Cultural Barriers to the Adoption of Systems Engineering Research

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Abstract. An extensive amount of time and money is spent on developing methodologies and tools to improve the systems engineering process but much less is spent on addressing the organizational factors that can facilitate or hinder their adoption. This is partially due to engineering approach to problem solving which is technology centric. What is needed is an organization centric approach that complements the methods and tools being developed and considers the context in which they will be used.

This paper explores the notion of adoption of systems engineering research by focusing on a specific example involving measurement systems. Results from an industry survey on the most critical attributes for adoption are presented and implications of these results are discussed in terms of the broader issue of systems engineering research.

Introduction

The cultural characteristics of organizations exist at many levels: country, region, company, and even department. But these cultural dimensions are not the only factors that impact adoption of research into practice. The technical culture of the developers of this research plays an equally significant role. In particular, the embedded culture in the methodologies and tools that reflect the footprint of the developers. Understanding both the supply and demand side of this cultural question as it relates to the adoption of research can help improve the rate of adoption of systems engineering methods and tools. Furthermore, it can improve the return on investment that organizations make on research.

This paper addresses the following questions:

How can organizations foster higher adoption rates of systems engineering methods and tools? How can systems engineering methods and tools be better designed to be more likely to be adopted?

To attempt to answer these questions, this paper explores the literature from four areas: sociology (culture of organizations), product development (culture of technology and product architectures), information systems (technology acceptance model), and business administration (absorptive capacity) to identify the ingredients that need to exist from both developers and users of systems engineering research to improve adoption rates. In order to identify the enablers and barriers to adoption, we provide results from an industry survey focused on the adoption of measurement systems. From these results we identify the most important attributes of an organization that increase their propensity to adopt as well as the particular attributes of tools that make them more adoptable.

Prescriptive advice is given to systems engineering researchers as well as the consumers of their work to increase adoption of systems engineering research. Ultimately, this work is intended to help bridge the gap between researchers that develop methods/tools and the practitioners that aim to adopt them.

Adoption of Technologies

Adoption is studied by sociologists, economists, marketing, educators, engineers, and historians. Recently, increased emphasis has been placed on the rate of adoption of technologies in households in the United States. Nearly all American families now have refrigerators, stoves, color TVs, telephones and radios. Air-conditioners, cars, VCRs or DVD players, microwave ovens, washing machines, clothes dryers and cellphones have reached more than 80 percent of households (Cox & Alm 2008). The rate of technology adoption among consumers is extremely high but historically this was not always the case as shown in Figure 1. The conveniences we take for granted today usually began as niche products only a few wealthy families could afford. In time, ownership spread through the levels of income distribution as rising wages and falling prices of technology made them affordable. The average American household typically took the equivalent of 365 hours of average wages to afford a VCR in 1972. Today, this has dropped to 2 hours. A mobile phone dropped from 456 hours in 1984 to 4 hours. A personal computer, jazzed up with thousands of times the computing power of the 1984 I.B.M., declined from 435 hours to 25 hours. Even cars are taking a smaller toll on our bank accounts: in the past decade, the work-time price of a mid-size Ford sedan declined by 6 percent.

