Master's in Statistical Science (MSS)
Executive Summary

November 11, 2013

The Department of Statistical Science is a nationally ranked top 5 research department with a top 10 graduate program and is recognized as the world's leading center for Bayesian statistics and its applications. Building on the success of our PhD, undergraduate major, the recently launched joint MS in Statistical and Economic Modeling, and strong demand for statistical scientists and enhanced quantitative training in many fields, we propose a new admitting MS in Statistical Science (MSS) to begin Fall 2014.

Audience

The MSS will be attractive to students from statistics, mathematics, computer science, natural and social sciences, and digital humanities, who seek educational opportunities in advanced statistical modeling for the computational challenges of today and tomorrow. In addition to a solid core in theory and methods of stochastic modeling, and in advanced computation for statistics, MSS students will be broadly exposed to challenging applied problems from many areas. They will graduate with skills in emerging as well as traditional methods of data analysis and conceptually well-founded reasoning in the face of uncertainty.

The MSS will prepare students for careers in industry or government; as a terminal degree, it will be a major attraction to employers increasingly seeking statisticians and "data scientists." The degree will serve, in parallel, as a basis for students transitioning to PhD studies in statistical science or allied fields. Further, the MSS is an additional gateway to recruit under-represented groups to advanced quantitative and computational science. Statistical Science's strengths in advanced stochastic modelling for complex data, interdisciplinary applications of statistics, and advanced statistical computation distinguish this program from our peers.

Students are expected to enter the program prepared in multivariate calculus, matrix algebra, a two semester undergraduate calculus-based sequence in probability and mathematical statistics, and with at least basic experience in computation and data analysis (such as applied regression modeling). We anticipate a number of applicants with "real-world" job experience aiming to return to graduate school or transition into statistical science. Based on the strong applicant pool for the MSEM, continual inquires about a Master's in statistics, and the reputation of Duke and Statistical Science, we foresee no difficulties attracting an initial class of 10-12 students for the first year, and ramping up to admitting $\sim$24 students each year thereafter.

Overview of the Degree

- Courses
  - 36 credits over four semesters (some will complete in 3 semesters).
  - 8 (mainly new) core courses: solid foundation in theory and methods of stochastic modeling, advanced statistical computing, applied statistics.
  - MSS electives (some new MS courses; select PhD courses and advanced undergrad courses; non-STA electives).
  - Course selections subject to approval by the MS Director and student's MSS faculty advisor.
- Statistical Application & Experience
  - Consulting experience: (at least) one semester of STA 851 Statistical Consulting Workshop.
  - Applied statistics proficiency: demonstrated through at least one of: (1) formal consulting or applied research-related project mentored by a Duke Statistical Science professor (outside STA 851); (2) summer internship in industry; (3) 2 detailed, course-related applied projects in application areas.
- Completion Exercise
  - MSS Committee oversees either portfolio or thesis.

- *(i) Portfolio option:* presentation and defense of an electronic portfolio of work that demonstrates mastery of statistical methods, application and computation; the portfolio will be assembled from material from at least 2 elective courses. Primarily expected for professionally oriented students.
- *(ii) Master's thesis option:* submission and defense of a Master's thesis, representing a written record of original work of the student under the guidance of her/his MSS faculty advisor and advisory committee. Primarily expected for students aiming to move to PhD program following the MSS.
- Choice of completion exercise will be made by the student in consultation with faculty advisor and the MS Director. Each student presents (either portfolio or thesis) in a final defense to his/her MSS committee.

Financial Model

The program will be completely self-supporting through tuition revenue and will return just over $1 million to the Graduate School annually once the program is up and running. We anticipate admitting strong US applicants– including some returning to formal education following a period of working experience– as well as strong students from non-US countries with an enrichment of applications from Asian countries. We will make concerted efforts to recruit US-based students and students from under-represented groups in STEM disciplines. The budget plan anticipates a 17% reduction on gross tuition revenues to address financial aid in support of recruiting minority, women, and other deserving top candidates. Qualified students may also be partly supported as TAs or RAs; such opportunities will be used to partly offset tuition for some MSS students making the program financially competitive with our peers that have one year programs. Budgets will be reviewed annually and adjusted as appropriate.

The budget includes the costs of teaching replacement time for the MS Director and an administrative assistant, as well as three new faculty lines to cover the expanded teaching and mentoring load of the program. The program requires the development of 9 new MS courses, beginning with 6 in the first year. The majority of these will be developed and taught by current regular rank faculty, with visitors used to cover other courses. Space for graduate Teaching Assistants, new faculty and staff offices, as well as an open interactive space for the 2 year cohorts of 48 MS students are also included in the budget.

Concurrent MS: Educating non-STA PhD students at Duke

The MSS will subsume the concurrent MS in Statistics offered to PhD students in other programs at Duke. Several new MSS courses will have capacity for such students as well as MSS students, and will be very attractive to the increasing numbers of Duke PhD students interested in more extensive education and preparation in statistical science linked to their PhD field. Variable costs (primarily more TAs) for these students are not accounted for in the financial model and will need to be addressed separately, and increasing numbers of concurrent students will require continual revision of teaching and TA support mechanisms across schools. To date, two programs that routinely send large numbers of students to StatSci courses have been willing to provide additional TAs. However, with expanded numbers this, and the expanded support for teaching additional course sections, will need to be addressed at School-School levels.

Master's in Statistical Science (MSS)
Duke University

Proposal to the Graduate School

November 11, 2013

1 Overview and Rationale

The Department of Statistical Science (StatSci) at Duke is nationally ranked in the top 5 research departments and as a top 10 graduate program. Recognized as the world's leading center for Bayesian statistics and its applications, the department is distinguished by its foci in complex stochastic modeling, Bayesian statistics, scientific computation, and inter-disciplinary applications of statistics. The current graduate program is highly-regarded, attracts outstanding students, has excellent completion and placement records, and has vibrant ties to industry and government as well as academic and non-profit organizations. The undergraduate major is, after just a few graduating classes, following this path.

