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Trends of systems engineering job postings and their implications for curriculum development

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Trends of Systems Engineering Job Postings and their Implications for Curriculum Development

Recent studies in systems engineering indicate that the design, development, and management of systems will continue to increase in complexity. The foreseen growth is expected as future capabilities require understanding the system and its operating environment, adapting to rapid-changing scenarios, integrating more independent hardware and software elements, and coordinating with multiple stakeholders across the system's lifecycle, among others. To develop the next generation of systems, alignment between industry needs and curricula from higher-education institutions should exist. Therefore, this research contributes to the human capital development of systems engineering in the United States by exploring current job opportunities and their relationship to existing academic offerings in Hispanic-Serving Institutions. The study analyzes job openings from INCOSE's CAB Members to capture current needs in terms of role description lifecycle experience, tools, and methodologies needed in the job market, and it explores the relationship of systems engineering methodologies covered in Hispanic-Serving Institutions. The outcome of this research provides a direction to support the development, adoption, and update of higher-education systems engineering curriculum that aligns with current industry needs.

Keywords: *systems engineering, curriculum development, workforce development, job posting analysis, MBSE, digital engineering*

Introduction

The design, development, and management of complex systems are expected to continue increasing in complexity as traditional federated systems transition towards multidisciplinary collective systems that incorporate software, networks, and decentralization concepts. Complexity is reflected in the integration of independent systems to create new capabilities, an increase in the number of interfaces to be managed, behavioral adaptation to rapidly evolving scenarios, more lines of code to be written, and participation of more stakeholders across the system's lifecycle. For example, the Mars Pathfinder was launched in 1997, at the time it consisted of 4 instruments with approximately 850 functional interfaces. In 2003, the Mars Exploration Rover incorporated 9 instruments resulting in 1750 functional interfaces. The recent Mars Science Laboratory Mars 2020 Perseverance included 8-10 instruments for an estimate of 2,500 functional interfaces [McKelvin, et al., 2015]. In another example, Lockheed's Martin F-22 Raptor has an estimate of 1.7 million lines of code while the F-35a includes almost 8 million lines of code [Capaccio, 2021]. Following previous examples, it could be seen that existing engineering methods, tools, and processes would be overwhelmed by the increasing complexity and characteristics of emerging digital systems such as Cyber-Physical Systems, Industry 4.0, Model-Based Engineering, and Society 5.0.

Professional and government organizations have recognized the need to approach emergent digital systems from a holistic perspective. For example, the Department of Defense in its digital Engineering Strategy recognizes the need to transition from document-centric to model-centric approaches by formalizing the use of models as methods for managing the system ((ODASD(SE)), 2018). It also emphasizes the concept of transforming the current culture and setting the basis for training the future workforce. In addition, the International Council on Systems Engineering (INCOSE) in its Systems Engineering 2035 vision identifies the roadmap for the future trends, workforce competencies, practices, and challenges for the discipline of systems engineering in the following years [INCOSE, 2022]. The report suggests the implementation of the two perspectives when seeking to approach future systems: the socio-technical systems and the system-of-systems viewpoint. In terms of expected competencies, modeling and simulation are expected to grow by exploiting Model-Based Systems Engineering, Immersive visualizations, and semantic web technologies. Also, data-driven approaches such as Machine Learning, Artificial Intelligence, and High-Performance Computing will play a key role in leveraging more complex systems.

As organizations work on a digital transformation and train their workforce in the development of new skills, it is key that higher education institutions understand and translate the present and future skills and competencies, required to develop complex systems. This paper contributes to the future workforce development of systems engineering by analyzing job openings from INCOSE's CAB Members to capture current needs in terms of role description lifecycle experience, tools, and methodologies needed in the job market, and it explores the relationship between systems engineering methodologies covered in HSI institutions

Dataset

To identify future trends in the systems engineering workforce and the relationship to Hispanic-Serving Institutions, data extracted from the INCOSE Corporate Advisory Board (CAB), Worldwide Directory of Systems Engineering and Industrial Engineering Program, which is a directory created by the Systems Engineering Research center and INCOSE, and a current list of Hispanic-Serving Intuition members of the Hispanic Association of Colleges and Universities and the National Center for Education Statistics.

