. Ratio of subsidy (all sources) to total cost recovery.
f. Ratio of salaries funded by user fees to total operating costs.

Discussion

This study (FY 2011) took nearly a year to complete. The FY 2008 study took more than a year to complete. The authors invested more than 300 hours and visited 12 sites across the country. The study also required approximately 2–10 additional man-days from the cooperating sites. This investment in time and money was difficult to justify initially, but the authors were able to gain additional support from their administration to complete the study as the value of the data became apparent.

As the study progressed, the scope broadened. Originally the intention was to benchmark the cost of operating a nanofabrication facility but soon was expanded to include the total cost of research. That is, what was the total cost to a research faculty to support a student in the laboratory? That calculation would include the entire cost of a graduate student assistant (GSA), not just the cost of that GSA in the laboratory. This small change increased the relevance of the study tremendously. The data now have far more appeal to the administration since the data comprehensively displayed the total costs of research and not just those of an individual laboratory. In addition, student and faculty demographics of the institutions were included to assess the potential for increases in the user base and to broaden the appeal of the study to an even wider audience.

When looking at the entire data set, numerous quandaries arise. For instance, the data appear inconsistent at times. At face value and without a contextual framework the data seem conflicting at best. For example, a lab with more users should have higher operating costs but not proportionately since there is a base operating cost regardless of the number of users. Thus, with more users tool utilization increases and therefore lower hourly rates should follow, but the data indicate otherwise. We believe this is due to market forces dictating rates, especially in the case of non-academic external users. The bottom line is that there are no simple "rules of thumb." The data need to be reviewed carefully in the context of each site, and site-to-site comparisons should be done judiciously.

The data are also somewhat revealing in that there are broad ranges among the individual sites for many of the operational and financial metrics. The authors, however, still believe that the overall goals and objectives for the sites are very similar in many ways, particularly regarding research objectives. Thus, within the proper framework, comparisons may be made that are very helpful to decision makers.

Conclusions

After nearly a year of gathering and verifying the data to assure the best possible fidelity, it is time to look closely at what the data are telling us. Questions that may be answered by analyzing the data include:

- Are we running the laboratory as efficiently as possible?
- Are we providing our users with the best possible value for their research dollar as an institution?
- Are we capitalizing on our potential internal user base?
- Are we fully utilizing the staff to maximize tool and customer support?
- Are our recharge rates comparable and fair to our users?

Each site should look at the data and assess these questions for itself. Without the actual context of the site as an overlay to the data, the conclusions will not be relevant or useful. In addition, as each site reviews its data relative to the entire data set, the authors believe the sites will need to "reinterpret" their inputs if they see they are not competitive. This is where follow-up work could be very helpful to the overall data set.

An important consideration is whether the survey effort should continue. If so, how? The authors would be willing to continue the process but that would require the support of the other sites. A standardized form of the data set would have to be determined, and a control site would be needed. The authors recommend that a standardized format be adopted by all the participating sites and that we all meet at the semi-annual University/Government/Industry Micro-Nano (UGIM) conference to exchange and tabulate the data. This would reduce the cost and effort to any one site and assure a more homogeneous data set.

The data clearly indicate two apparently diametric observations: (1) how similar the labs are in operations and finances, and (2) how significantly different they are regarding their approach to addressing the needs of their users. That is, many similarities between labs were found while the ranges between the labs were, typically, large. This diversity underscores the difficulty in creating a benchmark data set that is useful and accurate. Each site faces similar problems of cost control, staffing, funding, and supporting the correct mix of technologies, but they all seem to find their own niche solution (which drives the staffing count as well as the budgets). This point is underscored by data found in Table 7 and the two cited references.[1,2] In the Purdue study, the cost of fabrication was calculated by a simple survey and follow-up inquiries. The results were tabulated and presented at UGIM 2010.[1] The conclusions were disputed by several of the participating sites, and Stanford presented data at UGIM 2012 that disputed the finding of the Purdue team.[2] This example illustrates the problem with comparing site-to-site capabilities and costs unless the research team spends considerable time drilling down on the question it is attempting to answer.

Moreover, this is an expensive game played with high-stake bets for jobs, reputation, and the success of an institution's research community. There is a minimum investment for any institution wishing to produce world-class research spanning a broad spectrum of fields of interests, and a minimum cost for sustaining such facilities.

A final consideration when evaluating costs is that the choices made by the users are critical. That is, if users choose to work in a field that requires many hours of electron beam lithography (EBL) time, then their costs will be high regardless of where they perform the work. This study illustrates that cost recovery (the supply-side of the cost equation) is controlled, in large part, by a facility's efficiency, but the users (the demand-side of the cost equation) control their use of the facility. Therefore, the users have at least as much control over their costs as the facility (based on the users' choice of topic). For all the sites the expectation to deliver complex processes and tools at a reasonable price is a given. Conventional wisdom offered by many users about their high research or business costs is the cost recovery rate of the fabrication facility. The data illustrate otherwise. The ultimate responsibility for cost is, therefore, borne by both the users and the facility offering the services. Thus, each must approach the problem cooperatively if both are to succeed.

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