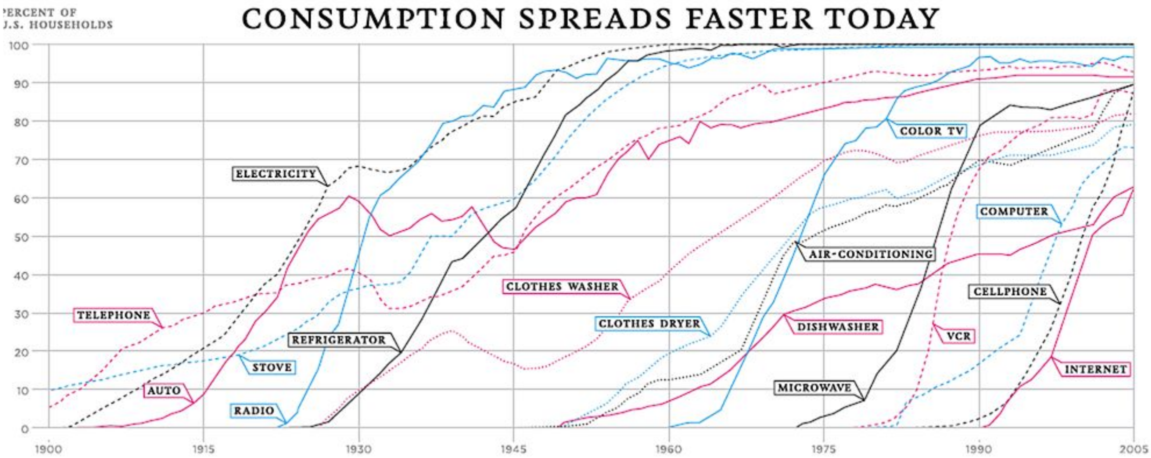

Figure 1. Adoption of technologies in households in the United States (Cox & Alm 2008).

Adoption refers to the stage in which a technology is selected for use by an individual or an organization. From an economic perspective, adoption itself results from a series of individual decisions to begin using the new technology, decisions which are often the result of a comparison of the uncertain benefits of the new invention with the uncertain costs of adopting it (Beal, et al 1957; Ozanne, et al 1971).

Adoption and Diffusion

In the process of exploring adoption it is important to distinguish adoption from diffusion. Diffusion refers to the spread of something within a social system. It denotes flow or movement from a source to an adopter, paradigmatically via communication and influence. Diffusion includes the process of contagion, mimicry, social learning, and organized dissemination (Strang & Soule 1998). On the other hand, adoption is the choice to acquire and use a new invention or innovation which involves a decision between fixed costs of adoption against the benefits expected (Hall & Khan 2003).

The most important thing to observe about this kind of decision is that at any point in time the choice being made is not a choice between adopting and not adopting but a choice between adopting now or deferring the decision until later. The reason it is important to look at the decision in this way is because of the nature of the benefits and costs.

There are two facts about the adoption of new technologies: first, adoption is usually an absorbing state, in the sense that we rarely observe a new technology being abandoned in favor of an old one. This is because the decision to adopt faces a large benefit minus cost hurdle; once this hurdle is passed, the costs are sunk and the decision to abandon requires giving up the benefit without regaining the cost. Second, under uncertainty about the benefits of the new technology, there is an option value to waiting before sinking the costs of adoption, which may tend to delay adoption (Hall & Khan 2003).

Network Effects of Adoption

Adoption of a new technology is often very costly for various reasons. New machines need to be purchased and often the technology is a specific asset; employees need to be trained to operate the new technology; if there are network effects then complementary machines need to be updated or replaced; if operation needs to be shut down for installation there will be a cost from lost output (Church & Gandal 1993). Organizations are likely to be unsure about whether or not they can recoup the cost of adopting the new technology, or how long it may take to recover the cost. As a result, it might not be worthwhile for them to adopt even if the technology has the potential of improving productivity or product quality.

Network effects due to technology standards are very important because there is a high degree of interrelation among technologies (Majumdar and Venkataraman 1998). A technology has a network effect when the value of the technology to a user increases with the number of total users in the network. Network effects in adoption can arise from two different but related reasons, often characterized as direct and indirect. Direct network effects are present when a user's utility from using a technology directly increases with the total size of the network. For example, the utility that a user gets from using electronic mail directly depends on how many other people are accessible by electronic mail.

Indirect network effects also arise from increased utility due to larger network size, but in this case the increase in utility comes from the wider availability of a complementary good. For example, a user's utility from purchasing a DVD player may be increasing with the total sales of DVD players, since the availability of appropriate software will increase as more DVD players are sold. This is often called the "hardware-software" example, where the availability of software increases as more hardware is sold because of the complementarity between the hardware and the software (Gandal et al, 2000). Similarly, network effects may also be present in the case of durable goods where beliefs about post-purchase service may depend on the total number of sales, and therefore consumers will prefer to purchase from a firm that is older or more popular.

It is clear that network effects are likely to significantly impact technology adoption since they affect the expected benefit from a new technology. Most empirical work in this area has confirmed this fact. Researchers have found evidence for the role of network effect in their study of ATM adoption by banks (Saloner & Shepard 1995). In the case of ATM machines, the network effect emerges in the following way: if ATM's are largely available over geographically dispersed areas, the benefit from using an ATM will increase since customers will be able to access their bank accounts from any geographic location they want. This implies that the value of an ATM network increases with the number of available ATM locations, and the value of a bank's network to a customer will be determined in part by the final network size of the bank. As a result, assuming that a bank can extract part of the consumer surplus, a bank will adopt ATM more rapidly if it expects to have a larger number of ATM locations in equilibrium, which implies that its network will have more value for its consumers (Hannan & McDowell 1984). This research found that banks adopt sooner the more branches they have and the larger the value of the deposits from their customers, and interpret this result as evidence of network effects in ATM adoption.