Systems engineering job descriptions were extracted using two keywords: Systems Engineer and Systems Engineering. Data were collected from June 2021 to August 2021 for a total of 25 INCOSE CAB organizations. The analysis resulted in a total of 150 job descriptions from domains including defense, aerospace, engineering solutions, automotive, and healthcare.

Methodology

To create an aggregated reference dataset for the analysis of job descriptions, the framework in **Figure 1** was implemented. The initial step is to identify what organizations offer systems engineering jobs. It has been previously identified that searching for systems engineering jobs may retrieve job descriptions dedicated to electrical engineering majors that focus on network and communications rather than on the lifecycle management of a system. Hence, to extract only systems engineering jobs that fit our understanding of systems engineering, organizations recognized as INCOSE CAB members were selected. By becoming a CAB member, affiliated organizations can access strategic guidance for the development of elements and standards that meet their needs.

The focus of the study is the job description in system engineering, therefore data collected consisted only of industry organizations and government entities such as Federally-Funded research development centers (FFRDC) and institutions. Next, to identify job descriptions, organizational careers websites were accessed to identify current job openings. For instance, if company X was identified, the Careers Section was reviewed from company X using the keywords: Systems Engineer and Systems Engineering. Then, the job description was aggregated to a data frame for analysis based on organization domain, roles, life cycle phase, tools, and methodologies. Each indicator was explored using frequency distribution to derive such patterns.

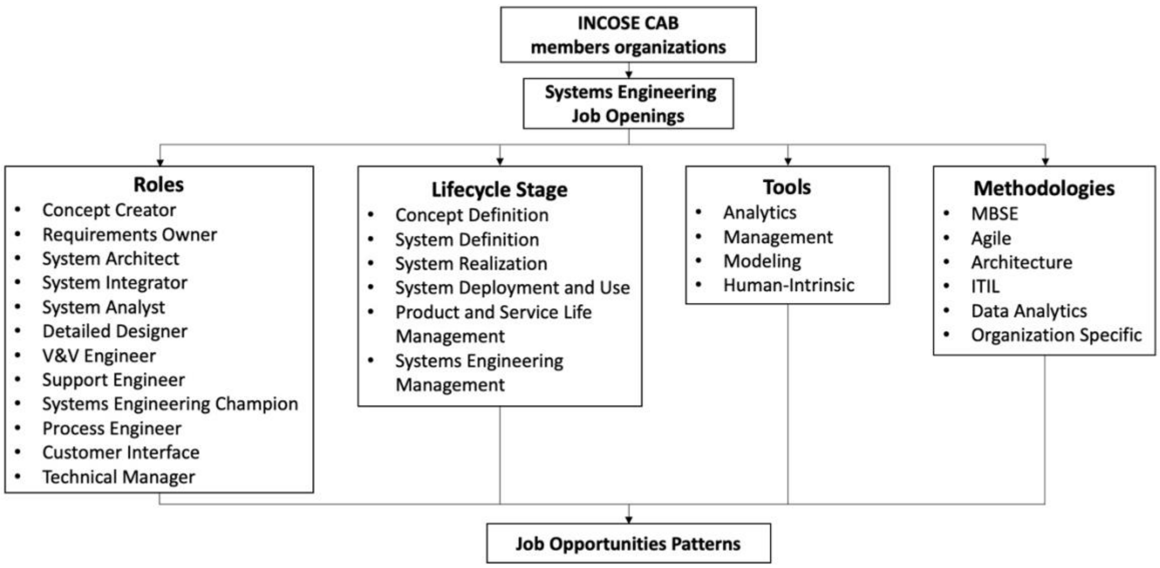

Figure 1. Methodology for systems engineering job description

1. Patterns in Systems Engineering Roles

Emergent parents for activities were captured by using the roles defined by the Systems Engineering Research Center through the Helix Project. In the manuscript "The Roles of Systems Engineers Revisited" [Hutchison, Wade, and Luna, 2017] and Atlas 1.1 "An update to the Theory of Effective Systems Engineers" [Hutchison, et al., 2018], researchers classified 15 systems engineering roles into three main clusters as seen in Table 1:

