

Systems Engineering Process Standardization and Cultural Diversity

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Abstract—Systems engineering is the branch of engineering concerned with the development of large complex systems, managing both the design processes and the design of the systems. As such systems engineering has both a technical and a managerial focus. SE originated during the 1950s as a means to address the problems presented by large and consequently high risk US government acquisitions. The approaches described in the 1950s were largely broad guidelines for the approach to engineering projects. In later decades an approach to systems engineering which codified the processes through the use of detailed standards such as MIL-STD-499 became prevalent. These standards codified process for the execution of projects from a set of assumptions valid in the community which wrote the standards. The success of SE methodology in the US in improving the probability of project success has led people in other countries, with quite different cultures to apply the process centric SE standards in the hope of improving outcomes. This paper explores some specific matters related to Chinese culture to illustrate limitations in the use of copying process centric standards from one context to another, and explores means by which the field of concern oriented approach of the ISO15288 SE standard can enable development of appropriate SE methodology in diverse cultures and to enable cooperation in projects involving teaming across cultural boundaries.

Index Terms—Systems engineering, engineering process, culture

I. INTRODUCTION

Systems engineering is the branch of engineering concerned with the development of large complex systems and as such is concerned with the development of appropriate technology to satisfy the need prompting the project and the processes required to manage the project through to a successful completion. The field of systems engineering appeared in the early post-World War II period, as a response to the difficulties which had been encountered with the development of large complex product systems both during and soon after World War II. The problems were diverse, including difficulties in designing systems which adequately matched the acquirer's expectations, or provided an adequate technical performance, or had sufficient reliability, maintainability or supportability under field use

conditions.

The very early work in systems engineering, during the 1950's, provided an outline method for addressing significantly complex projects which mirrors the broad description of systems engineering provided in modern textbooks, such as Blanchard and Fabrycky [1]. That is, in the early descriptions of systems engineering the emphasis was on the broad outline of the stages which should be addressed in the performance of a major project rather than the emphasis on the details of processes for performing the work which have been emphasized more recently, and which have led to the perception that systems engineering is not suitable for use in industries which require significant agility, such as typical commercial product development.

II. EARLY HISTORY OF SYSTEMS ENGINEERING

A review of the IRE publications from 1950 to 1960, including both those available in IEEEExplore and those only available in hardcopy identified about 300 papers which either use the terminology "project management", "systems engineering" or "systems engineer", or which appear, by title, to contribute to the conceptualization of the engineering of product systems as systems, in contrast to continuing the previous interest in engineering of products as relatively small equipment items. This review has been published as [2, 3] in two parts, one identifying the problem with respect to engineering methodology when applied to the development of systems and elements intended for incorporation into systems and the other identifying the range of responses revealed in the literature corpus selected.

In summary, the problems recognized were of several kinds. First, it is necessary to design product systems as systems, using engineering modeling and analysis of the performance of the system as a whole system rather than concentrating on the equipment items considered separately. Second, it is necessary to study the system user to determine the appropriate user interface. This work included the early work in the physical aspects of ergonomics, but also included embryonic work in the cognitive and psychological aspects of the user interaction with the system. Third, the significant problems experienced with reliability during the 1940's and 50's, leading to the establishment of many of the fundamental statistical principles which continue to be applied in the various strategies to design high reliability products.

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The approach taken to reliability resulted in the *IRE Transactions on Reliability* becoming the first of the *Transactions* to develop the strongly mathematical form which is characteristic of most titles today. The other *Transactions* titles through the 1950s primarily contained material written by practicing engineers for other practicing engineers, usually in the case study style of accounts of projects and lessons learned.

In dealing with the challenges presented by the problems discussed above the engineering community made several advances. The first advance was to increase the explicitly stated knowledge about the character and motivation of individual engineers in the engineering community. The major observation was that engineers are personally motivated through their interest to apply technology to solve problems, and that recognition is associated with success in this pursuit. In turn the standing accorded to engineers by engineers follows from success in the design of technology, with an emphasis towards the magnitude and complexity of the technological product designed. In addition, the career development of engineers commences with a period of largely technical work, and promotion depends on the individual's performance and success in addressing the technical problems of their early career phase. This professional culture is poorly adapted to developing respect in engineers for the need, and ability, to address the complex socio-technical issues of larger and more complex projects which must interface with a broad range of entities, both technical and social or organizational, outside the designed and constructed technology of the system itself.

