Development of a Curriculum for Service Systems Engineering Using a Delphi Technique

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Abstract

The U.S. economy has gradually changed from one based in agriculture, to one focused on manufacturing, to one now that relies heavily on the service sector. The service sector, including governmental agencies, retail stores, the entertainment business, public utilities, and providers of similar services, now makes up more than 80% of the total U.S. economy. Engineering programs, which typically have their roots in the era of manufacturing, have a focus on the design and fabrication of "products" rather than the design and creation of service systems. While curricula such as engineering management and industrial engineering provide some support to service systems engineering, their legacies are tied to the manufacturing sector, and as a result, they are not optimized to support the service sector. With this in mind, a Delphi Study was performed to identify the features, characteristics, and topics relevant to a service systems engineering curriculum. This paper describes the planning, conduct, and results of the service systems engineering Delphi Study and how this information is being used to establish a new degree program.

Introduction

The modern-day engineering profession has its origin in the 14th century when individuals such as Leonardo daVinci were hired to design better weapons or better defenses, depending on the client.[3] Early engineers were engaged in the art of war – building better roads, bridges, and sanitation systems. Soon, the civilian population demanded luxuries such as those afforded the army, giving birth to civil engineering. With the dawn of the Industrial Age, mechanical engineering evolved to feed the need for individuals who could design and build efficient steam-powered machinery. Electrical and chemical engineering soon followed as the standard of living continued to improve in the developed world. Engineering disciplines have continuously evolved throughout history, giving birth to disciplines such as biomedical, computer, and aerospace. Throughout its long history, however, the engineering profession has been clearly focused on designing better devices, mechanisms, objects, and the processes used to realize these articles.

At the same time the engineering profession evolved to meet the needs of society, the economic basis for society also changed dramatically, due in large part to the technological advances that were developed. Two hundred years ago, the economy was primarily based on agricultural production. Manufacturing superceded agriculture in terms of size, employment, and importance during the twentieth century. Today's economy is based largely upon the service sector, with the service sector now accounting for nearly 80% of all economic activity in the U.S., far

outstripping manufacturing (14%) and agriculture (2%).[8] In addition, the service sector dominates the employment picture (78.6%) as compared with manufacturing, construction, mining, and agriculture (21.4%).[10]

In July 2001, the National Science Foundation sponsored a Workshop on Engineering the Service Sector, highlighting the significance of the service sector to the economy as well as the importance of engineering applied to the service sector.[5] An outcome of the workshop was the creation of the Service Enterprise Engineering program within the NSF Division of Design, Manufacture, and Industrial Innovation in recognition of the need for engineers to work within the service sector in order to improve this sector's productivity. Tien and Berg note that "despite the growing role that services play in the U.S.'s economic well-being, productivity in the service sector has shown limited growth."[10] They further note that one of the reasons that the service sector is such a large part of our economy today is due to its inefficiency – especially in terms of government services. However, as other countries begin to provide services, our own service industries must improve their productivity in order to remain competitive.

In May of 2004 the National Academy of Engineering unveiled its report "The Engineer of 2020".[7] In this report the need for engineers to be involved in solving the problems of the service sector industries is clearly articulated. However, even though NSF and the NAE recognize the need for engineers to work within the service sector, present-day engineering curricula are inadequately suited to meet the needs of the sector. The curricula reflect a focus on designing and building better machines, instruments, and other devices or manufacturing processes. Major design experiences are geared towards solving problems in the manufacturing and construction industries. Thus, if we are to better serve society and students for work in the 21st century, we believe that it is essential to provide them with an engineering career path aimed at the service sector.

In response to the need for a service systems engineering curriculum, the authors received a planning grant from the Department Level Reform program of the National Science Foundation in September 2003. Through this grant we conducted a Delphi Study to define a new engineering discipline – Service Systems Engineering. The remainder of this paper outlines the Delphi technique as we applied it to this project and presents our results obtained to date.

Delphi Technique for Curricular Design

A Delphi Study is a consensus-building forecasting technique that has been used by organizations, agencies, and corporations for making predictions and setting agendas. Although this technique was developed in the "business world," a number of educational leaders have suggested its use in the design of curricula and programs.[2, 9, 11, 13] In this context, a Delphi Study typically consists of four rounds, conducted with a panel of experts, to reach consensus on defining the important elements of a curriculum. A Delphi Study also lends itself to reaching a consensus without the need for face-to-face meetings among panel members, making the study relatively easy to implement, especially for a panel with broad geographic representation among its members. For these reasons, we employed the Delphi technique in the development of the curricular requirements for the Service Systems Engineering discipline.