- Roles Focused on the System Being Developed – These roles are what may most quickly come to mind when describing a systems engineer. They are roles that align closely with the systems engineering lifecycle and the critical activities systems engineers must enable throughout the lifecycle.
- Roles Focused on SE Process and Organization – These roles focus on the organizational context in which systems engineering occurs and the critical role of systems engineers in guiding how systems engineering should be utilized.
- Roles Focused on Teams That Build Systems – Systems engineering does not occur in a vacuum; it is, instead, an intensely social discipline. The roles in this category are those that focus on enabling diverse, multi-disciplinary teams to be successful.

Table 1. The roles of systems engineers identify by Hutchison, Wade, and Luna [2017].

Role Name	Role Description
Focused on the Systems Being Developed	
Concept Creator	An individual who holistically explores the problem or opportunity space and develops the overarching vision for a system(s) that can address this space.
Requirements Owner	Individual who is responsible for translating customer requirements to system or sub-system requirements; or for developing the *functional* architecture.
System Architect	An individual who owns or is responsible for the architecture of the system.
System Integrator	Individual who provides a holistic perspective of the system; maybe the 'technical conscience' or 'seeker of issues that fall in the cracks' – particularly, someone who is concerned with interfaces.
System Analyst	Individual who provides modeling or analysis support to system development activities and helps to ensure that the system as designed meets the specification.
Detailed Designer	Individual who provides technical designs that match the system architecture; an individual contributor in any engineering discipline who provides part of the design for the overall system.
V&V Engineer	An individual who plans conducts or oversees verification and validation activities such as testing, demonstration, and simulation.
Support Engineer	Individual who performs the 'back end of the systems lifecycle, who may operate the system, provide support during operation, provide guidance on maintenance, or help with disposal.
Focus on Process & Organization	
Systems Engineering Champion	Individual who promotes the value of systems engineering to individuals outside of the SE community - to project managers, other engineers, or management.
Process Engineer	Individual who defines and maintains the systems engineering processes as a whole and who also likely has direct ties into the business. This individual provides critical guidance on how systems engineering should be conducted within an organizational context.
Focus on Teams That Build Systems	
Customer Interface	An individual who coordinates with the customer, particularly for ensuring that the customer understands critical technical details and that a customer's desires are, in turn, communicated to the technical team.
Technical Manager	An individual who controls cost, schedule, and resources for the *technical* aspects of a system; often someone who works in coordination with an overall project or program manager.
Information Manager	Individual who is responsible for the flow of information during system development activities. This includes the systems management activities of configuration management, data management, or metrics.

Coordinator	Individual who brings together and brings to agreement a broad set of individuals or groups who help to resolve systems-related issues. This is a critical aspect of the management of teams.
Instructor/ Teacher	An individual who provides or oversees critical instruction on the systems engineering discipline, practices, processes, etc. This can include the development or delivery of a training curriculum as well as academic instruction of formal university courses related to systems engineering.

Systems Engineering jobs and their Lifecycle Stage

The second classification is related to the lifecycle phase where the job position is needed. To map a job description to the respective lifecycle stage, the desired activities were contrasted against the six generic lifecycle phases identified by Luna, Partacz, and Hutchison [2018] in the Discovering Career Patterns in Systems Engineering. Table 2 describes the activities conducted at each phase.

Table 2. Definition of life cycle phases according to Luna, Partacz, and Hutchison, [2018]

Lifecycle Stage	Definition
Concept Definition	A set of core technical activities of SE in which the problem space and the needs of the stakeholders are closely examined. This consists of the analysis of the problem space, business or mission analysis, and the definition of stakeholder needs for required services within it.
System Definition	A set of core technical activities of SE, including the activities that are completed primarily in the front-end portion of the system design. This consists of the definition of system requirements, the design of one or more logical and physical architectures, and analysis and selection between possible solution options.
System Realization	The activities required to build a system, integrate disparate system elements and ensure that a system meets both the needs of stakeholders and aligns with the requirements identified in the system definition stage. This includes integration, verification, and validation (IV&V).
System Deployment and Use	A set of core technical activities of SE to ensure that the developed system is operationally acceptable and that the responsibility for the effective, efficient, and safe operations of the system is transferred to the owner. Considerations for deployment and use must be included throughout the system life cycle. Activities within this stage include deployment, operation, maintenance, and logistics.
Product and Service Life Management	Deals with the overall life cycle planning and support of a system. The life of a product or service spans a considerably longer period than the time required to design and develop the system. This stage includes service life extension, updates, upgrades, modernization, and disposal and retirement. The organizations in the current sample are primarily concentrated on new development, so this is a very under-represented aspect of the life cycle.