There were two families of approaches offered as solutions to the problem observed with system development. One approach, to be dealt with here second, was of the form of the current systems engineering field of practice, and the other was sundry other approaches to project management. The diverse project management techniques described were largely approaches which had been successfully applied in particular organizations, each with distinct engineering management needs. The methods described were often heavily organization context specific, and so described in considerable detail the technical processes for dealing with certain matters of importance to that situation, but often the detail was of limited value to others, except as illustration and application of general abstractions which were probably also available at the time. Other papers provided discussions of the methodology or value of using particular parts of what is now recognized as the general project management process. Amongst this material there were descriptions of the Gantt chart [4] and the PERT approach to project planning and control [5].

Amongst the non-systems engineering project management methods there were descriptions of a couple of methods which were probably more a description of how things were done at the time [6], and advice to young engineers as to how to succeed in that framework [7], than reasoned discussions of how complex projects should be addressed. Of greater influence was Bridges [8], writing out

of the DoD perspective about limitations with the Weapon System Management methodology which had been introduced in 1948, with particular concern for efficient use of engineering effort.

The terminology "systems engineer" and "systems engineering" were used frequently in the publications, principally to express the idea of performing engineering work, in design and analysis, at a whole system level, including interest in, and techniques for dealing with, the proposed technology viewed as a total system, and incorporating consideration of the human and social interface of the technology. The project processes described followed the broad outline as found in modern textbooks of systems engineering, such as Blanchard and Fabrycky [1]. The broad outline regards the project, at least superficially, as following a waterfall progression through the stages of need exploration, concept of operations analysis, requirements analysis or development of system level specification, system design, detail design, system integration and test, manufacture and delivery. In some cases the terminology is different. What differs from modern systems engineering is that the early authors described their process in broad outline whereas the present approach to systems engineering has developed many detailed processes.

Of particular historical interest was the production of a special issue of the *Transactions on Military Electronics* in 1959 [9]. The contributions in this issue came from both the government and industry sides of the Defense, aerospace and commercial industries. This breadth of origin shows that what was understood as systems engineering at the time was broadly applied. This is consistent with the fact that many references in the study were derived from the telecommunications industry and that the first two textbooks of systems engineering reflect a commercial or telecommunications industry origin [10, 11]. These books acknowledge that the engineering methods described are applicable to a diverse range of systems, including military, but have not limited their scope.

Systems engineering was understood during the 1950's as a broad approach to addressing large complex projects that required a thorough investigation of the purpose and application of the intended system, and then deriving design from that, using an approach to analysis which considers the matter holistically, rather than in a fragmented manner.

III. FOCUS OF SYSTEMS ENGINEERING

The concern of systems engineering is both the technical and managerial matters related to the progress of projects. This concern is expressed in the combination of interests in the determination of what should be made, the product system, which has substantial technical components, and must be suitable for its social or organizational context of deployment. The product concerns relate to designing the right thing in order to achieve benefit for the owner or user of the product system. Therefore the product concerns are largely technological concerns.

Systems engineering also has a management concern, addressing the planning and control of the technical work. This concern is seen in the inclusion in systems engineering of processes to manage the projects. The management processes are drawn from the range of project management processes with particular emphasis on processes addressing the complications of design, which increases uncertainty.

Systems engineering selects from the range of project management processes and technical processes for product system development. This understanding is clearly shown in the ISO/IEC 15288 standard [12]. However, project managers would also argue that their array of methods includes the technical processes which must be harnessed in order to successfully complete the project. The difference is that project management is more suitable for precedented situations, in contrast to the particular benefit of the systems engineering methodology in dealing with the novel and complex.

The particular benefit of the systems engineering approach is found in development projects in which the interaction of the proposed system with its environment of planned deployment is significantly complex, particularly if the combination of the social and technical issues makes it challenging to determine what technical product system is suitable [13].