Organizational and Environmental Determinants of Adoption

Literature on the topic of technology and innovation adoption points to organizational factors as the main drivers of adoption. A study of technology adoption in the Brazilian medical equipment industry showed that organization factors are the largest contributors to the adoption of an innovation, specifically the presence or absence of leadership supporting the implementation (Zilber et al 2006). Similarly, a study sponsored by the Software Engineering Institute showed that social systems are the main enablers of innovation diffusion in software engineering organizations (Bayer and Melone 1989).

According to the economist Schumpeter, firms that are large or have large market shares are more likely to undertake innovation, both because appropriability (the benefits of new technology adoption) is higher for larger firms and because the availability of funds (the costs of new technology adoption) to these firms is greater (Harris 1951). Firms with larger market share are more likely to adopt a new technology because they have a greater ability to appropriate the profits from the adoption. Use or innovation of a new technology often involves huge upfront costs, for example, investment in production, training of workers, marketing, and research and development. A firm will have an incentive to invest in a new technology only if it can later obtain profits that justify the initial investment. Since profits erode in the presence of competition, only firms with sufficient market power would find it profitable to adopt.

New technologies are scale-enhancing, and therefore larger firms adopt them sooner because they capture economies of scale from production via the learning curve more quickly and can spread the other fixed costs associated with adoption across a larger number of units. However, large size and market power may also slow down the rate of diffusion. First, larger firms may have multiple levels of bureaucracy and this can impede decision making processes about new ideas and projects, and the hiring of new workers. Second, it may be relatively more expensive for older and larger firms to adopt a new technology because they have many resources and human capital sunk in the old technology and its architecture (Henderson and Clark 1990). In the presence of networks, this problem may be worse since it may be a very expensive undertaking to convert the entire network to the new technology.

The regulatory environment and governmental institutions more generally can have a powerful effect on technology adoption (Hannan & McDowell 1984), often via the ability of a government to “sponsor” a technology with network effects. Economic regulation has effects similar to the market structure/size effects discussed earlier, in that the effect of regulation is often to foreclose entry and grant fairly large market shares to incumbents, reducing incentives for cost-reducing innovation but also in many cases increasing the benefits from innovation due to the small number of firms in the market.

Customers may require organizations to adopt a certain technology or process in the same way the United States Government requires prime contractors to follow the Capability

Maturity Model Integrated (CMMI 2002) approach to measuring process capability. But the lack of understanding of the organizational culture embedded in software process improvement initiatives is credited as the cause for their high rate of failure (Ngwenyama & Nielsen 2003). Other countries such as Mexico have found it more effective to develop their own software maturity models that are more compatible with their cultural norms (Oktaba 2006).

Dimensions of Organizational Culture

Two notable perspectives on organizational culture come from the social sciences and Management disciplines. In the social sciences, organizational culture is characterized by the following five dimensions (Hofstede 2001):

- **Power distance –** the extent to which a society accepts the unequal distribution of power in the organization
- **Uncertainty avoidance –** the extent to which people are comfortable or uncomfortable with uncertainty and little structure
- **Individualism –** the extent to which individuals are supposed to be self-reliant and look after themselves, versus being more integrated into a group
- **Masculinity or Femininity –** hardness vs. softness; toughness vs. tenderness
- **Long term or short term orientation –** the culture's members having a stance on delayed, or immediate, gratification

In the management discipline, organizational culture is characterized by the following seven dimensions (O'Reilly, et al 1991):

- **Innovation and risk taking –** willing to experiment, take risks, encourage innovation
- **Attention to detail –** paying attention to being precise vs. saying its "good enough for chopped salad"
- **Outcome orientation –** oriented to results vs. oriented to process
- **People orientation –** degree of value and respect for people. Are people considered unique talents, or is an engineer an engineer an engineer?
- **Individual vs. Team orientation –** are individuals most highly noted, or are collective efforts
- **Aggressiveness –** taking action, dealing with conflict
- **Stability –** openness to change