Systems Engineering Management	Managing the resources and assets allocated to perform SE activities. Activities include planning, assessment and control, risk management, measurement, decision management, configuration management, information management, and quality management. These activities can occur at any point in the systems engineering lifecycle.

Tools

This classification refers to both the logical and physical tools required to design, analyze, and manage systems engineering activities, and the soft skills desired from a candidate. Tools identified are used for designing, and developing new processes, analyzing system behavior in terms of performance or effectiveness, and lastly for system management via monitoring of performance through a measure of performance parameters [Fanjiang, et al., 2005].

Methodologies

A methodology is defined by the processes and frameworks required to design, develop, and manage systems. It includes life cycle management, quality improvement, modeling and simulation, and similar process.

To infer patterns from the 150 systems engineering job descriptions extracted from INCOSE CAB member's careers websites, a data frame was created to facilitate its manipulation across multiple attributes such as organization, domain, role description, life cycle, tools, and methodologies. The study provides insights based on aggregated data consisting of seven domains including Defense, Engineering Solutions which refer consulting services, Aerospace, Automotive, Defense, FFRDC, Healthcare, and Manufacturing. Data was collected from all 25 organizations starting June 2021 to August 2021.

The first analyzed scenario consisted of understanding the aggregated data in terms of domain and sample size. To do so, each organization was classified according to its main associated industry or services provided. In **Figure 2**, it can be observed that 67% of the 25 identified organizations belong to the Defense sector. The second domain with more relevance is Engineering Solutions, which refers to enterprises that offer a range of wide range of services, rather than self-identifying with a single domain. The analysis indicates that 21% of the total positions identified relate to Engineering Solutions organizations. In summary, 98% of the overall dataset includes domains such as aerospace, automotive, and government organizations such as FFRDC. Hence, it can be deduced that Defense and Engineering Solutions domains are the two sectors that had the more systems engineering openings.

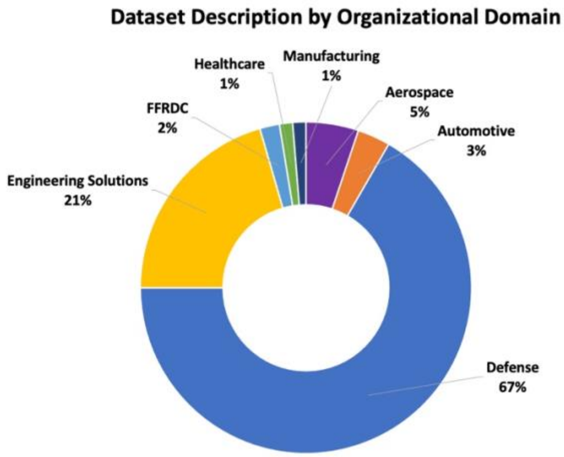

Figure 2. Distribution of systems engineering job descriptions by domain

The second analysis seeks to understand how the activities from job descriptions relate to the Systems Engineering Roles description by Hutchison, Wade, and Luna [2017]. The purpose of role classification is to capture activities and requirements for content and curriculum instruction at higher-education institutions. **Figure 3** indicates that the roles with higher demand are:

- 1) System Analysis - Individuals who support system development by providing modeling and simulation expertise.
- 2) Support Engineer - Individual who may support the operation, sustainment, maintenance, or disposal of the system
- 3) Requirements Owner – Individual responsible for translating stakeholder needs to system or sub-system requirements or developing a functional architecture.
- 4) System Architect – Individual responsible for the system architecture.