At the Master's level, the department has– since inception of our graduate program in 1990– offered the concurrent MS to PhD students in other Duke departments. Since 2012, we offer the joint Master's in Statistical and Economic Modeling (MSEM). To date, we have not offered a free-standing Master's degree program to entering students. We now propose to do so, based on the major growth and interest in the broad field of statistical science and its intersections with many disciplines, and in view of the major and– for the foreseeable future– fast-growing demand among students worldwide. Each year we receive numerous enquiries from potential MS applicants, the interest being fueled by a rich combination of effects: recognition of our departmental standing and the nature of education and research here; the upsurge in computation and data-enabled enquiry across all fields of activity, which represents a persistent societal evolution as well as being impacted by rapidly engaging trends such as the current "big data" phenomenon; the increasing recognition of the importance of statistical ideas and concepts in many fields; and, of course, Duke's broader reputation.

The Master's in Statistical Science (MSS) at Duke will prepare students for careers in industry or government, and/or for advanced graduate work and further studies in the statistical sciences broadly. The "broadly" relates to the rich intersection of statistics with other disciplines, many of which increasingly involve advanced computational skills and abilities in data-enabled scientific enquiry at all levels.

In addition to a solid core in stochastic modeling and advanced computation for statistics, MSS students will be broadly exposed to challenging applied problems from many areas, and become skilled in emerging as well as traditional methods of data analysis and conceptually well-founded reasoning in the face of uncertainty. The interfaces of statistical science with big-data applications are obviously very germane as we define a new program to begin graduating MS students in 2016-17. Making sense of increasingly large and complex data sets requires statistical sophistication to handle challenges poised by the ever-increasing volumes of data being generated as well as increased velocity of data in real time. Veracity in statistical methods is all the more critical in the face of massive data as verification of results are often limited in scope. However, while big data is currently adding to the demand for statisticians and data scientists, the core statistical savvy, concern for relevance and reproducibility, and general technical ability required to provide meaningful insights and answers are just as relevant to analysis and inferences from "small data" (see http://www.youtube.com/watch?v=jbkSRLYSojo).

The MSS will link to some existing undergraduate and PhD graduate courses, the concurrent MS and MSEM, and reflect Duke's world renowned expertise in Bayesian statistics, stochastic modeling, computational science and frontier interdisciplinary applications of statistics. New course offerings tailored for the MSS will also benefit students from other graduate programs at Duke, including the MSEM students, and those graduate students interested in pursuing a concurrent MS or simply increasing their quantitative knowledge, perspective and skills through select courses. Critically, the MSS degree provides an additional gateway to attract and recruit underrepresented groups (minorities and women) to statistical science, provides additional preparation as a bridge to the PhD in statistical science or other quantitative fields, as well as serving as a primary terminal degree that will be a major attraction to employers of all flavors.

2 Relationship to Existing Programs

2.1 Statistical Science Programs

In addition to the primary goals of defining a unique and leading MSS program, the MSS will be directly beneficial to the other two Master's level programs we currently run. The new MSS will provide additional course offerings to broaden and better meet the needs of our *concurrent MS students*, and enable us to modestly expand the concurrent MS student numbers to address persistent internal demand; it will similarly positively impact the joint MSEM program through new and expanded MS-level courses.

2.1.1 Concurrent MS

Since the inception of the PhD program in 1990, StatSci has offered the opportunity to apply for and pursue a concurrent MS in Statistical Science to all PhD students from other departments and programs at Duke (see http://stat.duke.edu/people/masters-alumni-pages for a list of alumni). These students take courses largely drawn from our PhD course offerings. Coupled with the continually increasing demand for our graduate courses from PhD/MS students from other departments, this means that outside students in our first year PhD courses now outnumber StatSci students 3:1 in many cases. The number of students who complete the course work sequence required for the qualifying exams that all concurrent MS students take is at the level of about 10 students a year. We have downplayed the program in recent years due to increased PhD class sizes and lack of TA resources. While several of the departments that send large numbers of students to StatSci graduate courses have been willing to support our teaching/resource needs by providing additional TAs, additional resources provided through the MSS would allow us to expand interdisciplinary quantitative training across campus at all levels and meet the growing demand for training in "Data Science".

2.1.2 MSEM

The joint Master's in Statistical and Economic Modeling (MSEM) was started in 2012/13. First year MSEM students take three core courses from the Statistical Science first year PhD curriculum, and second year students select others based on their chosen areas of specialization. The 2013 intake is 9, with an informal target of 10-12 per year over the next several years. In 2012 and 2013 we had very strong applicant pools of $\sim$400 students, and this in the context of a new program with no track-record or serious advertising efforts. This is partly indicative of the broader interest in, and demand for, Master's level programs in statistics, and we expect that this applicant pool will generate cross-over applicants to the new MSS, starting immediately. In creating the MSEM two years ago, no new courses or administrative support were added. Realized tuition income from the MSEM will now allow us to develop new courses targeted for the MSEM to bolster and broaden the opportunities for MSEM students, as well as provide shared administrative support with the MSS.

2.2 Other Duke Programs

Several other departments with PhD programs that are generating increasing interest in our courses are naturally interested and supportive of our MSS proposal, as it will add courses that will also attract their students. Although this has a downside for StatSci and our proposal– in that we are already over-subscribed by graduate students from many departments– this must be regarded as a positive for Duke. And, if the appropriate budgetary policies and mechanisms can be aligned, is wholly positive for all involved. The programs in question include, ECE, CBB, B&B, programs in NSOE, computer science, economics, political science, and others. Emerging interests in big data/information and data sciences are very obviously positively impacted and already engaged as partners in the development of MSS, new courses and educational initiatives.