Regardless of the dimensions used, it is important to also understand the determinants of organizational culture. In sociology, culture is defined as a combination of social heritage, human behavior, values, control, and rules (Bodley 1996). In engineering organizations, organizational culture is influenced by legacy processes, corporate heritage, customer demands, nature of product/systems delivered, and geographic location. A subset of these areas is an important enabler of technologies, that is, absorptive capacity. This is a unique characteristic that describes an organization's ability to value, assimilate, and apply new knowledge (Cohen & Levinthal 1990). For instance, one reason for companies to invest in research and development instead of simply buying the results (e.g., patents) it to raise their level of absorptive capacity. Internal R&D teams greatly increase the absorptive capacity of a company. This organizational attribute is driven by two characteristics: receptivity and innovative routines. Receptivity is an organization's overall ability to be aware of, identify and take effective advantage of technology. Innovative Routines are practiced routines that define a set of competencies the firm is capable of doing confidently and the focus of the firm's innovation efforts.

Adoption Theories

The technology adoption lifecycle is a sociological model originally developed to track the purchase patterns of hybrid seed corn by farmers (Beal, et al 1957). Rogers (1962), considered by many the "guru" of adoption/diffusion research since publishing *Diffusion of Innovations*, reveals three important ways in which the adoption of interactive communications differs from that of previous innovations. First, a critical mass of adopters is needed to convince the "mainstream" of the technology's efficacy. Second, regular and frequent use is necessary to ensure success of the diffusion effort. Third, technology is a tool that can be applied in different ways and for different purposes and is part of a dynamic process that may involve change, modification and reinvention by individual adopters. In a 1995 update to his book, Rogers presented four additional adoption/diffusion theories.

Innovation Decision Process theory. Potential adopters of a technology progress over time through five stages in the diffusion process. First, they must learn about the innovation (knowledge); second, they must be persuaded of the value of the innovation (persuasion); they then must decide to adopt it (decision); the innovation must then be implemented (implementation); and finally, the decision must be reaffirmed or rejected (confirmation). The focus is on the user or adopter.

Individual Innovativeness theory. Individuals who are risk takers or otherwise innovative will adopt an innovation earlier in the continuum of adoption/diffusion.

Rate of Adoption theory. Diffusion takes place over time with innovations going through a slow, gradual growth period, followed by dramatic and rapid growth, and then a gradual stabilization and finally a decline.

Perceived Attributes theory. There are five attributes upon which an innovation is judged: that it can be tried out (trialability), that results can be observed (observability), that it has an advantage over other innovations or the present circumstance (relative advantage), that it is not overly complex to learn or use (complexity), that it fits in or is compatible with the circumstances into which it will be adopted (compatibility).

Determinist and Instrumentalist Perspectives

But there is one other adoption/diffusion theory discussion that is relevant here. The distinction is between a determinist (developer-based) focus and an instrumentalist (adopter-based) one (Marx 1997). Determinists regard technology as the primary cause of social change. The process is seen as a series of revolutionary advances that are thought to be out of direct human control. Consequently, focus is on an innovation's technical characteristics. Successful adoption/diffusion is the assumed result of an innovation's technological superiority. The innovation's developer is viewed as the primary change agent.

For instrumentalists the process is evolutionary, and the causes of change are in social conditions and in human aspirations for change and improvement. Thus their focus is on the user (adopter) of a technology and its value as a tool to bring about desired change. Human control over the innovation is a key issue, and it is considered essential to understand the social context in which it will be used and the function that it will serve. It is evident that the development of systems engineering tools often done from the determinist perspective. In order to improve adoption of systems, an instrumentalist view must be incorporated.

Critical Factors for Successful Adoption

There are a number critical adoption factors identified in the literature (Farquhar and Surry 1994; Geoghegan 1994). Some include:

Low barrier of entry. Technologies are more likely to be adopted if the have a low barrier of entry. This can be enabled by different stages of adoption, or an adoption funnel that includes stages such as sign-up, evaluation, trial, and substantial usage (Lambrecht et al, 2008). These have shown to improve adoption of online banking applications.

