Astro2020 APC White Paper

Observatory Operating Costs and Their Relation to Capital Costs

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Introduction

Observational astronomy has long faced a challenge in balancing the costs of constructing observational facilities and those associated with operations. In both the public and private observatory domains the source of funds for construction and operations are largely separate and it has often proven difficult to secure the resources needed to sustain operations of front-line facilities following the end of construction. Even when operations are well supported, funding for new instrumentation and renewal of infrastructure following the first decade or two of operations is challenging. Ground-based astronomy supported by the National Science Foundation faces the further challenge that operating funds for facilities are drawn from the same budget that supports individual investigator grants. This tension between the need to allocate limited resources between facilities operations and grants, when both are needed to advance our science, is acute and will surely influence thinking about construction of observational facilities in the coming decade.

As observatories and instruments become larger and more complex, their associated operations costs grow. However, the scaling between capital and operations costs is by no means clear, either from first principles or from anecdotal experience. In this short APC white paper we present information for currently operating facilities and estimated operational and capital costs for future facilities to stimulate informed discussions on the topic of operation costs. In particular we address a commonly held perception that annual operations costs are a fixed fraction (e.g., 10%) of an observatory's capital cost, and examine the actual fractions for today's operating observatories. This white paper does not address how we as a profession balance operations budgets with other needs; rather we attempt to bring accurate information on operations costs and their relation to capital costs to this important discussion.

Capital Costs for Ground-Based Observatories

A number of authors have attempted to compile the construction costs of ground-based optical/IR telescopes and to put them on a common basis. This is a necessarily inexact process. Inflation corrections must be applied to telescopes built at different times and corrections must be made for the differing scope from one project to another. Some projects have included base support facilities in their budgets, others include a first generation of science instruments, while others include only the telescope and essential infrastructure. We have attempted to collect costs on as uniform a basis as possible with the limited information available after the construction of the facilities. One of the goals of these enquires has been to derive scaling laws between the aperture and the capital construction cost.

Meinel (1987) and van Belle, Meinel and Meinel (2004) have compiled the most complete lists of observatory capital costs as of the date of their respective publications. Meinel (1987) and van Belle, Meinel, and Meinel (2004) found that the capital costs scale as the diameter, D, to the 2.8 power for telescopes built before 1980. The $D^{2.8}$ scaling law was derived for equatorially mounted telescopes with slow primary focal ratios. Breaking the $D^{2.8}$ scaling law was one of the drivers behind the evolution to Alt-Az mounts and fast optical systems. The scaling law for more modern telescopes, from the MMT, the Keck 10 m telescopes and others has a shallower slope, with van Belle, Meinel and Meinel (2004) estimating a $D^{2.5}$ dependency for Alt-Az telescopes.

Within each of these classes there is considerable dispersion, reflecting differing choices and environments in which the telescopes were developed.

For our purposes, the capital cost scaling laws are important in the sense that they allow us to frame the question: if operations costs are a fixed fraction of capital costs, can we understand why they should scale as $D^{2.8}$ or $D^{2.5}$? To reverse the question — why would we expect operation costs to scale as a fixed fraction of capital unless we have reason to expect that they scale as D^x where $2 < x < 3$?

Operational Costs

Observatory operations are people-intensive and thus labor costs usually dominate operating budgets. Labor costs are typical ~80% of the total operating budgets for 4-8 m class telescopes. The size of the operations staff, however, is bounded on each end. Setting aside robotic telescopes, classically operated telescopes need a minimum number of FTEs — telescope operators, instrument specialists, maintenance staff and service personnel — to support the observers and staff on site. Thus, the fractional cost of operating a small telescope on a site with limited cost sharing can be high. At the other extreme, there are only so many people that can effectively work on a single telescope without getting in each other's way. The largest optical observatories operate with ~100–150 FTEs in different shifts to provide 24/7 coverage; the distributed radio frequency arrays sometimes require more personnel. A 10 m telescope does not require 300–600 times as many FTEs as a 1 m telescope, as a $D^{2.5}$ or $D^{2.8}$ scaling law would dictate.

The expected level of service plays an important role in setting the operations budget as well. The larger aperture telescopes usually include the cost of operating and maintaining a science archive as part of their operations budget, reflecting the high capital cost and intrinsic value of the data they deliver. The more complex technology on modern telescopes (e.g., active and adaptive optics) requires not just an increase in maintenance costs but also an increase in the level of sophistication and overall service level to enable users to make optimal use of the technology.