The aggregated data suggests a need for individuals who can support system development from initial concepts including mission and business analysis to the system disposal activities. Key understanding of activities such as translating customer's needs into formal requirements; design, development, and maintenance of system architecture, and use of modeling and simulation tools to explore system behaviors during given scenarios.

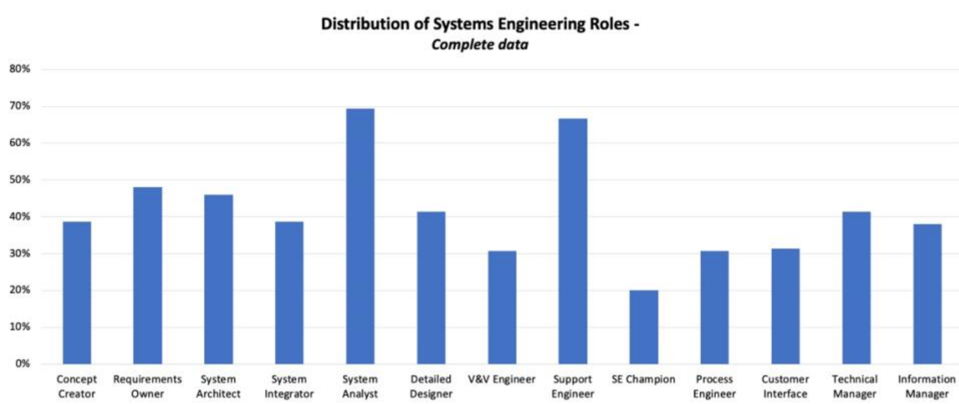

Figure 3. Classification of job descriptions to systems engineering roles

In terms of life cycle needs, **Figure 4** indicates that almost two-out-of-three available positions require some level of experience in Systems Engineering Management. The candidate is expected to have proficiency in managing and allocating resources to perform systems engineering activities. Also, the individual is expected to be familiar with activities relevant to assessment and control, risk management, decision management, configuration management, information management, or quality management. The findings from the life cycle phase analysis will serve as a foundation to assess current universities curriculums that meet current offerings to existing job requirements.