Listening to early adopters. Addressing the needs implied by the early adopter-early majority differences when designing diffusion strategies can greatly enhance the likelihood that a technology will be successfully integrated into the curriculum by groups beyond the innovators and early adopters. The chances of successfully "selling" an innovation to the pragmatic early majority will significantly increase if their differences are addressed in terms of their perceptions and needs. They should be recognized as a distinct group within the community and made a part of the planning and policy making process. Attempts to "convert" them to the point of view of the innovators and early adopters are likely to be futile, not to mention almost certainly disastrous to impose the technology on them otherwise. Diffusion of the innovation to the late majority and laggards is more likely to occur through this early majority involvement since the vertical lines of communication between the three groups are more direct than with the innovators and early adopters.

Need for vertical support structure to overcome technophobia. When technology adoption begins from the grass roots, innovators and early adopters, with their strong technology orientation, may be able to get by on their own initiative. Narrowly focused technical support staff may not pose a threat or discouragement to them and their needs for initial training and support may be relatively easy to accommodate. Members of the early majority, however, tend to have no interest in the technology per se and some may exhibit a form of technophobia. Their introduction to the technology should be related to their perceived program and process needs. Since they tend to focus vertically within a discipline, training and support provided by staff who enjoy discipline/content credibility will likely be best received. Correspondingly, such training and support will be more transferable to the late majority and laggards.

Need for well-defined purpose or reason. The very existence of a technology may be reason enough for innovators and early adopters to pursue it. Their bent for experimentation and their innate interest in technology may dispose them to adopt it and be content with "finding a problem to fit the solution". Members of the early majority (and the others by extension), however, tend to derive their purposes from problems related to their disciplines. If the innovation can be demonstrated as an effective, efficient and easily applied solution to those focused needs, it is more likely to be adopted and integrated into the program.

Need for ease of use and low risk of failure. The early majority's aversion to risk quite naturally translates into a need for ease of use and usefulness (Davis 1989) and early success if they are to adopt and diffuse the technology.

Need for institutional/administrative advocacy and commitment. Without advocacy and resource commitment by the institution's "policy setters" and "holders of the purse strings", other issues become moot as the process is likely doomed. But innovation that occurs from the bottom-up also requires institutional attention, and an administration as an entity (except for some possible rare exceptions) tends to emulate the early majority rather than the innovators and early adopters. Even when an institution initiates an innovation from the top, their perspective tends to be a pragmatic one based on a problem or need that a given technology promises to alleviate. The mindset is similar to that of the early majority and, as always, there is a need for advocacy to occur if the conditions and activities that can promote adoption by the early and late majorities and laggards are to prevail.

First-time success. No one enjoys frustration or failure. An innovation is most likely to be accepted and integrated by the early and late majorities if success is experienced initially and subsequently built upon. E-mail is typically introduced early on because of its ease of use, and its success is almost guaranteed. It also extends the peer network, both within and outside the institution, thereby magnifying its impact on adoption and diffusion.

On-going peer support. Complementing the experience of initial success, there should be ample "hand-holding" along the way of integration as other technologies are introduced. Live peer support not only serves as assistance and encouragement; it contributes to the person-to-person communication that promotes diffusion throughout a community. In addition to a training cadre of recognized peers, a network of on-line mentors can expand the potential of the support structure to promote the exchange of innovative techniques. Some of this peer support may come from professional societies.

Real task activities. The early and late majorities are pragmatists who see technology in terms of real problem and task solutions. Activities designed to introduce and teach the technology should address those needs. As pointed out earlier, institutional administrations tend to emulate this pragmatic perspective. Internet access to information and resources, and its use for intra and inter-institutional communication can address many administrative needs as well as establish a well-defined and recognizable need for adopting the technology.

Variety of incentives. Attempts to impose a technology through explicit mandates and requirements, as in the top-down scenario, are not likely to be effective. Policies and procedures promoting the technology should grow naturally from its application, and incentives for using it likewise should be tied to its practical use. Adoption and diffusion is more likely to occur where incentives and policies encourage a natural acceptance and use of the new technology.

