Work in Progress: Large-Scale Sampling and Recruitment of Engineering Doctoral Students

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Introduction and Background

This work in progress paper proposes a probabilistic multistage sampling protocol for doctoral engineering programs. Mathematical and statistical protocols and methodologies are improving rapidly, and as such quantitative research in engineering education is primed for substantial advances. Methodological considerations need to be made to ensure that data being collected lead to valid and reliable results. To date, most sampling methodologies of engineering doctoral students have favored simplicity of design and rapid data collection from local populations of students.[1] However, local sampling can lead to poor representation of engineering doctoral students among engineering disciplines and minority groups. Students from programs of different sizes and disciplines across the country are often not considered, thus hindering the ability to generalize quantitative results and observe the true variability of the doctoral engineering student population.

We seek to collect survey data from a minimum of 5,000 engineering doctoral students from across the country to examine their identity and motivation profiles within the context of previous academic and research experiences in STEM fields. To promote recruitment of a nationally-representative sample of students, we discuss development of a sampling technique based on *geographic location, engineering subdiscipline, and departmental size.*

Geography

Geographic differences have been hypothesized to contribute to cultural differences. Lu proposes that "[t]he concept of culture recognizes that individuals from different backgrounds are exposed to different traditions, heritages, rituals, customs, and religions."[2] An exploratory study conducted by Judith Spain generated results that are consistent with the discussion that geographic differences influence values and ethics in school settings[3]. Spain found evidence that the region of the school influenced students' decision making processes, and since the universities were generally within the region in which students previously resided, then the culture of a particular region is also a significant variable in shaping students' values and ethics. International students are a notable exception. *Engineering by the Numbers 2015*[4] reports that 54.7 percent of doctoral engineering degrees awarded in 2015 were awarded to international students, while international students made up 56.9 percent of the total enrollment in doctoral engineering programs. However, consistent with Spain's findings, international students should still be influenced by the regional culture of a program. Consequently, regional differences should be considered in a sampling plan.

Sub-disciplines

Evidence exists that different academic disciplines exist as unique cultures. Researchers postulate that academic disciplines are not simply different fields of study and knowledge, which can be simplified down to differences in subject matter, but rather they can differ on content from semantics to social habits. Henry Bauer[5] posits that "chemists and historians differ much as do Germans and Frenchmen." Therefore, failure to consider the subgroups within each major population can lead to generalizations that ignore the diversity of a population. By treating the field of engineering as its own separate entity rather than separately considering the subdisciplines, potential cultural differences between engineering subdisciplines are trivialized.

Departmental Size

Considerations are given to the size of the department in which each program is housed. It is commonly assumed that institutional size is proportional to influence in policy making; larger institutions affect policy more than smaller institutions. However the lack of direct measurements and the use of poor proxies to measure institutional influence have limited empirical research. Based on responses from 6,000 organizations from 60 countries measuring perceived influence over governmental policy making, there is evidence of a positive relationship between institutional size and perceived influence.[6] Analysis of the same survey reveals another story where larger institutions have advantages over small institutions in governmental policy-making and strategies. Based on the trend observed, departmental size is inferred to have an impact on national policy making in academic fields. Larger doctoral engineering programs would then dictate the policies for engineering doctoral programs, which in turn are directly related to doctoral level programmatic experiences.

Methods

To begin developing a multistage sampling methodology, an initial list of engineering graduate programs was obtained from the American Society for Engineering Education (ASEE) and pared down to isolate doctoral degree-awarding programs. The programs were distributed into six regions: Northeast, Midwest, West Coast, Southwest, Southeast, and Northwest, which were created by consolidating Environmental Protection Agency regions[7]. Figure 1 illustrates the geographic distribution of states into regions.

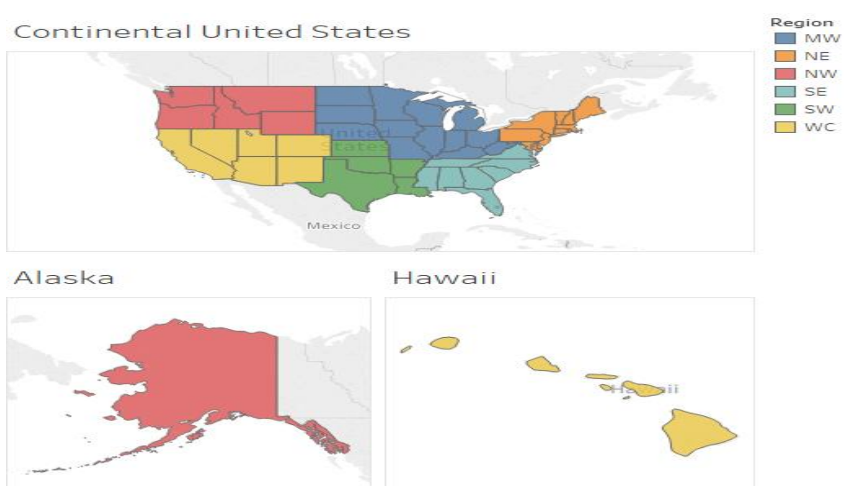

Figure 1. The geographical distribution of doctoral degree-awarding programs.