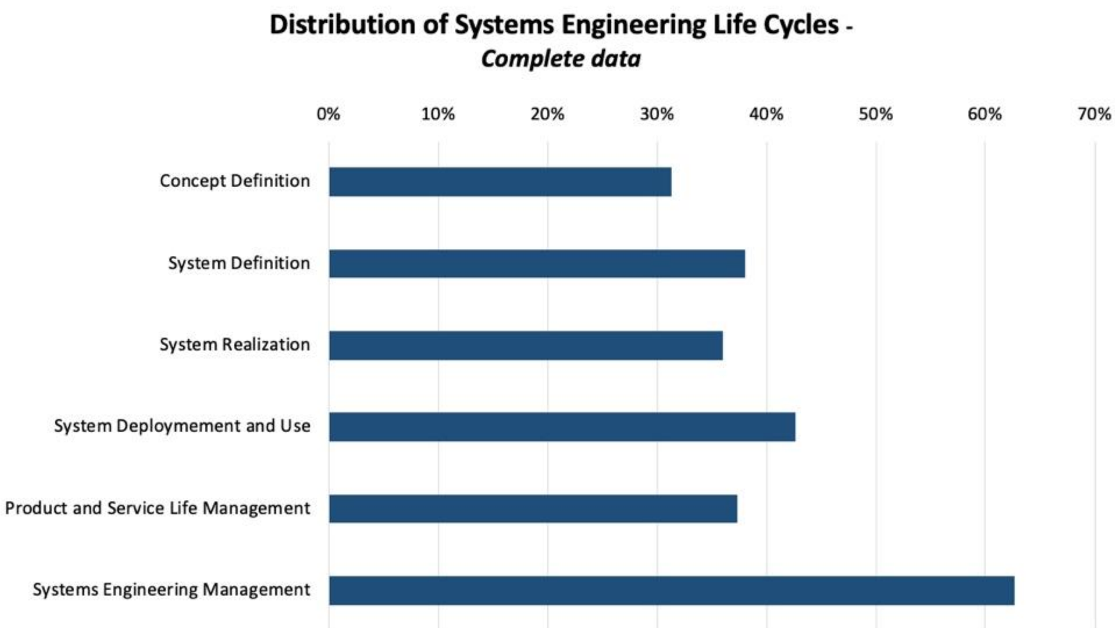

Figure 4. Classification of job descriptions to system life cycles phases

Once the needs for role activities and life cycle experience were captured, the study focused on analyzing the data to investigate what tools are currently used in the systems engineering job market. **Figure 5** provides a frequency of multiple tools used by organizations across multiple domains. The data indicate that systems engineers are expected to be effective communicators by having strong verbal and written communication skills, which are relevant indicators for a need to develop not only strong technical but also soft skills in the engineering discipline. Furthermore, it has been found that tools for Model-Based Systems Engineering (MBSE), agile methodologies, and programming languages are three clusters of systems engineering tools. Tools relevant to MBSE including Systems Engineering Modeling Language (SysML) and Cameo Enterprise Modeler developed by Dassault Systems were found to be relevant as more than 30% of descriptions mentioned their implementation. The second cluster related to agile project management indicates that Jira developed by Atlassian, and SCRUM principles are of interest when developing rapid-evolving systems. Lastly, programming tools such as Python, C++, and Java indicate the need for systems engineers to be familiar with coding and development of scripts, while using GitLab is for the data repository.

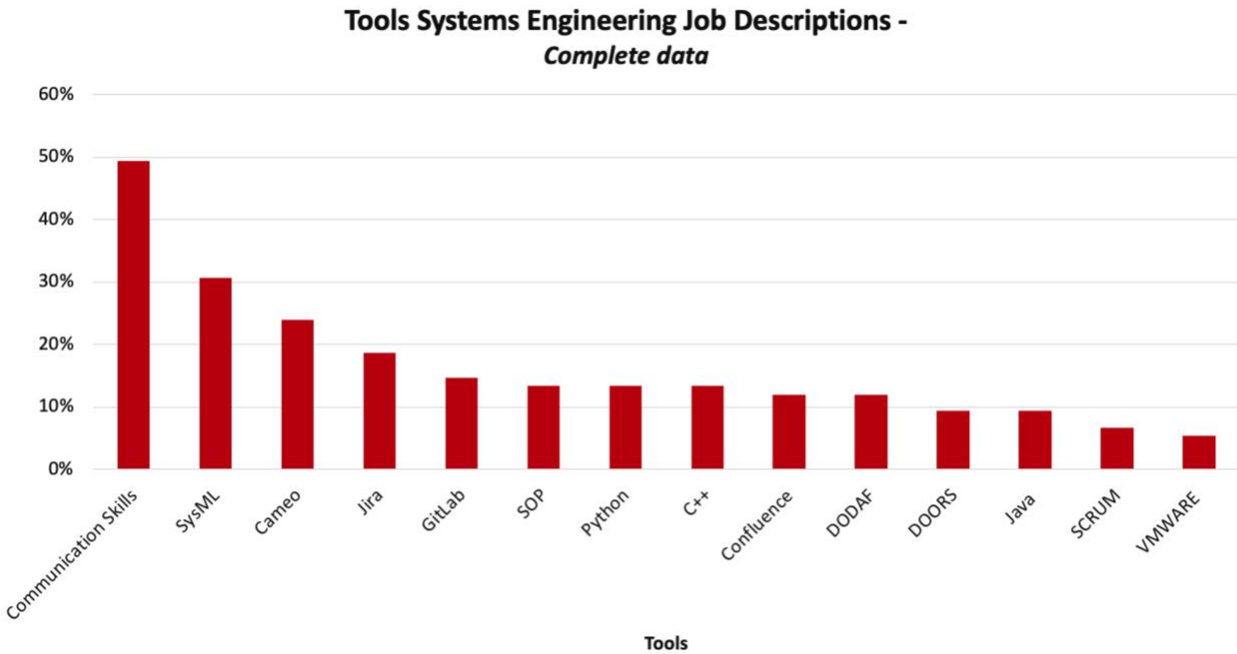

Figure 5. Tools described in systems engineering job descriptions.