Adoption Survey Results

In order to put the adoption theories to the test, we interviewed both developers and adopters of systems engineering tools to determine from them what the critical success factors were for successful adoption. The theories and critical factors described above motivated the development of a survey to better understand the preference of attributes on systems engineering measurement systems in large organizations. The survey was administered to a group of 35 systems engineers in the defense industry. Respondents were asked to categorize 12 attributes in terms of three categories:

- **Must-be** – referring to attributes where user is dissatisfied from its absence but never rises above neutral no matter how much of the attribute exists (i.e., having good brakes in your car).
- **One-dimensional** – referring to increasing user satisfaction from the presence of this attribute and decreasing satisfaction from its absence (i.e., having good gas mileage on your car).
- **Attractive** – indicates areas in which the user is more satisfied when the measurement system has the attribute but is not dissatisfied when it is absent; lack of an attribute leads to a neutral reaction (i.e., having a radio antenna that lowers into car body).

The following 12 attributes and associated definitions were provided:

1. **Well documented.** Adequate documentation and training is readily available and helpful
2. **Trialability.** User can "try out" high-level features and incrementally increase their use
3. **Low barrier of entry.** Not overly complex to learn; minimal knowledge or training needed
4. **Transparency.** Data/results are readily available throughout all levels of the organization
5. **Demonstrates value.** Either through ROI, risk reduction, or by helping make better decisions
6. **Variety of Incentives.** Personal incentives of use are clear; use of measurement enhances job performance
7. **Tailorable.** The ability to be customized or adapted for particular needs of the organization
8. **Information freshness.** How current the information is with respect to the decisions it needs to support
9. **Relative Advantage.** It has an advantage over other innovations or the present circumstance
10. **Compatibility.** Fits in with the culture (organizational, political, technical) into which it will be adopted; does not contribute to process improvement saturation
11. **On-going peer support.** Ample "hand-holding" is provided along the way and peer network is available for support
12. **Credibility.** Based on a credible method/approach/tool/standard

The order in which the attributes are shown here is the order in which they were presented in the survey. Respondents identified each attribute belonging to one of the three categories "must-be", "one-dimensional", or "attractive". For analysis purposes, the selections were assigned a score of 3, 2, or 1, respectively. The numerical results are shown in Table 1 and Figure 2.

Table 1. Ranking of adoption attributes (n=35).

Attribute	Average	Standard Deviation
Well Documented	2.63	0.65
Credibility	2.49	0.74
Demonstrates Value	2.40	0.65
Low Barrier of Entry	2.29	0.67
Information Freshness	2.29	0.75
Transparency	2.23	0.69
Compatibility	2.23	0.84
Tailorable	2.11	0.67
On-going Peer Support	1.97	0.79
Variety of Incentives	1.89	0.76
Relative Advantage	1.77	0.72
Trialability	1.57	0.70