Non-labor costs include utilities, spare parts, consumables, contract services, fees, licenses and other items. These generally grow with the size, and hence capital cost, of the facilities and might be expected to scale as D^x where x is between 2 and 3. Since these costs are typically a minority (e.g., ~20%) of the total operations budget their weight in any overall scaling relation is modest.

Results for Current and Planned Observatories

We have tabulated the construction and annual operating costs for a number of astronomical observatories. The capital cost numbers typically come from van Belle, Meinel and Meinel (2004), supplemented with information from observatory websites or NSF and NASA budgets as published by the agencies. Operations budgets are drawn from observatory web sites and from federal sources (published NSF or NASA budgets), public data from the facilities (e.g., Subaru), or from local staff (e.g., Keck). The construction and operations costs naturally apply to different epochs and must be put on a common-year basis. We have scaled the construction and operations costs to 2019 dollars for each facility using a 3.5% annual inflation rate. There are uncertainties in these comparisons — different observatories include different scope in operations (instruments or not) and the scaling of the capital costs to 2019 dollars is uncertain.

The results for several observatories are listed in Table 1 and shown in Figure 1.

Table 1. Capital and operational costs of major existing observatories

Observatory	**Capital**			**Operations**		
	Year	**\$2019M**	**Source**	**\$2019M**	**%**	**Source**
Mayall	1973	52	1	3.8	7.4	10
Blanco	1976	70	1	4.7	6.7	10
IRTF	1980	114	1	5	4.4	11
Keck I & II	1994	405	1	17	4.2	12
Magellan I & II	2000	150	2	7	4.6	13
Gemini N & S	2000	308	3	21	6.8	14
Subaru	2001	350	4	22.5	6.4	15
LBT	2008	235	5	6	2.6	16
LSST	2021	660	6	30	4.5	14
VLA	1976	395	7	79	2.5	14
ALMA	2004	803	8	43.5	5.4	14
LIGO	2000	2115	9	40	1.9	14

[1] Van Belle et al. (2004); [2] Magellan budget documents; [3] Gemini budget authorization; [5] LBT [6] NSF MREFC budget and DoE Budget for LSST; [7] NRAO web site; [8] NSF MREFC budget and partner budgets; [9] NSF and LIGO web sites; [10] NOAO 2019 Program Plan; [11] NASA 2019 Budget; [13] Private Communication; [14] NSF FY2019 Budget; [15] NAOJ Website; [16] Private Communication.