The last analyzed pattern at the aggregated level was Methodologies. The process consisted of analyzing job descriptions to capture emerging processes and frameworks to design, develop, and manage systems of interest. Results from **Figure 6** indicate consistency with INCOSE's 2035 vision and the DoD Digital Engineering Strategy. Organizations are exploring how to leverage concepts such as an authoritative source of truth via digital models to enhance the development and management of systems. The analysis indicates that Model-Based Systems Engineering principles are desired in 1 out of 3 job descriptions suggesting the need for candidates to be familiar with its processes. The second most described methodology is the Agile development strategy which indicates a current trend for incremental and iterative processes. Also, the development of reference architectures is of significant interest including experience with architecture frameworks such as Modular Open Systems Approach (MOSA), Department of Defense Architecture Framework (DoDAF), and the Information Technology Infrastructure Library (ITIL). Lastly, Data Analytics methodologies for inference of large datasets include understanding Amazon Web Services (AWS), Apache Hadoop, and Apache Spark, among others.

Figure 6. Methodologies are described in systems engineering job descriptions.

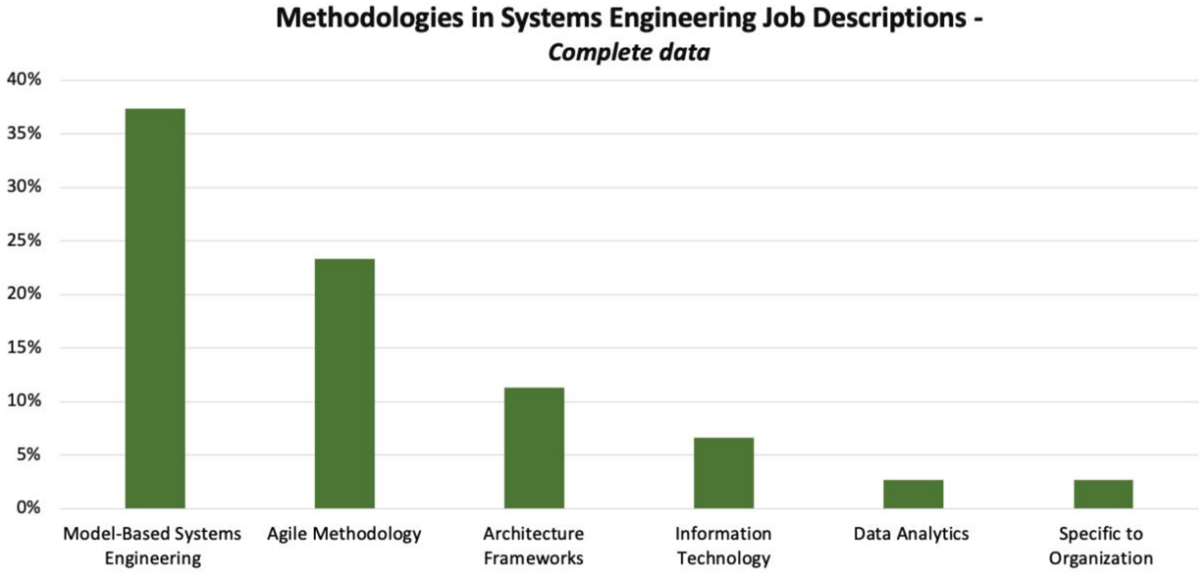

Figure 6. Methodologies are described in systems engineering job descriptions.

Systems Engineering Methodologies in Hispanic-Serving Institutions

To understand the current state of systems engineering in Hispanic-Serving Institutions (HSIs) and support their curriculum against industry needs, HSI universities were identified by mapping universities with recognized systems engineering programs according to the Worldwide Directory of Systems Engineering and Industrial Engineering (WWDSIE) Program, a directory created by the Systems Engineering Research center and INCOSE, and a current list of Hispanic Serving Intuition members of the Hispanic Association of Colleges and Universities and the National Center for Education Statistics. It was identified that only 12% of the overall universities in the U.S. offering a graduate degree in systems engineering are identified as HSI institutions. Hence, to support the systems engineering programs for HSI, this study explores their current programs by reviewing their curriculum and degree offering as seen on their respective websites.