In general, a Delphi study for curricular design comprises surveys in four rounds. During the first round, a survey instrument is prepared with curricular topics listed by categories. Within each category are several characteristics. In this round, panelists rate each item using a Yes/No scheme – Yes if they agree that the category/characteristic belongs in the curriculum, No if they do not agree. Panelists are also free to add new items to the categories/characteristics or they can move things from one category to another. Results from the first round of the survey are used to create the second survey instrument, with some items deleted from the categories and some added to them. For the second survey round, panelists are asked to rate each item using a 4- or 5-point Likert scale, with 5 being very important and 1 not important. Categories and characteristics that receive low rankings are deleted from the survey and a new instrument is prepared. For the third round, panelists are asked to rank-order the categories as well as the characteristics within each. Results from rounds 2 and 3 are combined to create the survey instrument for the final round. In the final round, surviving categories and characteristics are again rated using a Yes/No scheme – Yes for items that must be included in the curriculum and No for those that are not critical. Analysis of results from the fourth round should be the "consensus" opinion of all panel members.

Delphi Study for Service System Curriculum Development

In September 2003, Michigan Tech received a planning grant from the Department-Level Reform program of the NSF to define a new engineering curriculum with the help of industry leaders – Service Systems Engineering. We have recently completed our Delphi study and through this we have identified several components of a curriculum for this new discipline.

Brainstorming Session

In December 2003, we conducted a brainstorming session with several industry leaders on the campus of Michigan Tech to help us identify topics that might be important for the curriculum. The authors of this paper also participated in the day-long session. Table 1 provides a list of the curricular topics identified by these leaders.

Panel of Experts

A key to conducting a Delphi Study for curricular design is to identify and recruit an appropriate panel of experts. For our planning grant activities, we contacted program officers at NSF, attended an NSF-sponsored conference on engineering the service sector, met with individuals from various industrial advisory boards associated with Michigan Tech, and networked with others identified through our efforts. We sent a letter to potential panel members asking for their assistance in defining the curriculum.

Approximately 21 leaders from a range of service industries agreed to participate as members of our panel of experts. The major service sectors represented were: 1) universities, 2) health care services, 3) banking, insurance, and legal services, 4) technology and engineering services, 5) shipping and transport, 6) consumer and retail services, 7) utilities and communications, and 8) community services. It should be noted that not all panelists returned the survey in all rounds, so the sample size (n-values) differed slightly from one survey round to the next. The years of experience for the panelists ranged from 6 to 43 years with a mean of 22 years. Consultant was the most frequently checked occupation category (n = 4).

Table 1: Topics identified from brainstorming session

• How an organization works	• Modeling processes
• Psychology – creativity, innovation	• Data collection/management/analysis
• Resource Allocation	• Statistical work
• Customer/client relations	• Supporting metrics with tools
• Service systems – measurement, metrics	• Domain knowledge
• Leadership and change management	• Optimization/networks
• Management/management philosophy	• Queuing
• How does an individual make decisions?	• Simulation
• Organizational decision making	• Legal issues
• Identifying organizational processes	• Project management
• Documenting how processes work	• Scheduling
• Reference Models (SCORE, ITIL)	• Risk assessment, insurance
• Performance Metrics	• Estimation, bidding
• Benchmarking	• Government issues
• Six Sigma, Reliability	• Regulations/compliance
• Quality Assurance	• Budgeting/accounting
• Perfect Order Performance	• Finance/economic justification
• Decision making	• Algorithms/computing

Round 1 – Delphi Study

After establishing our panel of experts and identifying potential curricular topics, we began the Delphi Study. For the first round of the study, we developed a survey instrument that was based on examples from previously successful curricular Delphi studies.[1, 6, 12] This instrument contained several categories and characteristics that might be relevant to a Service Systems Engineering curriculum. In the first round, experts were asked to accept, modify, delete, or add to the list of categories and characteristics on the instrument. Panel members then had several options: 1) they could state that an entire category should be deleted, 2) they could select individual characteristics from each list for deletion, 3) they could add to the list of characteristics within a category, or 4) they could rename individual characteristics. In addition, panel members were allowed to move characteristics from one category to another if deemed necessary. When developing our instrument for round one, we took care to ensure that all categories and characteristics were listed randomly (structured ordering within the survey might bias the feedback from panel members).

The survey for Round 1 consisted of 9 major curriculum sectors/categories, each containing multiple characteristics. A total of 50 characteristics were available across the 9 categories. We asked survey respondents to Accept or Reject each characteristic and to provide specific comments about other items that needed to be included, or general comments. We obtained a variety of demographic data: gender, years of experience, terminal degree, and occupation. The Round 1 survey was distributed by regular mail, and responses were returned either by mail or

facsimile. Nine of the 50 items were rejected by greater than 50% of the respondents and we received many valuable comments and suggestions for characteristics to add.