Among other MS programs, we note the new MS program of the Department of Biostatistics and Bioinformatics, a professional Master's degree in biostatistics that emphasizes methods for biomedical applications, is oriented toward medical applications, and targets career paths into medical and pharma industries. The B&B Master's of Biostatistics requires a core competency in biology, and the courses are generally focused at a level consistent with the primary program goals and the biomedical statistics industry. StatSci has been and remains a main campus supporter of the B&B Master's program, and its current proposal to launch a Biostatistics PhD program, and will continue with a high level of enthusiasm. There are no obvious disciplinary or programmatic conflicts, or areas of duplication, the core goals and missions of B&B being quite distinct from those of StatSci.

There are clear interests in collaboration. B&B faculty have been appointed as secondaries in StatSci and serve on DSS graduate committees. One primary B&B/IGSP faculty member who is secondary in StatSci teaches for us; we anticipate further development of teaching relationships through this proposal. One current area under discussion, as an example, is that of traditional statistical computing, where we can identify potential opportunities for productive collaboration on MS level teaching that could aid with our MSS development, feed into broader student interest on campus, as well as buoy a component of the B&B program. We are interested in this as a part of our broader portfolio of interconnections with other Duke departments and programs. We also have a number of ties with biomedical companies and organizations that are distinct from the more clinically oriented operations of B&B, and see opportunities for bipartite synthesis around a developing MSS internship program that could build out of our current collaborations.

2.3 Other Statistics Programs

To be clear about positioning, we recapitulate that the Duke MSS will provide a unique environment with strengths in Bayesian modeling and related probabilistic machine learning, advanced statistical computation, and a wealth of interdisciplinary collaborations across the university, around RTP and the nation through collaborations and networks. Duke StatSci has strong connections to industry through alumni and collaborations at Google, Facebook, Yahoo, IBM, Morgan Stanley, BEST, PIMCO, Avaya, Quintiles, MaxPoint, etc, as well as multiple other financial, IT-related and research organizations, who seek out StatSci students for internships. MSS students will be exposed to ongoing, application-driven research that will help to prepare them for careers in industry or government, as well as for graduate work in statistical science and allied fields. We anticipate some MSS students will apply for PhD studies in statistics or related fields after completing the degree, which is one of the programmatic goals.

Many of the top universities in the US and world offer 1 to 2 year Master's in Statistics (as well as a MS in Biostatistics). Peer institutions including Harvard, Carnegie Mellon and Columbia offer one-year MA professional degrees in applied statistics, as well as 4+1 continuation programs. There is no imaginable concern for competition with these or any other US (or other) program, given the distinctive positioning of Duke StatSci and the huge market for MS programs in statistics.

Regionally, there are long-standing and high-quality MS programs at NCSU and UNC, both two year, course-based degrees. These programs provide broad training in traditional areas of probability and mathematical statistics, coupled with competency in applied statistics to prepare students for positions in industry, government or advanced degrees in statistics. NCSU is a local feeder program for professional/vocational students; UNC serves that role to a degree but at a much less productive level. Both use their MS programs as filters for PhD students. Neither program intersects much at all with our MSS– in terms of core philosophy of statistical science and education, core program goals, program courses in Bayesian modelling and exposure to applied fields, or in terms of employment areas and prospects. Even if they did, the current demand, growth of demand and interest and broadening of the base of potential consumers of a Duke StatSci degree are all expanding substantially year-by-year, so that the numbers involved make any question of "local competition" simply moot.

3 Resources & Financial Planning

3.1 Review of Available Resources

The Department of Statistical Science occupies space on parts of three floors in the Old Chemistry building, with offices for 19 faculty members, several postdocs and visiting faculty, approximately 42 PhD students, and 4 supporting staff members. The Department has a Business Manager and 1 staff member to support graduate and undergraduate programs. The Department operates a large computer network for all (over 200) users, including all traditional services and a number of high-performance facilities, as well as interconnections across Duke, with one full time systems administrator to support users and maintain the system.

3.2 Spaces Needs and Projections

The Department is in need of additional faculty and staff office space, graduate student offices, and meeting and team working space, i.e., educationally vertically-integrated collaboratory space. This proposal anticipates that this will be remedied by allocation of additional space in Old Chemistry Building over 2014-2016 as: (a) the MSS program (and other programs) generate income to aid in discussions with central administration about space allocation, i.e., to buy space for the developing program; and (b) as other current groups in Old Chemistry (EOS) move to their new premises and vacate the requisite space for StatSci. The budget includes costs for maintenance and operation (M&O), with allocations to cover office space for new faculty lines, office space for new Teaching Assistants, and an open interactive space for MS students, undergrads, and PhD students to support team-based learning in courses and research.

3.2.1 Faculty Space

Regular and non-regular teaching faculty will be augmented to provide the expanded teaching and mentoring for the MSS program, as well as the implied faculty-based administrative workloads. We again note that this expansion will positively impact the existing concurrent MS and MSEM programs, as well as graduate teaching and education serving Duke graduate students more broadly. The new and expanded faculty to develop and grow the program all need dedicated faculty and supporting office space.

3.2.2 Student, Teaching, Collaboratory and Administrative Space

The Department has no dedicated conference/team meeting/team teaching and collaborative space, nor current desk/compute/collaboratory-style space for MS or undergraduate students. The allocation of additional space in Old Chemistry Building over 2014-2016 for the MSS program will remedy this.

In industry and academia, problem-solving involving statistics increasingly involves integrated teams. To facilitate team-based learning in MSS, we need open office space for working groups with laptops around tables with walls as white boards. Virtual servers will provide a "desktop" environments similar to the computing environment provided to PhD students, but without the investment in individual workstations, allowing secure access to data and providing the computational tools and infrastructure needed to address data analysis challenges of today and tomorrow.

Office space for full-time staff personnel involved in program admissions, coordination, day-to-day management, career advising and placement is evidently needed, as well as additional new faculty offices. Revenue from the MS tuition will be used to provide additional space in the Old Chemistry Building.

3.3 Student Population Projections

We will draw applicants from the top universities worldwide. MSS will appeal to students with backgrounds in statistics, mathematics, computer science, natural and physical sciences, engineering, multiple areas of the more quantitative social sciences, and emerging areas such as the digital humanities where quantitative skills and inclinations are increasingly recognized as important and desirable. We anticipate admitting many strong students from non-US countries, with an enrichment of applications from Asian countries.