IV. STANDARDS FOR SYSTEMS ENGINEERING

The rehearsal of the early history of systems engineering above indicates that systems engineering was first regarded as an attitude to the development of large complex systems which guided the holistic approach to large complex projects. The general approach provided guidelines for kinds of activities required to develop and analyze the performance of the proposed product system. The general approach required a lot of responsible decision making by leaders of the engineering effort, including both process and product matters. The general approach to systems engineering demanded much responsibility and so depended upon very capable people, “heroes”> The method was vulnerable to either unavailability of suitable staff, or inappropriate action by those in responsible positions. Thus, whilst useful, systems engineering as a general approach did not completely assure acquirer’s of obtaining the most suitable product system.

The response to this matter was that acquiring organizations in US DoD developed codified processes for systems engineering work and project documentation. The first standard, MIL-STD-499, was followed by 499A and a draft 499B, which was never enacted [14]. This standard sought to determine the processes and documentation required, and consequently included all the processes demanded for the execution of the most complex project, and a rubric to tailor the systems engineering process to suit the specific issues associated with the particular project.

Upon the discontinuation of MIL-STD-499 the industry moved to develop a replacement standard which led to the

preparation of both EIA 632 and IEEE 1220. These standards were both oriented towards the precise statement of what processes are required and the definition of how those processes should be performed. That is, the approach was one of precise activity prescription. This approach is well-supported in the systems engineering community, where it is common to hear support for the view that practice would be improved with a closer codification of the standards for performing systems engineering work [15].

The ISO/IEC 15288 standard [12] has a quite different form. It defines a number of classes of processes which are required for success in systems engineering but does not stipulate how those processes are to be performed. Some see this as a weakness of the standard, but this author has contended elsewhere [16] that this characteristic is a strength of the standard for worldwide application. The issue in the application of a standard worldwide is that the geographic distribution necessarily entails the application in diverse cultural situations.

V. THE PROBLEM WITH STANDARDS

At first glance the global application of systems engineering standards may appear good since engineering concerns making stuff out of stuff, and the properties of technological things follows the laws of sciences and mathematics, which are universal. Therefore the behavior of any product system will be the same regardless of where it was developed. It is also clear that people in different cultural situations will have different expectations of product systems, but this can be factored into the design process by careful investigation of the need associated with the particular product system proposal. The latter effect of culture on engineering concerns the product system design, not the process by which the engineering design is done, and is not relevant to the present discussion.

In each ethnic culture there are accepted ways of behavior and interaction between people which influence the workplace relationships developed between people. These differences in relationship affect information flow in a work team and in turn can profoundly affect the product system designed by the team [17]. The fact that people in different cultural settings do not work together in the same manner precludes the application of any set of engineering processes developed in one setting, and appropriately addressing the needs of that setting, to another setting, in which the underlying presuppositions, valid in the original setting, cease to be valid.

The above observation indicates the error of seeking to develop a global prescription of the processes for engineering teams. This statement is consistent with Hofstede’s conclusion that there cannot be of universal theory of management in anything other than a trivially superficial sense [18]. This indicates the need for local development of detailed process in organizations conducting projects at a single site, and a significant challenge for organizations seeking to use global virtual teams. In the case of global

virtual teams constraints include the use of tools, both for project and technical processes, which must be used across the entire team because of the need for common information and data formats. The use of such tools both assumes and forces certain relationships between the users.

The forcing of certain formal relationships assumes that the users share the values related to the engineer's relationship with the product system and the relational values within the design team embodied in the design of the tool. This forcing of relationship is not unreasonable if the team's actual cultural form of relationships is close to that assumed by the tool but if the tool requires relationships which are significantly different than the form of relationship into which the people would naturally enter there will be problems because the reality of their relationship will not reflect the qualities of communication and robust debate about design ideas assumed in tools developed around the process of systems engineering described in the standards. This mismatch of practice and the underlying assumptions of the standards may result in implementation of the outward form of the standard without achieving the purposes of the processes.

VI. THE MOTIVATION FOR STANDARDIZING STANDARDS

The discussion above has outlined the history of systems engineering standards from pre-standards general outline approach, the detailed prescriptive standards, MIL-STD-499(A), EIA 632, IEEE 1220 and the matters of concern approach of ISO/IEC 15288.