Round 2 – Delphi Study

Based on the Round 1 survey data we added and deleted items and reorganized the curricular topics into 6 major categories: Analysis Skills, Interpersonal Issues, Business Management and Finance, Service Processes and Systems, Management and Operation of Service Systems, and Public Policy and Law. We asked respondents to rate each item on a 5 point Likert scale with "1" denoting "Not Important" and 5 "Important." To compare mean scores of items we performed an analysis of variance, treating respondents as blocks and items as treatments. We conducted this analysis for each major category. If we found a significant difference among item mean scores ($p < 0.05$) we then compared items using Bonferronni pairwise comparisons. We also asked each respondent to rate the 6 main categories.

We received n = 20 completed surveys in Round 2. Of the 6 main categories, the "Public Policy and Law" category received the lowest overall score (mean = 3.4), with "Analysis Skills" and "Interpersonal Issues" receiving the highest mean scores of 4.5. Five of the 6 categories had significant differences among item mean scores, the exception being "Public Policy and Law" in which all items received uniformly low scores with means ranging from 3.1 to 3.7. Within the category "Analysis Skills", computer programming and database design received significantly lower mean scores. The mean scores for the other items were not significantly different. In "Interpersonal Issues", public relations and dispute resolution received low scores. In "Business Management and Finance" marketing had the lowest mean and project costing and change management the highest scores. Other characteristics receiving significantly lower scores within their categories were simulation (Service Processes and Systems) and human resources (Management and Operation of Service Systems). Items with mean scores significantly lower than the other items within a category were eliminated for subsequent Delphi rounds.

Round 3 – Delphi Study

In Round 3, each respondent was requested to rank order the items within each major category. The six categories each contained approximately 6 items of interest, and therefore, an item rank ordered as 1 was the most important, and an item rank ordered as 6 was the least important. The major topic categories were also rank ordered based on their importance. Treating each respondent as a block and the 6 items as the treatments, we employed Friedman's test to check for significant differences ($p < 0.05$) between mean rankings. If significant differences were found we conducted pairwise comparisons among the mean rankings to further test for differences.

We also requested each respondent to identify 10 of the 36 characteristic items that they thought should be included in a service systems curriculum. We calculated the fraction of respondents who checked each item and compared the calculated proportions using an analysis of means for proportions.[4]

We received n = 19 responses for Round 3. Considering the 6 major categories, we found that there were significant differences among the mean rankings (p = 0.019). The lowest mean rankings were associated with interpersonal skills and analytical skills (Table 2). It should be remembered that a lower value for the mean rank indicates greater importance.

Table 2. Mean Rankings for 6 major categories.

Category	Mean Rank
Interpersonal Skills	2.08
Analysis Skills	2.58
Business Management	3.25
Service Processes	3.42
Operation of Service Systems	4.25
Management of Service Systems	4.92

In considering the rank order means associated with the items within the six major categories, the statistical analysis revealed several conclusions. Within the category "Analysis Skills", there were significant differences among the mean rankings (p = 0.021). The highest mean rank (least important item) was received by simulation (mean = 4.63) and the lowest mean (most important item) was received by probability and statistics (mean = 2.79). For the category "Interpersonal Issues" there were no significant differences among the mean rankings (p = 0.11), as means ranged from 3.1 for verbal skills to 4.6 for facilitator skills. For "Business Management", the differences in means were borderline significant (p = 0.06). The lowest mean rank was 2.8 for project costing and budgeting and the highest mean rank was 4.5 for cost accounting. In the category "Service Processes" the mean ranks were significantly different (p = 0.01). The performance measurement item had the lowest mean rank (2.3) and lean concepts the highest mean rank (4.6). For "Operation of Service Systems" the mean ranks were significantly different (p = 0.002). Process evaluation and improvement received the lowest mean rank (2.2) and safety the highest (4.8). In "Management of Service Systems" the item mean ranks were significantly different (p = 0.017) ranging from 2.6 for scheduling to 4.7 for liability.

In considering the proportion response (fraction of respondents checking an item as being one of the ten most important items in the survey), three of the 36 items evaluated received significantly more selections than the other characteristic items. These items were Problem Solving (13 of 19), Economic Decision Analysis (11 of 19), and Technical Writing (11 of 19).

We then examined in detail the combined results of Rounds 2 and 3. This examination included assessing the relationship between the item mean scores from Round 2 (large value indicates greater importance) and item mean rank order from Round 3 (small value indicates greater importance). The relative importance of a characteristic item was judged by comparing its mean Round 2 score to the overall mean of Round 2 and its mean rank to the overall mean rank from Round 3. High priority items were considered to be those characteristic items with mean ranks below the average and above average mean scores, whereas an above average Round 3 mean rank and below average Round 2 mean score indicated a low priority characteristic item and a

candidate for elimination. We also conducted a principal components analysis to produce a composite score for each characteristic to facilitate prioritization of characteristics.