We will make concerted efforts to recruit US-based students and students from under-represented groups (minorities and women) in STEM disciplines and will advertise the program through the International Society for

Bayesian Analysis, American Statistical Association, Institute for Mathematical Statistics, Women in Statistics, as well as through the network of Chairs of Statistics Departments. Our current network of minority students (4 African-American - 2 PhD students and 2 MSEM) and women (roughly 30% of the graduate student population) as well as alumni in academics (University of Texas, Chicago, Harvard, UC Santa Cruz, New Mexico, Rice, etc) will play a critical role in recruitment and advertising. We aim to capitalize on the initial momentum generated by the MSEM, linking into the Economics minority outreach efforts with recruiting at top elite US minority serving institutions, including technical universities (NC A&T, FAMU, Southern), liberal arts institutions (Morehouse, Spelman, Howard) and urban universities (CCNY, Rice, UC Riverside) as well as using the Office of Graduate Student Affairs to expand advertising and recruitment efforts nationally. StatSci faculty routinely participate in education and outreach programs organized by SAMSI (the Statistics and Applied Mathematical Science Institute in RTP, of which Statistical Science is a partner), targeted at undergraduates and under-represented groups; these events will provide opportunities for faculty to recruit and for potential students to visit campus.

Financial aid has been a key component to recruit and support minorities and women in the MSEM and will be critical for the MSS as well, with the goal of increasing these under-represented groups in statistics and providing a bridge to the PhD. The budget plan includes a 17% reduction on gross tuition revenues to address financial aid in support of minority, women, and other deserving top candidates. The department routinely seeks qualified students to serve as teaching assistants and graders for undergraduate courses; such employment opportunities (and others, i.e., part-time RAs) will be used to partly offset tuition for some MSS students.

For reference, we received over 360 applications to MSEM last year with 9 students accepting admission, close to our current upper bound of 10 students per year, which we expect to increase to 10-12 next year. We expect to take in 12 students for year 1 of the MSS program and then ramp up to the steady-state population of 24 students admitted per year to the MSS. We also expect increased interest from the concurrent MS (MSC) as the revised MSS program will be more attractive to students in other PhD programs with the new course offerings and the restructured requirements.

3.4 Faculty and Resources Projections and Other Costs

The department will initially expand the teaching faculty (adjunct, visiting, term contract) to release regular rank faculty to develop and teach a majority of the new courses (as described in Appendix 1), and to build and engage in the new MSS. The budget anticipates additional regular-rank appointments over 2015-2017 to ensure the development and success of the program longer term.

The MS Director, a position established in 2013, oversees MS (MSS, MSEM, concurrent) admissions, MS student advising, annual program evaluation (SACS) and day-to-day operations such as internship and job placement. The budget provides a one course-teaching release each semester based on the expected demands, with 75% of the effort supported through the MSS. The MS director naturally works closely with the DGS and advises on policy changes, issues, etc.

We have worked closely with financial officers in Arts & Science and the Graduate School to prepare a financial plan for the program that will be completely self-supporting and will return just over $1 million annually to the Graduate School once the program is up and running. The budget includes the costs of teaching replacement time for the MS Director and an administrative assistant, as well as three new faculty lines to cover the expanded teaching and mentoring load of the program. The program requires the development of 9 new MS courses, beginning with 6 in the first year. The majority of these will be developed and taught by current regular rank. Space for graduate Teaching Assistants, new faculty and staff offices, as well as an open interactive space for the 2 year cohorts of 48 MS students are also included in the budget.

The summary budget in Table 1, with Tables 2 and 3 providing the specific assumptions about tuition levels, revenue sharing, salaries, benefits, and other costs over the coming six years, clearly shows that this is a win financially for the Graduate School and Duke broadly, with the expanded personnel, teaching, financial aid, space, and administrative resources being covered from the revenue generated from the MSS.

The MSS will subsume the concurrent MS in Statistics (MSC) offered to PhD students in other programs at Duke. New MSS courses will have capacity for MSC students, but will also be very attractive to the increasing numbers

of Duke PhD students interested in more extensive education and preparation in statistical science linked to their PhD field. StatSci faculty remain fully committed to teaching and mentoring these students, and it all comes down to resources. Variable costs (primarily more TAs) for these students are not accounted for in the financial model and will need to be addressed separately, and increasing numbers of concurrent MSC students and outside PhD and MS students will require continual revision of teaching and TA support mechanisms across schools. To date, two programs that routinely send large numbers of students to StatSci courses have been willing to provide additional TAs. However, with expanded numbers, this will need to be addressed at School-School levels with central injection of funds needed to address properly the full costs of PhD teaching assistants by increasing FTEs with a long-term view of improving cross-disciplinary quantitative educational opportunities at Duke.

Table 1: **MSS 6-year budget summary**

		[2013/14]	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
INTAKES:								
	MSS	*0*	12	24	24	24	24	24
	MSC	*4*	8	8	10	10	10	10
BUDGET SUMMARIES:								
	Full tuition in/MSS:		549,120	1,522,893	1,979,761	2,058,951	2,141,309	2,226,961
	Financial Aid		91,520	253,815	329,960	343,159	356,885	371,160
	GS tuition share in/MSS:		109,824	609,157	890,892	1,029,476	1,070,655	1,224,829
	StatSci in/MSS:		439,296	913,736	1,088,868	1,029,476	1,070,655	1,002,133
	MSS StatSci net:		***16,710***	***58,503***	***107,031***	***105,280***	***121,795***	***24,731***
STATSCI EXPENDITURES SUMMARY $s:								
	Financial Aid MSS		91,520	253,815	329,960	343,159	356,885	371,160
	MS staff admin		17,353	54,035	55,386	56,771	58,190	59,645
	Advising/reg faculty		29,118	239,333	398,640	408,606	418,821	429,291
	Teaching faculty		220,284	124,870	7,999	8,199	8,404	8,615
	Space M&O		8,615	26,267	26,267	26,267	26,267	26,267
	TA		45,696	66,912	68,585	70,299	72,057	73,858
	Grad Award		0	0	0	0	0	0
	Cash Reserve Input		10,000	90,000	95,000	10,895	8,236	8,565
	Total out		422,586	855,233	981,837	924,196	948,860	977,401