There has been a widespread belief, supported by *post hoc* evidence, that systems engineering is useful in improving the reliability of systems development work. This is currently under investigation by Honour in his Systems Engineering Return on Investment project [19], which aims to provide substantial evidence upon which to base a conclusion the value of systems engineering effort for system developers and acquirers.

Notwithstanding that the evidence for the value of systems engineering adduced and published to date supports, but does not quantify the value of systems engineering, the apparent success of the systems engineering methodology has encouraged the spread of the methodology through the defense and aerospace industries in many countries. This spread has been manifest in the spread of the US methods, as codified in the standards, published in USA, except for ISO/IEC 15288, to defense and aerospace projects and acquisition authorities in many other countries, with diverse cultures. The apparent success of the US methods for dealing with the big four dimensions of interest in public acquisition projects, product performance, budget, schedule and probity, in USA encouraged the use of the same methods elsewhere, with the expectation of gaining the same benefits.

The process copying approach adopted in some of these efforts provided less benefit than had been anticipated because of the mismatch between the culture that generated the process standards and the behavioral and relational

assumptions embedded in the standards and the ethnic culture in the place of application. The result was project outcomes less desirable than were expected [20].

A second motivation for copying the processes written into the standards is that there are a number of commercially available systems engineering tools available to support projects performed according to the published standards. The tool vendors design their tools to be consistent with particular standards to exploit the market amongst organizations using that standard. Since the only country which has developed broadly disseminated standards is the US then it follows that all the tool vendors have developed tools that support US methods. Systems engineering houses in other countries have an incentive to copy the US methods in order to obtain the support of existing tools, rather than to need to develop custom tools. The tool cost saving, added to the need to develop and validate local processes is attractive.

The third incentive for standardizing the standards in all countries is globalization. Many systems development projects involve collaboration across national borders. The collaboration situation requires interchange of product data between parties, and thus agreed standards for data representation and also for responsibilities, resulting in a need for considerable commonality of process and tools. Commonality of process is required in order that the parties have a shared understanding of the intended outcomes of design and evaluation activities. This has tended to encourage the spread of standards for project process because the dominant party in a collaboration often forces the others to conform to their will. Various factors including being in control of a key technology or being the buyer or supplier of funding may give a party the dominant rank in a collaboration, but whatever the tangible factor, the dominant party is one without whom the project cannot proceed. What is actually required in a collaboration is to get the interfaces between the parties properly organized the usual approach to solving the problems is to define the detail of process internal to each party, even if there is significant risk of a mismatch of process with ethnic culture.

VII. CULTURAL PRESUPPOSITIONS OF THE STANDARDS

The procedural systems engineering standards were developed in USA through a history dating back to the 1950s. The people who developed those standards codified their experience, embodying the "modern" worldview that held that things operate predictably [21]. These people also had experienced both the Depression and World War II at a formative age, which shaped their assumptions about normal interpersonal relationships. These events were crises in which individual survival and prosperity depended on cooperating with others. Therefore people normally sought to engage in society with a view to making a contribution to and receiving benefit from society as a whole, rather than in reciprocal transactional relationships. Because the attitude of the culture from which the standards developers came was one where to contribute to and draw from the common good was the

normal interaction of people the standards necessarily codified the relational aspects which were the gaps necessary in this framework to achieve the desired outcome of effective project completion. The matters which the culture embodied, and which were practiced did not need to be specified. The importance of these cultural characteristics of people of that generation in the advancement of engineering projects using the systems engineering methodology was highlighted in the PhD thesis of Lawson [22].

Following from this generational effect, was the embedding in the systems engineering standards of the assumption that the junior employees in a project team would report up the chain of command their findings in relation to the project, including those that were adverse to the progress of the project under current assumptions. So, if a lower ranked team member discovered a difficulty with the proposed system, it is assumed that the junior employee will report the difficulty and corrective action will be taken soon, at relatively low cost compared with assuming that there was no problem. This point is left to hang here, but will be considered again soon.