Thirteen characteristics had below average Round 3 mean ranks and above average Round 2 mean scores. Figure 1 shows the results from this analysis; in this figure, items in the lower right corner of this were deemed more important (higher than average on the Likert scale, lower than average on the ranking). The best composite scores were attained by the characteristics of process performance measurement and of process evaluation and improvement. The remaining characteristics with below average Round 3 ranks and above average Round 2 mean scores were task breakdown, change management, technical writing, professional responsibility, quality improvement, leadership, verbal skills, risk analysis, project costing, and flowcharting (see Figure 1). These characteristics received among the best composite scores as well. Other characteristics that received high composite scores that are not shown in Figure 1 were scheduling, customer relations, planning, and probability and statistics.

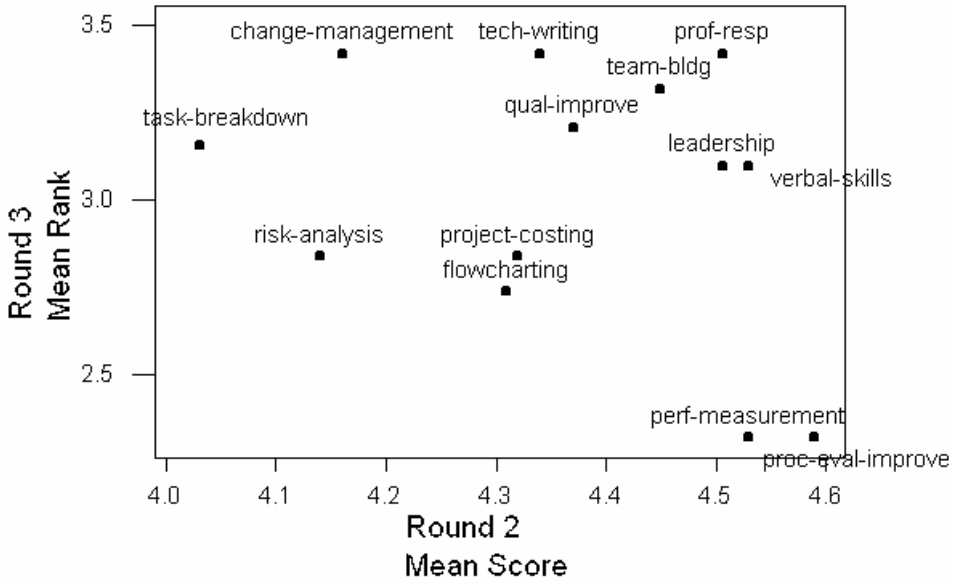

Figure 1. Items receiving below average mean ranks (Round 3) and above average mean scores (Round 2).

Round 4 – Delphi Study

A new survey instrument was developed based on the results from Rounds 2 and 3. For this round, surviving categories and characteristics were presented to the panelists who were asked to rate them as "Yes" (the topic *must* be included in the service systems curriculum) or "No" (the topic *need not be* included in the curriculum). Items were selected for inclusion when at least 75% of the panelists agreed that they *must* be a part of the service systems curriculum. Table 3 gives the results from this final round of the Delphi Study.

Table 3. Categories and Characteristics of Service Systems Curriculum

Category	Characteristics
Analysis Skills	Problem Solving Economic Decision Analysis Risk Analysis Cost Estimating Probability & Statistics
Interpersonal Issues	Professional Responsibility Verbal Skills Leadership Technical Writing Facilitator Skills Team Building
Business Management	Project Costing Business Planning Change Management
Service Processes	Performance Measurement Flowcharting Work Task Breakdown
Operation of Service Systems	Process Evaluation & Improvement Quality Improvement Customer Relations Risk Management
Management of Service Systems	Scheduling Budgeting MIS

The results from the Delphi Study will now be used to design the specific courses that will make up the Service Systems curricula. The challenge will be in making sure that the curriculum we design is viewed as an "engineering" curriculum in the eyes of external constituencies. One of the possibilities that we are considering is to include enough "traditional" topics (statics, mechanics of materials, thermodynamics, etc.) in the program to: a) fully develop a student's problem-solving skills, b) satisfy external constituencies (including ABET) that this really is an engineering degree program, and c) enable our graduates to sit for the Fundamentals of Engineering exam to obtain eventual licensure. We will be working in the coming year to fully develop the courses in this innovative new program.

Summary and Conclusions

The Delphi technique for consensus-building was successfully employed in this study to define the characteristics of an emerging engineering discipline – Service Systems Engineering. Through input from a panel of experts, elements of the curriculum were identified to meet the needs of the service sector industries. Through these planning activities we are now poised to begin the development of a curriculum aimed at service systems engineering.

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