Table 1 notes:

- *Intakes– MSS* is the targeted MSS intake. MSEM 2012 & 2013 applicant pools around 400. This applicant pool may generate cross-over applicants to MSS, starting immediately. *MSC total*– numbers of concurrent MS in Statistical Science for Duke PhD students from other Duke programs. Interest is very high. Program cannot be maintained (let alone increased) without real faculty teaching and TA resources. Note these numbers are not used in the financial planning.
- *All $ revenue and expenditure summaries* are based on parameters and assumptions in Table 2. This includes assumed attrition, 4th semester drop-off, and financial aid
- *Tuition revenues* are based on 2013/14 tuition with a Graduate School expected 4% annual increase.
- *Financial aid MSS* Costs for MSS Financial aid are charged against the StatSci share of tuition revenue with the goal of supporting 1 in 6 students.
- *StatSci in/MSS*– based on tuition sharing with Grad School. For MSS, StatSci receives 80% in year 1 for creating initial program infrastructure , 40% in year 2, 45% in year 3, 50% in year 4 and 5, ramping up to 55% in year 6. These values will be reviewed annually.
- *Expenditures* include all personnel costs for teaching, mentoring and administration of the proposed MSS, costs for new space and building a cash reserve (10% of gross tuition) for back-stopping.
- *Cash Reserve* is 10% of gross tuition to provide back-stopping.
- *Grad School in/net*– breakdown of income from the two programs.
- *StatSci in/net*– the difference covers *all* teaching and administrative expenditures detailed, as well as full financial aid for the MSS.

Table 2: **MSS budget planning assumptions**

	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
PARAMETERS ASSUMED - FINANCIAL:						
Financial aid	17%	17%	17%	17%	17%	17%
4th sem tuition drop	50%	50%	50%	50%	50%	50%
Yr2 attrition	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
MS tuition /semester	22,880	23,795	24,747	25,737	26,766	27,837
Tuition increase	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%
GS % tuition: MSS	20%	40%	45%	50%	50%	55%
PARAMETERS ASSUMED - FTES/COURSES/ADMIN:						
# per staff FTE	60					
# per Fac Dir FTE	60					
# new sections/courses equiv	7	9	9	9	9	9
# courses cover for Dir	1	1	1	1	1	1
M&O	15.43	16.00	16.00	16.00	16.00	16.00
Staff salary	55,000	56,375	57,784	59,229	60,710	62,227
Advising/reg fac salary	92,000	94,300	96,658	99,074	101,551	104,090
Teaching fac salary	72,000	73,800	75,645	77,536	79,475	81,461
TA	6,000	6,150	6,304	6,461	6,623	6,788
Ann increase		2.5%	2.5%	2.5%	2.5%	2.5%
Staff FB	26.2%	27.8%	*27.8%*	*27.8%*	*27.8%*	*27.8%*
Fac FB	26.6%	26.9%	*26.9%*	*26.9%*	*26.9%*	*26.9%*
TA FB	8.8%	8.8%	*8.8%*	*8.8%*	*8.8%*	*8.8%*

Table 2 notes– Financial:

- *Financial aid*– projected approximate subsidy for under-represented groups.
- *4th semester tuition drop*– some MSS students will complete course requirements in 3 semesters.
- *Year 2 attrition*– allowance for occasionally losing a student.
- *Per capita* semester tuition and concurrent MS fee, with nominal/projected annual increases.
- *Grad School % tuition*– share of tuition on MSS.

Table 2 notes– FTEs/Courses/Admin:

- *per staff FTE*– # MS students per 1 FTE program staff/admin.
- *per Fac Dir FTE*– # MS students per 1 teaching FTE faculty program director.
- *new sections/courses*– required new sections/new courses.
- *courses cover for Director*– (or Directors equivalent) for teaching remission.
- *Staff, faculty salaries*– based on based on current norms in Statistical Science.
- *TA*– per semester TA stipend. Additional support/subsidy must come from advisors or elsewhere. Some TAs will come from MS student body. *Nominal TA: 1.25 per section of 30 students*
- *Annual increase*– nominal rates for salaries only.
- *Staff & Faculty FB*– fringe benefits at current projected rates.

Table 3: **MSS budget FTE numbers**

	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
NEW FTEs:						
MS staff admin	0.25	0.75	0.75	0.75	0.75	0.75
MS Fac Director	0.25	0.25	0.25	0.25	0.25	0.25
Advising/reg faculty	0.25	2.00	3.25	3.25	3.25	3.25
Teaching faculty (non-reg rank)	2.4	1.3	0.1	0.1	0.1	0.1
TA	7	10	10	10	10	10

Table 3 notes:

- *MS staff admin*– required program administration staff FTE.
- *MS Faculty Director*– required MS director or directors equivalent (academics, admissions, advising, placement, etc.) teaching FTE (teaching remission).
- *Advising/regular faculty*– new regular faculty FTE (faculty load is 3 total)
- *Teaching faculty*– instructors to provide replacement teaching for current regular-rank faculty to develop and teach new courses, and ongoing teaching cover for faculty director (3 courses per cap).
- *TA*– course TAs for new courses and sections

4 Degree Requirements & Courses

4.1 Prerequisites

Admitted MSS students will satisfy the following minimal requirements:

- Two semesters of an undergraduate calculus-based probability and mathematical statistics sequence;
- One course in matrix algebra;
- One course in applied regression analysis;
- Some basic experience with computation and data analysis.

Prior exposure to formal programming, using *C, python, java, R, Matlab,* etc., is highly desirable. Exceptional students who may not have this complete list of prerequisites but have a compelling application otherwise may be admitted. Some such students will take STA 611: Introduction to Mathematical Statistics (a one semester version of a relevant two semester undergraduate probability and mathematical statistics sequence). Others will take additional prerequisites courses their first year, adding a semester to the course of study.