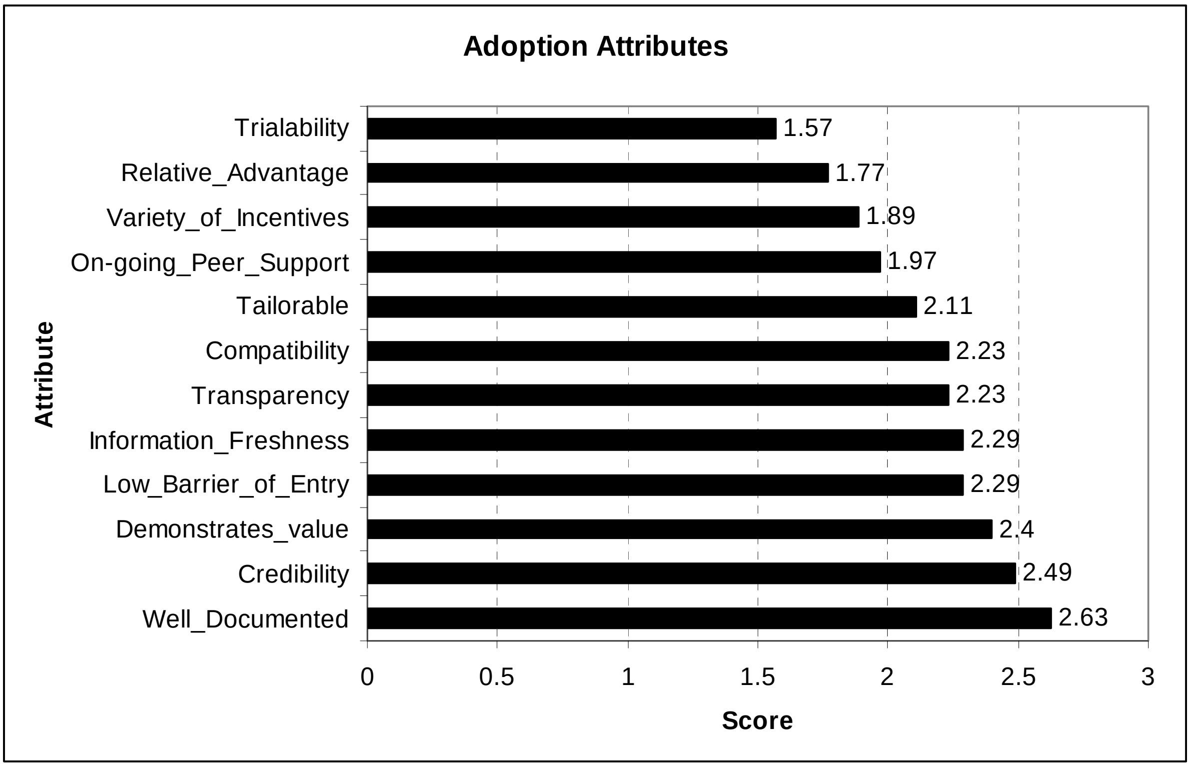

Figure 2. Ranking of adoption attributes (n=35).

Discussion of Results

The most important attributes for adoption were documentation, credibility, and value. The bottom attributes (approximately the bottom 4), seemed to pertain to stakeholder involvement and human factors or interactions. Hence, perhaps respondents rated these attributes as less necessary in a measurement system than functionality-related items. There is an apparent continuum of results, rather than a clumping effect. This means that there was no clear dominance from certain factors nor was there a clear dismissal.

One responded suggested that if the top factors were eliminated the importance of the other factors would become more distanced. The strength of the top factors made the other ones seem less necessary. Organizations seem to emphasize the design of technologies that are agile and flexible, but tailorability (which seems characteristic of agility and flexibility), was rated in the bottom half of the attributes list. One might have thought the respondents would have valued tailorability more.

Respondents felt that different job functions would have responded to the survey questions differently. Depending on whether the perspective of an engineer, manager, floor worker, etc. If the survey was for a metric rather than a measurement system, the results might be completely different. Note that peer-support would have been a lot higher for a “metric” as opposed to a measurement system.

Implications for Systems Engineering Researchers

There are three important implications for systems engineering researchers. First, there needs to be an increased emphasis on understanding the organizational culture in which the research or tools will be used. Without this consideration there is a risk of the organization not adopting the technology based on cultural incompatibilities rather than its technical merits. In addition, researchers should realize the cultural assumptions that are embedded in their work.

In terms of CMMI, for example, the cultural assumptions that are made about the organization undergoing process improvement initiatives are an important ingredient that should be considered.

Second, the determinist (develop-based) perspective is also one that should shift to a more instrumentalist (adopter-based) one in order to improve the adoption of research. This may not be simple given the tendency to approach problems from an academic standpoint rather than a user standpoint.

Third, from the survey results it appears that there is no single attribute that drives the likelihood of adoption of measurement systems. However, systems engineering researchers should use these results as a checklist for attributes that are be considered high priorities or "must haves".

Conclusion

The notion of technology adoption may be foreign to most engineers, but social scientists and economists provide a rich backdrop for identifying the most critical factors that influence adoption. Previous studies point our important cultural, organizational, and environmental considerations that can hinder or enable adoption. These outcomes should be in the toolset of every systems engineering research that seeks to develop innovations that can be adopted by practitioners. The implications outlined in this paper should inspire the systems engineering community to better recognize these intangible characteristics of our field and the organizations that can benefit from improved tools, methods, and models.

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Biography

Ricardo Valerdi is a Research Associate in the Lean Advancement Initiative and a Lecturer in the Engineering Systems Division at MIT. He is also the co-founder of the Systems Engineering Advancement Research Initiative (SEAri). He received his B.S./B.A. in Electrical Engineering from the University of San Diego in 1999, and his M.S. and Ph.D. degrees in Systems Architecting and Engineering from USC in 2002 and 2005. He is the author of over 50 technical publications which have appeared in several journals, including *Journal of Systems Engineering, Journal of Systems and Software, IEEE Software, International Journal of System of Systems Engineering*, and *CrossTalk - The Journal of Defense Software Engineering.* He serves on the INCOSE Board of Directors as Treasurer.