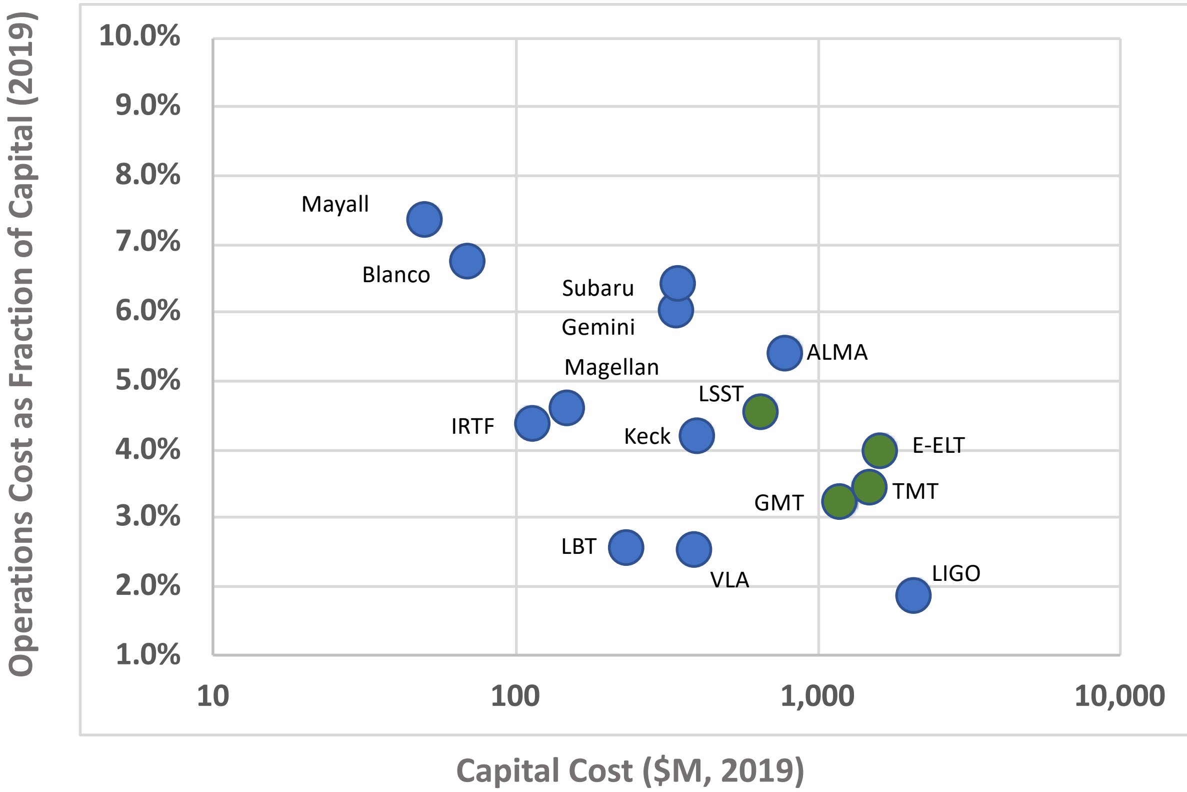

Figure 1. Comparison of Operations Costs for Various Observatories as a Percentage of Capital Cost. Data for facilities in the construction phase are colored green.

There are a number of interesting conclusions that one can draw from Figure 1. First, none of the operating observatories today have budgets that equal 10% of their construction costs in the same-year dollars. Most are in the 5 ± 2% range. The most expensive facilities, in terms of fraction of capital, are the smaller telescopes on mountains where they are the largest aperture (e.g., the NOAO 4 m telescopes) and the 1970's equatorial telescopes. Secondly, the cost as a percentage of capital declines with the cost of the facility.

Construction costs for observatories scale between the 2nd and 3rd power of the aperture — between the collecting area and the volume of the telescope/enclosure. The declining cost ratios reflect the fact that while some costs scale like the capital (spare parts, maintenance hours, power usage), others are roughly fixed or grow only slowly with aperture. One person is needed to point the Keck telescope just as one operator is needed for a 1-m telescope (most small telescopes are moving to automation for this reason). While more staff are needed for larger facilities, many staff positions are specialized and only a limited number of person hours are needed. The size of the staff (296 FTE) for the $1.5B ALMA observatory is roughly the same as that of NOAO at its peak, when they operate roughly $400M in capital assets.

Figure 1 shows some expected results. Facilities with lower levels of on-site support located in low-cost areas (e.g., LBT) stand out clearly from their peers, while facilities with high levels of support at expensive locations (e.g., Subaru) stand out as expensive even though their capital costs were among the highest in their class.

We have included the estimated operating fractions for GMT, TMT and the European ELT[1] in Figure 1. These are uncertain, as they have not yet completed construction or started operations. Based on current construction budgets (mapped to single-year dollars) and estimated operations budgets in 2019 dollars, they fall on the rough trend line and all have comparable operating cost fractions. The operation budgets for the three ELTs were developed entirely independently, but they cluster in Figure 1. If the operation costs for the ELTs turned out to be 10% of their capital costs, they would be true outliers from the 1950-2000 era telescopes along with the VLA, ALMA and LIGO in Figure 1.

Conclusions

Our analysis indicates that the operations costs, as a function of capital costs, for large ground-based observatories are in the 5 ± 2% range. This should inform planning for future facilities. Furthermore, it appears that the ratio of operations to capital costs declines with the scale of the facility. Groups planning budget for future facilities should keep these factors in mind when evaluating bottom-up operations budgets for future facilities. The dangers associated with under-funding observatory operations are well known and are very real; the opportunity costs or foregoing construction of new research tools due to concerns about operating costs is a risk that we must evaluate carefully as we plan the next generation of observatories on the ground as well as in space.

References

Meinel, A. B., 1978, in Optical Telescopes of the Future (eds. Pacini, F., Richter, W., Wilson, R. N.) 13-26 (ESO Conf. Proc.)

Van Belle, G. T., Meinel, A. B., Meinel, M. P. 2004, Ground-based Telescopes, Proceedings of SPIE Vol. 5489, pp. 563-570.

[1] The E-ELT capital costs are based on a 1.4B Euro budget and an exchange rate of 1.4 Euros to the US dollar.