4.2 Program Requirements

- MSS students will satisfy the general requirements of the Duke Graduate School for RCR training and English proficiency (see below).
- Each student will take a minimum of 36 units of graduate credit, including at least 30 units on STA courses of which at least 24 must be graded.
- Each student will enroll in STA 851 Statistical Consulting Workshop, for at least one semester.
- Each student will participate at least once in STA 5XX DataFest.

- Each student will satisfy the Applied Statistics requirement (see below).
- Each student will satisfy the Completion Exercise requirement (see below).

4.3 Courses

Most first year MSS students will take most of the core courses in Table 4. Students who have the equivalent may take alternatives approved by the MS Director. Depending on background, some students may take alternatives from among the STA electives of Table 5, or PhD courses, and/or relevant courses in other disciplines, but will in any case then complete the required MSS core during their years of study.

Table 4: **First Year MSS Core Curriculum**

Fall Semester
- Modern Regression and Predictive Modeling (New MS Course, 3 credits)
- Introduction to Bayesian Inference (STA 601, 3 credits)
- Programming for Statistical Science (New MS Course, 3 credits)
- ProSeminar: Becoming a Statistical Scientist (New MS Course, 1 credit)

Spring Semester
- Statistical Inference (New MS version of STA 732, 3 credits)
- Advanced Bayesian Inference and Stochastic Modelling (New MS Course, 3 credits)
- Advanced Statistical Computing (New MS Course, 3 credits)
- Statistical Consulting Workshop (1-3 credits)

Table 5: **MSS Elective STA Courses**

New MS Course STA 5XX: DataFest (1 credit)
New MS Course STA 6XX: Statistical Learning through Bayesian Nonparametrics (3 credits)
New MS Course STA 6XX: Time Series and Dynamic Models (3 credits)

New STA 561: Probabilistic Machine Learning I (3 credits)
New STA 562: Probabilistic Machine Learning II (3 credits)
New MS Course STA 6XX: Modern Design of Experiments (3 credits)
STA 321: Statistics of Surveys (3 credits)
STA 340: Introduction to Statistical Decision Analysis (3 credits)
STA 350: Statistical Methods in Computational Biology
STA 5XX: Causal Inference in Statistics and Social Sciences (3 credits)
STA 621: Applied Stochastic Processes (3 credits)
STA 622: Data Mining (3 credits)
STA 623: Statistical Decision Theory (3 credits)
STA 841: Generalized Linear Models (3 credits)
STA 942: Spatial Statistics (3 credits)

During the summer between Years 1 and 2, most students will seek out internships or summer research experiences. We have an excellent record of placing our undergraduate and PhD students in a variety of internships (locally, nationally and internationally), and expect that MSS students will be strong competitors for these. MS students may be supported as Research Assistants on faculty grants during the summer or serve as a TA for the summer sessions.

Second year students will complete the core (if not already completed in year one) and select from the menu of STA electives for Master's students; see Table 5. Electives may also be drawn from among a small number of advanced undergraduate courses, existing graduate courses, other new Master's level courses that will evolve as the program develops, and relevant courses in other graduate programs at Duke (including most of the natural sciences and computationally oriented social sciences). Course selections in both years are subject to approval by the MS Director and, in the second year, the student's MSS faculty advisor.

4.4 Applied Statistics Experiences

Each student must demonstrate proficiency in Applied Statistics through activities outside of core courses. This can be done via one of more of the following:

- Participation in formal consulting or applied research-related project mentored and overseen by a Duke Statistical Science professor (beyond the consulting experience from the required enrollment in one semester of STA 851 Statistical Consulting Workshop).
- Summer internship in industry; students following this route will provide a self-assessment of the experience and the department will consult with the internship mentor.
- At least 2 detailed, course-related projects in application areas and at a level of applied substance approved by the student's advisor, from graded graduate courses.

4.5 Committee

Each MSS student has an advisory committee of 3 graduate faculty members, assigned by the MS Director and approved by the DGS at the end of the first year of study. At least two members must be full-time primary faculty in Statistical Science, one of whom will be committee Chair. The third member can be from another Duke department, for example a faculty member from an applied area of the student's interest.

4.6 Completion

Students may choose to complete via either: (i) presentation and defense of a portfolio of work that demonstrates mastery of statistical methods, application and computation; the portfolio will be assembled from material from at least 2 elective courses; or (ii) submission and defense of a Master's thesis, representing a written record of original work of the student under the guidance of her/his MSS advisory committee.

The choice of completion exercise will be made by the student in consultation with faculty advisor and the MS Director. The portfolio option with additional courses will give students greater breadth which may be more attractive and beneficial for those pursuing jobs in industry and government; the thesis option allows students to delve deeper into an individual area of research. The program is designed to be flexible so that a student may take a capstone project (independent study, or related to course project(s), or linked to an internship, etc) under the portfolio model and expand it to produce a thesis. The scope of the MS thesis is expected to be directly comparable to the overall scope of portfolio project(s), but more focused on a single project/topic and presented differently. A student who is oriented towards further advanced study and research in statistical science and related areas, and potential PhD studies, will generally be advised to pursue the thesis option.

4.6.1 Portfolio Option

Students will provide evidence of creative work generated in 2 or more elective courses in Statistical Science. This evidence will be compiled in an individual electronic portfolio and be submitted at least a month prior to intended graduation. The portfolio will include:

- Final papers, slides or videos from oral or written presentations in the selected elective courses, as well as associated computer programs.
- If the student undertook an internship as part of his or her academic program, a written description of the project, including a discussion of how the experience relates to the students field and a summary of what was learned, along with copies of any non-proprietary documents or presentations created by the student during that period.
- Material created by the student as a research or teaching assistant also may be included.
- An updated curriculum vitae or resume.