Departments received codes for academic programs based on the different engineering disciplines considered in *Engineering by the Numbers 2015* with the exceptions of computer/electrical engineering and environmental/civil engineering[4]. In these instances, engineering disciplines were separated into two distinct academic program types. To account for potential crossover in academic programs within a department, each department could be coded for no more than three academic program types. The academic disciplines considered were aerospace, biological and agricultural, biomedical, computer, chemical, civil, electrical, environmental, general, industrial, mechanical, mining, materials, nuclear, petroleum, and other engineering fields. Engineering management and computer science were also considered as distinct disciplines and were given their own appropriate codes.

Department size was imputed using the number of doctoral degrees awarded in the 2014 calendar year to each program using information gathered from Doctorate Recipients from U.S. Universities[8] as a proxy. If no information was available, the number of degrees awarded was assumed to be one. Eleven programs (n=11) did not provide information and had data imputed. Imputing a value of one for missing observations can lead to an oversampling of medium and large programs. By oversampling large and medium programs, we may increase sampling variance leading to weaker estimates of population parameters. Departments were reclassified as small (< 3 degrees), medium (3 < degrees < 9), or large (≥ 9 degrees) using quantiles as determinants for allocation. Quantiles were chosen such that each classification for size had a theoretical probability of one-third (p_s=0.3333).

While previous research considers region, departmental size, and academic program type separately in analysis, little consideration was given to all three qualities simultaneously in a multi-stage stratified sample design. Region and department size were employed as stratum. The initial population of degree programs was divided into six distinct groups based on geographic location, serving as the primary sampling units (PSUs). Sequentially, secondary sampling units (SSUs) were created by stratifying the PSUs with regard to size of the degree granting program. Finally, academic programs were sampled from the SSUs as the ultimate sampling units (USUs) using probability proportional to size (PPS). PPS is a sampling technique in which the probability of being included in a sample is proportional to a size measurement. Size was defined as frequency of the academic program type within the SSU. For departments that offer multiple academic tracks such as a department of civil and environmental engineering, if one academic program was selected in the sample, all other academic programs were automatically considered as sampling units and counted against the expected counts for each program based on size and location. This was done to ease the program recruitment process.

Results

Two hundred fifty-three academic programs have been selected from the initial pool of 1,382 programs representing 18.31% of all doctoral engineering programs that participated in *Engineering by the Numbers*. The average graduating cohort is 8.9 students[8] after accounting for missing data. Assuming a five-year commitment, then the expected number of students per program is 44.5. Based on response rates of optional surveys conducted at the University of Nevada Reno and Clemson University[9], we assume a 50% response rate to our survey once academic programs have been recruited. Based on these assumptions, 250 academic programs needed to be sampled to reach our target of at least 5,000 responses to our survey. Due to rounding error in determining how many programs should sampled from each SSU, 253 degree granting programs were selected. The distribution of these 253 programs can be seen in Tables 1-3. The theoretical proportions of departmental size are uniformly 0.3333 because departmental size was determined by the thirty-third and sixty-sixth percentile. The sample proportions were defined as the percentages of degree granting programs in the sample of 253 programs that matched a specific criterion.

Table 1. Compares the population proportion to sample proportion for departmental size.

Departmental Size	Population Proportion	Sample Proportion
Small	0.3333	0.336
Medium	0.3333	0.336
Large	0.3333	0.3281

Table 2. Compares the population proportion to sample proportion for geographic region.

Geographical Region	Population Proportion	Sample Proportion
Midwest	0.2258	0.2213
Northeast	0.2605	0.2411
Northwest	0.0456	0.0751
Southeast	0.1744	0.17
Southwest	0.1295	0.1304
West Coast	0.1643	0.1621

Table 3. Compares the population proportion to sample proportion for academic program.

Academic Program	Population Proportion	Sample Proportion
Aerospace	0.0355	0.0395
Biological and agricultural	0.0195	0.0277
Biomedical	0.0825	0.0791
Computer	0.0355	0.0356
Chemical	0.0876	0.0830
Computer Science	0.1093	0.0988
Civil	0.1020	0.0949

Electrical	0.1302	0.1186
Environmental	0.0304	0.0237
General	0.0166	0.0277
Industrial/Manufacturing/Systems	0.0666	0.0672
Management	0.0065	0.0237
Mechanical	0.1165	0.1067
Mining	0.0051	0.0119
Materials	0.0796	0.0751
Nuclear	0.0174	0.0277
Other	0.0492	0.0435
Petroleum	0.0101	0.0158

The distributions for size, geographic allocation, and academic discipline are all non-normal as seen in Figure 2.