The existence of a generational effect is evidenced by reports from lead systems engineers of difficulties currently encountered in projects as a result of younger engineers, from generations post-dating those who developed the processes, behaving according to different motivations, being less well-connected across the entire project team, and being less interested in and less effective at using such connections to the advantage of the project. This observation of the influence of different motivations across generations affecting the implementation of a process written under the assumptions associated with a different generation is itself an indication of the cross-cultural issue under discussion in this paper.

A further evidence of a difference in cultural perspective is found in the difference in effort applied in the explanation of teamwork among systems engineers between USA and Britain and continental Europe [23]. It was found that with the exception of one US organization all the papers from US and British authors assumed that effective teamwork would happen when engineers were brought together in an organizational unit, whereas the Scandinavian authors described how to get effective teamwork in detail. This indicates a significant cultural difference, and suggests that in US and Britain the driving paradigm for systems engineering practice is the modernist worldview, whilst in Scandinavia that a stronger post-modern experience [21] may influence thinking.

The problem becomes much greater when considering the effect of the interaction of an obviously “foreign” ethnic culture and systems engineering process. In the case of the Taiwanese manifestation of Chinese culture there are perceptions of relationships and practice which are fundamentally different than in US and other English speaking cultures. This difference is associated with a difference of fundamental motivation in the two cultural circumstances. In US culture concern for the good of the

project outcome strongly dominates participant behavior. Individuals contribute into the project so as to achieve the best product system that can be achieved with the constraints. The reward structures encourage this behavior because individuals are rewarded by employers for contributions towards project success.

In the Taiwanese situation the primary motivation is to maintain relationships between the people because good relationships are the pathway to family or individual benefit. In addition, the state of relationships is different because the cultural interpretation of organizational hierarchy and “face” are different than in the US situation. These observations are found if one explores the Taiwanese case using its own categories of interest rather than categories imposed through a standardized approach to cultural analysis, such as Hostede’s dimensions [17, 24].

The organizational hierarchy in Taiwanese culture is significantly influenced by Confucian conceptualization of relationships and leadership whereas in the US situation the influencing factors are the Calvinist and Arminian theological positions from Christian theology [17]. This difference is important with respect to the nature of the relationships that are formed in engineering teams. In particular, in the Taiwanese setting the manager of a project or the leading systems engineer is a person who stands above the staff in all respects, not just administratively. The result is that staff are unwilling to raise issues which challenge the correctness of the leader’s technical views, either in private or in public. To do so would cause the leader to lose face, which in the Taiwanese conceptualization, is an offence caused by the subordinate who mentioned the matter of concern, and so it is possible for a project to progress for a long time before the inappropriateness of some decision of the leader becomes clear enough that the leader changes direction. An additional difficulty is that in many places the line manager of a person is very influential in determining recommendations for rewards leading to a need to avoid offence. This analysis was verified by a Taiwanese engineer in the discussion of [17] after presentation in Singapore, 24 March 2007.

VIII. CONCLUSIONS

This paper has discussed the rise of standards for systems engineering process. Systems engineering has been viewed as both the technical process of developing the product system and the task of organizing and leading the team. From the human process perspective it has been shown that ethnic culture is important to the effectiveness of implementation of any process, because all processes presuppose a particular ethnic cultural environment of work. The fact that an ethnic cultural environment of work is assumed, and cannot be excised from the effectiveness of any particular human process to do anything indicates that it is inappropriate to look for any detailed process centric systems engineering standard to be the manner in which systems engineering is done in all places.

In contrast, the nearest to a general, all-applicable, systems engineering standard that is possible is a standard of the form of ISO/IEC 15288, which identified the matters for which one must have a process, but does not define that process, leaving it to the decision of the local, organizational, authority to determine the appropriate manner to deal with the matter.

This paper has shown that a single systems engineering process cannot be successfully applied in all cultures.

In response this paper argues that systems engineering process must be constructed in order to effectively achieve the objectives of systems engineering in each cultural setting where it is applied. The objectives and the areas of concern remain, but how the problem is solved depends on the context.

This paper suggests that where projects involve interfaces across cultural boundaries the most appropriate solution is to determine the interface required across the boundary, and then call for the development of processes and procedures on both sides of the boundary to be developed to enable the interface and the effective development of the intended product system components in the most culturally appropriate manner, so that the interface at the boundary may operate correctly.

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