4.6.2 Thesis Option

The MS thesis comprises a report on a project approved by the MS Director. This is a detailed, self-contained report covering aspects of the student's contribution to the project area: introduction, summary of contributions

and results, discussion of open questions and bibliographic material. The MS thesis and its submission must conform to the Duke University Graduate School MS thesis requirements. The student presents the MS thesis in an oral examination administered by her/his MS Committee, and must pass this examination as the Completion Exercise.

4.7 Other Graduate School Requirements

Students are subject to all requirements of Master's students enrolled at Duke University. In particular, all students must complete the mandatory Responsible Code of Research (RCR) training in academic integrity and research ethics. Additionally, all international students whose native language is not English must enroll in English language courses as determined by the English language placement exams administered during Orientation, unless formally waived from this requirement by the Graduate School upon certification of competency in English.

4.8 Duke Undergrads Four+One Option

Undergraduate in Engineering at Duke may earn a Bachelor's degree and a MS in five years through a $4+1$ degree program, by taking graduate level statistics courses during their senior year and completing the remaining units of credit for the MS in one year (Summer, Fall, and Spring semesters). We believe such a program would be highly beneficial to our best undergraduate majors, particularly students who have become actively involved in research as an undergraduate and wish to continue independent research and advanced course-work or those who feel the additional breadth provided by advanced MS courses will provide greater career opportunities.

Note, that the $4+1$ option has not been factored into the budget planning, as such programs do not exist in A&S currently, and questions about tuition-sharing and transfer credits would need to be resolved. We do regard this as an option to pursue with A&S and the Graduate School in the future.

Appendix 1: New and Designated MSS Courses

Course descriptions for all other existing courses that the MSS program draws on– including existing courses that are MSS core courses as well as a number of electives– are available at http://stat.duke.edu/courses.

- **New MS Course STA 5XX: Modern Regression and Predictive Modeling**: Exploratory data analysis techniques and visualization of data with interactive graphics. Multiple linear regression and model building, predictive distributions, penalized and Bayesian estimation, model selection and model uncertainty including variable transformations, variable selection, and Bayesian Model averaging, diagnostics and model checking, robust estimation, hierarchical models.
  3 credits. Instructor: Clyde or Dunson

- **New MS Course STA 5XX: Programming for Statistical Science**: Statistical computing and computation using R, python, and/or Matlab or other languages and environments. Custom code development for central statistical models, best practices and software development for reproducible results, interfacing R or Matlab with other languages, including markup languages, understanding data structures, design of graphics, object oriented programming, vectorized code, scoping, documenting code, profiling and debugging, building modular code, and version control.
  Designed to complement STA 601. 3 credits. Instructor: Clyde, Wolpert, or Mukherjee

- **New MS Course STA 5XX: ProSeminar: Becoming a Statistical Scientist**: Statistical paradigms and current directions, communication of statistical ideas and arguments, statistical ethics, overview of study designs, building a statistical network, professional societies, developing a web/social media presence, career paths.
  1 credit. Instructor: multiple.

- **New MS Course: STA 5XX Advanced Bayesian Inference and Stochastic Modelling**: Art and science of building graphical models and stochastic simulation methods for inference and prediction. Mixture models, networks, and other latent variable probability models, i.e. hidden Markov models. Review of discrete and continuous multivariate distributions used in building graphical models, tools of linear algebra and probability calculus. Aspects of Monte Carlo methodology and related dynamical modeling theory. Statistical computing using Matlab or R.
  3 credits. Instructor: Schmidler or West

- **New MS Course: 5XX Advanced Statistical Computing**: Statistical modeling and machine learning involving complex, large data sets and challenging computational problems. Managing data pipelines and data bases, "big data" tools for statistical inference, sequential algorithms and subsampling methods for massive data sets, efficient programming for multi-core and cluster machines, elements of GPU programming, introduction to cloud computing, Map/Reduce and general tools of distributed computing environments. Real world topics and case studies. Intense use of statistical and data manipulation software will be required. Data drawn from areas such as astronomy, genomics, finance, social media, networks, neuroscience, and beyond.
  3 credits. Instructor: Heller, Ma, Mukherjee, and/or Schmidler

- **New MS Course: 5XX DataFest** (1 credit) Students work in teams to solve this year's big data challenge on campus. Instructor: Çetinkaya-Rundel (this will provide ongoing support for DataFest, which will be in its third year in 2013/14)

- **STA 561/2: Probabilistic Machine Learning I/II**: Introduction to concepts in probabilistic machine learning with a focus on discriminative and hierarchical generative models. Topics include directed and undirected graphical models, classification, kernel methods, exact and approximate parameter estimation methods, and structure learning.
  3 credits. Instructor: Heller and/or Engelhardt. STA 561 was launched with support of iiD in Fall 2013 with a first class of almost 100 students across the university. MSS revenue will provide ongoing faculty salary and partial TA support.

- **STA 5XX: Causal Inference in Statistics and Social Sciences**[1]: Overviews of methods for estimating causal effects: how to answer the question of "What is the effect of A on B?" Includes discussion of randomized designs, but with more emphasis on alternative designs and methods for when randomization is infeasible: matching methods, propensity scores, longitudinal treatments, regression discontinuity, instrumental variables, and principal stratification. Methods are motivated by examples from social sciences, policy and health sciences.
  3 credits. Instructor: Li and/or Locke

- **New MS Course STA 6XX: Modern Design of Experiments**: Classical and Bayesian design notions and techniques– experimental units, randomization, treatments, blocking and restrictions to randomization, and utility of designs. Optimal sample size determination for estimation and testing. Factorial and fractional factorial designs, response surface methods, conjoint designs, sequential designs and bandit problems used in online advertising. Design and modeling of complex computer experiments. Designs for multiple objectives. Computational algorithms for finding optimal designs.
  3 credits. Instructor: Berger, Banks, and/or Clyde.