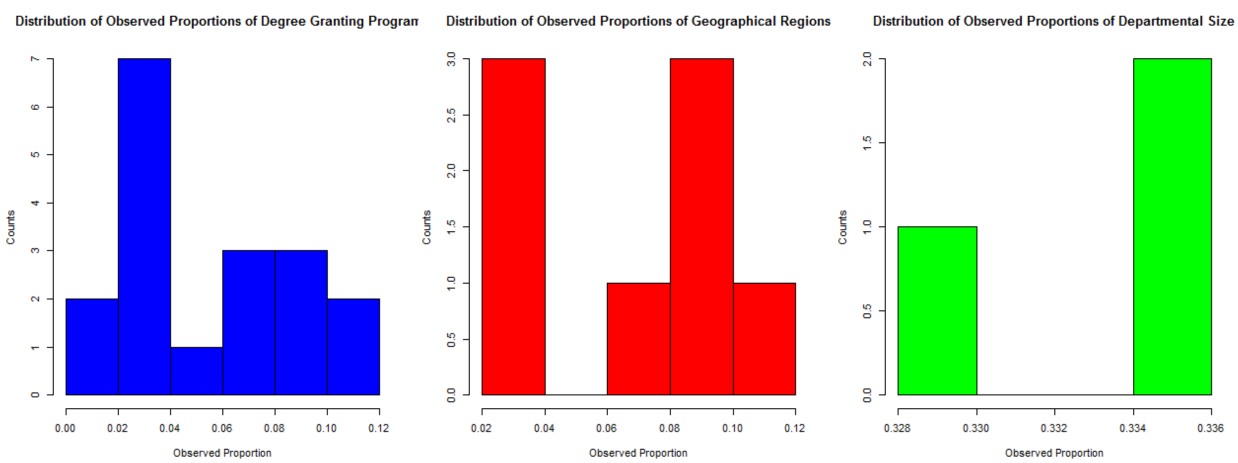

Figure 2. Illustrates the distribution for the observed proportions of degree granting programs, geographical regions, and departmental size.

To compare the population proportions to the sample proportions, we conducted three separate Wilcoxon signed-rank tests. We used the Wilcoxon signed-rank test because the distributions for size, geographical allocation, and academic disciplines were non-normal and had less than thirty observations for each variable; having non-normal data and fewer than thirty observations would violate the necessary assumptions of normality for a paired Student's t-test. We defined our null hypothesis as the true location shift parameter is zero ($\Delta=0$). The alternative hypothesis was the true location shift parameter is not zero ($\Delta\neq0$). We defined our significance level to be $\alpha=0.05$ for all tests. Applying the Wilcoxon signed-rank test to size, we observed the test statistic $W=6$

with a p-value of 0.6579. Repeating the test for region and academic program, we obtained test statistics W=19 and W=155 with p-values 0.9372 and 0.837 respectively. We failed to reject the null hypotheses on all counts. Independently all strata appeared to follow the expected distributions.

Discussion

Advantages of Multistage Sampling

Employing a multistage sampling methodology has comparative advantages over using simpler methodology. Principally, sampling frames are often available for PSUs or USUs. Stratum can easily be developed and employed with minimum input allowing a researcher to consider or mitigate secondary variables. Consequently, if a researcher decides that additional or fewer strata are needed, the methodology proposed can be easily generalized to increase or limit the probability of a person or institution being included as an USU.

Multistage Sampling has both economic and statistical benefits. Simple random sampling is both costly when implemented on a national scale and does not guarantee an accurate representation of the population. Comparatively, multistage sampling designs are considered more cost effective without sacrificing size because multistage sampling plans are designed to capture subpopulations that exist within a sampling frame. This eliminates the need to continuously conduct random sampling until all the subpopulations of interest are adequately represented. Equally as important, multistage sampling plans also retain randomness while controlling for subpopulations that need to be included in the sampling frame. Many multistage sampling plans allow contributions from different stages toward sampling variance to be estimated separately. The methodology we propose is a probabilistic sampling methodology guaranteeing that we can effectively calculate variance for our results, and it allows us to identify engineering doctoral programs for recruitment.

Disadvantages of Multistage Sampling

Although a multistage sample can afford greater control over elements of the population, it sacrifices variance compared to simple random samples. Due to the complexity of variance calculations and by ensuring a more diverse sample, multistage sampling tends to have greater estimates of variance. Without prior information about variances of subpopulations, this error can be exacerbated as highly variable groups that are included contribute significantly toward increased variance estimates. Consequently, this reduces our ability to make specific predictions about individual outcomes. Additionally, the rationale behind stratum may be fundamentally flawed. Strata potentially could be found unnecessary and can complicate the sampling process. The use of proxies to estimate elements can lead to faulty conclusions about the distributions of data and thus alter variance estimates. In the case of the sampling methodology we propose, the use of doctoral degrees awarded by each department demonstrates this possibility. Due to the lack of available data, we imputed one for the number of degrees awarded four times. By underestimating departmental size, we now face the possibility of over representing medium and large sized engineering doctoral programs by misclassifying those programs as small. This can lead to poor estimations of variances.

Future Work

The sampling methodology has generated a nationally-representative sample of engineering doctoral programs by stratifying by location, degree type, and departmental size. We will proceed by contacting department heads and graduate program administrators of selected engineering doctoral programs to assist with survey promotion and distribution. The large number of responses will provide our analysis with the statistical power to identify and measure the significance of identity and motivational profiles of doctoral engineering students.

Acknowledgements

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