Figure 7 describes how HSI institutions meet the current job opening requirements. It was found that almost 75% of universities introduce a type of MBSE methodologies and tools such as Cameo Enterprise Modeler developed by Dassault Systems. Also, 100% of institutions offer a project management course that addresses lifecycle management. Methodologies dedicated to systems engineering such as information technology and data analytics are the identified areas of opportunity for curriculum development. From the limited course offering in IT and Data Analytics, the available course description and available syllabus do not provide details on the methodologies to be covered. Therefore, a system engineering curriculum that covers relevant methodologies could result in increased job accessibility for HSI students.

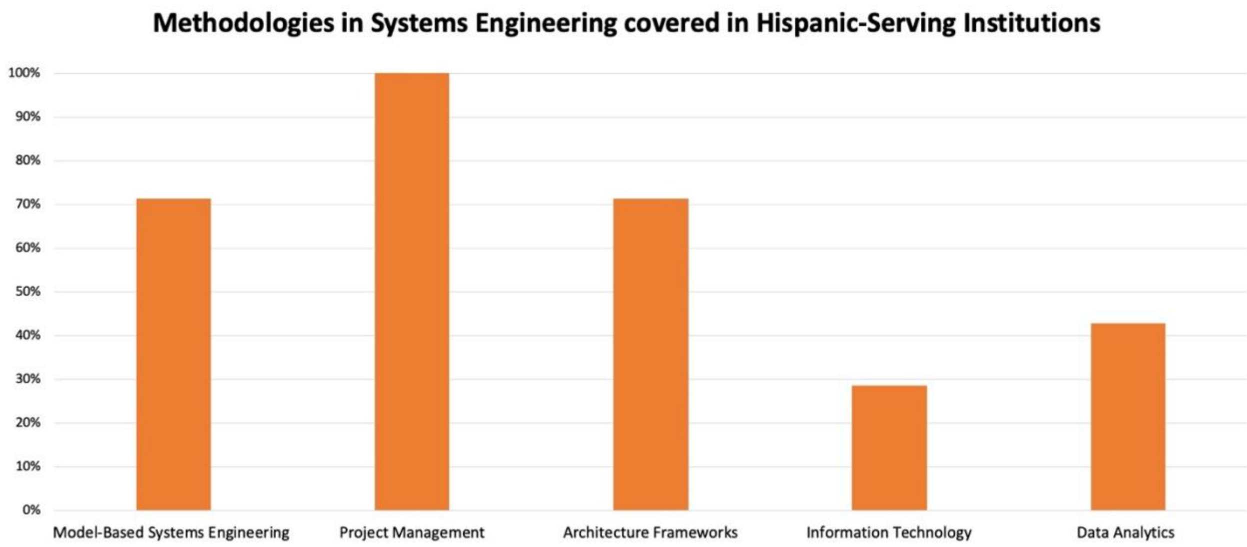

Figure 7 HSI universities' curriculum and their relevance to systems engineering methodologies

Conclusion

The development and management of systems are increasing in complexity as new capabilities, components, and interfaces are introduced. As organizations work on a digital transformation and train their workforce in the development of new skills, it is key that higher education institutions understand the skills and competencies, required to develop complex systems. To do so, this study analyzed systems engineering job openings to capture current needs in terms of role description lifecycle experience, tools, and methodologies needed in the job market, and it explores the relationship of systems engineering methodologies covered in Hispanic-Serving Institutions. Results indicate the need to provide formal training in modeling and simulation, requirements management, and system architecture. Regarding systems engineering tools, it was inferred that there is a need to train students in tools to develop activities of MBSE including diagram development, agile methodologies, and programming languages. A comparison between current job openings and the curriculum offered at HSI institutions indicates that universities are covering MBSE and agile methodologies, but limited concepts for information technology and data analytics for systems engineering. Future work will consist of including additional job descriptions from additional domains to explore the methodology and tool requirements. The analysis of future datasets will assist universities by providing them with a point of reference for curriculum development.

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