- **New MS Course STA 6XX: Time Series and Dynamic Models**: Applied studies motivated by problems and time series data from a range of applied fields including economics, finance, neuroscience, climatology, social networks, and others. Statistical models for modeling, monitoring, assessing and forecasting time series. Univariate and multivariate dynamic models; state space modeling approaches; Bayesian inference and prediction; computational methods for fast data analysis, learning and prediction; time series decomposition; dynamic model and time series structure assessment. Routine use of statistical software for time series applications.
  3 credits. Instructor: West and/or Tokdar

- **New MS Course STA 6XX: Statistical Learning through Bayesian Nonparametrics.** Overviews modern nonparametric Bayesian models and methods for complex data analyses with non-linearity adjustment, flexible borrowing of information, local uncertainty quantification and interaction discovery. Focuses on computationally and theoretically efficient nonparametric regression techniques based on advanced Gaussian process models, with motivating applications in causal inference and big data genomics. Includes several illustrative examples with R codes. Basic coverage of asymptotic theory and MCMC and greedy algorithms. Instructor: Tokdar and/or Dunson.

- **STA 851: Statistical Consulting Workshop**: Participation by students in data analysis projects from the StatSci Statistical Consulting Center. Projects led and directed by faculty, involving students in real world consulting, exposing them to all aspects of research including data collection, modeling, and evaluating results, and communication with non-specialists. MSS students interact with undergraduate majors and PhD students in vertically-integrated consulting activities.
  1-3 credits. Instructor: Çetinkaya-Rundel, Iversen or Lucas

[1] This course is being restructured from an existing undergrad course and will be assigned a new number

Appendix 2: Participating Faculty

CVs of faculty participating in the program are appended. As detailed in the business plan, the department will initially expand the teaching (adjunct, visiting, term contract) faculty to release regular rank faculty to develop and teach the required new courses, and to build and engage in the new MSS mentoring and advising. The plan anticipates additional regular rank appointments over 2015-2017, to ensure the development and success of the program longer term.

Appendix 3: Letters of Support

Letters of support are appended.

Appendix 4: MSS Assessment Plan

Program assessment is a continual process involving routine monitoring, review, evolution and updates, engaging all departmental faculty. MSS graduate faculty continually review the operations of the program, developing relevant modifications to curriculum and requirements, as well as the ongoing assessment of student progress on all counts defined under the goals and outcomes details below. Formal review of specific program components are undertaken frequently via a faculty review committee specifically constituted for such tasks, with recommendations refined through full graduate faculty discussions.

One aspect of the overall program assessment is an exit questionnaire/interview for each graduating MSS student. This will aim to assess the logistics of the MS degree, including subjects such as coordination of scheduling, whether or not the core courses prepared them for electives, etc. The MS Director will meet with selected students to probe further. Information from these questionnaires/meetings will be discussed in faculty meetings, and course programs and content will be adjusted accordingly.

MSS: Detailed Student Assessment Plan

Student assessment goals and outcomes, and assessment plans addressing them, are detailed below.

A. Goals

The MSS aims to prepare students as effective and successful practitioners in modern statistical science and its interdisciplinary applications, capable of achieving success in career positions in commerce, industry, government and elsewhere, as well as in admission to PhD programs.

B. Goals with Outcomes

By the time of graduation, students should be able to:

1. demonstrate knowledge and abilities in core areas of statistical modeling, applied statistics and statistical computing;
2. demonstrate ability to address and solve real-world problems with relevant statistical and computational methods;
3. demonstrate ability to communicate in oral and written forms with professional audiences in applied statistics and application fields.

C. Assessment of Outcomes defining Achievement of Goals

Outcome	Evidence of Outcome	Frequency	Reports Due
(1) Demonstrate knowledge and abilities in core areas of statistical modeling, applied statistics and statistical computing	Core & elective course-work	Annual	Annual
(2) Demonstrate ability to address and solve real-world problems with relevant statistical and computational methods	Course-work Independent or other applied studies Prior/concurrent applied projects or internships	Annual	Annual
(3) Demonstrate ability to communicate in oral and written forms with professional audiences in applied statistics and and application fields	Applied course projects Prior/concurrent applied projects or internships Completion presentation	Completion	Year 2

D. Student Outcomes Assessment Report

As part of the continual process of program monitoring, review, evolution and update, the MSS graduate faculty will continually review student progress on all outcome counts. Each student will then also be formally reviewed

by the MS Director, in consultation with MSS advising faculty, at the end of the student's first year. These reviews feed any subsequent recommendations for action on individual student cases and/or programmatic change.

The MSS Director consults with faculty advisors at the end of each academic year (end of spring semester) to review progress of all students, case-by-case, with assessments on all outcomes. This includes review and recommended actions on detailed aspects in the written MSEM Annual Year Report (appended) for 1st year and then 2nd year (completing) students. The same full set of outcomes is assessed each year.

Evaluation & Feedback Report — MSS Annual Report

Student: _____ *MSS Year:* _____ *Date:* _____

A student progressing will satisfy *all* evaluation criteria at *Satisfactory* or *Excellent*. A student will otherwise receive written feedback on those aspects marked *Unsatisfactory*, including comments on remedial paths recommended. All students will receive a copy of the written feedback and oral feedback from her/his MSEM Advisor.

1. *Progress towards and/or achievement in core areas of statistical modeling, applied statistics and statistical computing:*

   Circle one: **Unsatisfactory - Satisfactory - Excellent**

   In cases of **Unsatisfactory** outcome, detail here specific areas of knowledge, topics and skills in which the student is apparently deficient, and recommended remedies:

2. *Progress towards and/or achievements in defining the ability to address and solve real-world problems with relevant statistical and computational methods:*

   Circle one: **Unsatisfactory - Satisfactory - Excellent**

   In cases of **Unsatisfactory** outcome, detail here specific areas of knowledge, topics and skills in which the student is apparently deficient, and recommended remedies:

3. *Progress towards and/or achievements in communicating in oral and written forms with professional audiences in applied statistics and allied fields:*

   Circle one: **Unsatisfactory - Satisfactory - Excellent**

   In cases of **Unsatisfactory** outcome, detail here specific areas of knowledge, topics and skills in which the student is apparently deficient, and recommended remedies: