# Achieving Value in Complex Systems Development

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**Abstract:** Applying **'**best practice' in system engineering has been essential for many organisations in their aim to achieve high value in the development of complex systems. Value in product-oriented complex systems, comes from the capacity for the delivery of specific operational capabilities of the system as expected by stakeholders. This paper provides further insights into the nature of the UCLse (University College London Centre for Systems Engineering) Principles of Systems Engineering Management and relates them to specific professional practices and the creation of value in a supplier organisation. Using face-to-face open questions among 20 practitioners of different organisations that supply complex systems, this study identified valuable practices of systems engineers that fall within the UCLse Principles. These provide support to a wide organisational context driving efforts to achieve a value-based management.

Key words: systems engineering; value; complex system

## 1. INTRODUCTION

Applying 'best practice' in Systems Engineering has been essential for many organisations in their aim to achieve high value in the development of complex systems. Value is one of the most important concepts for business; it is in the centre of every financial and psychological transaction (Resburg, 2012). Nevertheless, the biggest challenge is how to define it and then achieve it in each organisation. When customers choose to acquire a product from an organisation they do this based on their "perceived value" of the product (Resburg, 2012). The Systems Engineering function may be considered as being a direct "value-adding" process, because it focuses on the interaction between the engineering, project and organisation process areas (SE-CMM, 1995).

Some studies have been conducted in an attempt to improve the overall value delivered by Systems Engineering. There are many observable values in Systems Engineering, but it is difficult to express some of them. Honour (2004) argues that there is an optimal Systems Engineering effort of the total project efforts and expressed them as function of Systems Engineering cost and Systems Engineering quality. Valerdi (2005) proposes to evaluate the way that Systems Engineering creates value by a model that links Systems Engineering practice to cost.

Almost every research about value of Systems Engineering has the dimension of cost. In this research the discussion about value of Systems Engineering is beyond the financial measures. Patanakul and Shenhar (2010) argued that not only should value be explicitly defined for all the program stakeholders but that value should be more than just financial gains or "value for money" as it could also be about intangibles, such as; market opportunity and strategic positioning, amongst others.

To deliver value, the organisation should invest in capabilities to build value (Beverland, 2012). The UCL Centre for Systems Engineering - UCLse team based on the experiences from the Mullard Space Science Laboratory (MSSL) space projects developed five principles that are deemed to have been guiding the delivery of successful projects in one of the most challenging of contexts. Emes et al. (2012) have presented the UCLse principles as:

I. Principles govern process
II. Seek alternative systems perspectives
III. Understand the enterprise context
IV. Integrate systems engineering and project management
V. Invest in the early stages of projects

This paper provides further insights into the nature of the UCLse Principles of Systems Engineering Management and relates them to specific professional practices and the creation of value in a supplier organisation.

Systems Engineering Management is related to the field of Management through the processes dedicated to control the design, creation and use of complex man-made systems (Shenhar and Sauser, 2009). Sharon et al. (2011) emphasized that Systems Engineering and project management work together and create an overlap of activity known as Systems Engineering Management and pointed to 14 factors of project management that are present in Systems Engineering Management.

Moreover, it is important to develop an expanded presentation of the UCLse principles that could help the exploration of how to implement them. It is widely believed that practices are the description of how an activity is to be achieved. But above all, we will argue that breaking the UCLse principles down into practices could help organisations achieve value for complex systems' development.

Figure 1 depicts our view of the value generation process from the perspective of the supplier organisation. First, it is imperative to engage with the project stakeholders and understand what value means for them. Secondly, knowing where the stakeholder values lie and under the guidance of the 5 principles, the scope and details of the systems engineering process can be appropriately tailored. The processes can then be implemented, guided by previous good practice and examples from successful projects. Finally the perceived value is instilled in processes, organisation and teams, and is manifest as value realised by the stakeholder.

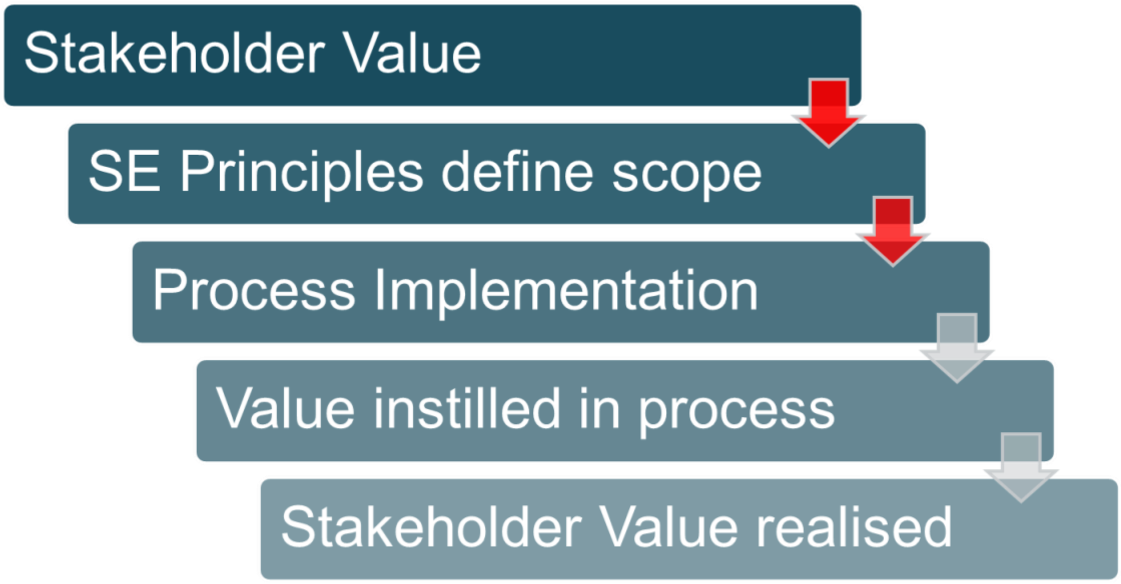


Figure 1: The value generation process from the perspective of the supplier organisation

The aim is not to produce another set of systems engineering processes but to guide the organisation in the tailoring and implementation of the process methodology that they have adopted. The 5 principles (Emes et al., 2012) are based on experiences at MSSL so the continued use and feedback, not surprisingly, adds value to the organisation and to the customer. Indeed, the red arrows in figure 1 represent a translation stage that can only come through experience of the organisation and the customers that it supplies. However, if the principles are to be validated as generic in nature then we need to find a way to map them to 'value adding' practices from a wider set of organisations. This study attempts to get a quick look snap shot of these practises and see how well it aligns with the 5 Principles.

Focusing on this context, this study poses two research questions:

(1) while engaged in Systems Engineering Management, do practitioners perceive valuable practices in projects that can be correlated with the UCLse principles?

and

(2) how do these practices contribute to achieving value for complex systems' development, or at least, where is the value realised?

In this paper we define complex systems and then explore the idea of value. After that we present our method to obtain, analyse and discuss relevant data. We end with conclusions and ideas for future work.

## 2. COMPLEX ENGINEERED SYSTEM

While the concept of system is widespread as an arrangement of elements that have some emergent property, which is different to the sum of the elements' properties, the concept of a complex system needs to be discussed.

Mitchell (2009) describes a complex system as "a system in which large networks of components with no central control and simple rules of operation give rise to complex collective behaviour, sophisticated information processing and adaptation via learning and evolution". In this view a complex system is less of a designed entity but an emergent property of a simpler entity. A similar non-centralised view of complex collective behaviour comes from Sheard and Mostashari (2009) who describe complex systems as "not have a centralizing authority and are not designed from a known specification, but instead involve disparate stakeholders creating systems that are functional for other purposes and are only brought together in the complex system because the individual agents of the system see such cooperation as being beneficial for them".

Blanchard and Fabrycky (2011) proposed these characteristics of a successful engineered system: have a set of functional purposes to satisfy customer needs; have a lifecycle; be composed of different kinds of harmonized resources; be composed by components and subsystems that interact to achieve an expected system behaviour; take part in a larger system through a hierarchy structure; be an integral part of the environment and allow interchanges with it. In this description the expected system behaviour comes from the design authority, but the definition is more akin to description of how to successfully develop a complex system.

Rouse (2003) commented that complex systems are systems exhibiting complicated behaviours with at least one of the following characteristics: huge number of components, large number of relationship among components, relationships are characterized as non-linear and discontinuous, and the elements and relationships present unclear characteristics.

Another view of what defines a complex system comes from Hitchins (2003) who argues that the inherent difficulty in defining complexity is due to subjectivity: it is a perception that depends of the person who is analysing the system and can decrease with knowledge. Calvano and John (2004) suggest the application of the field of complexity theory to better understand the complex engineered systems and ensure that the Systems Engineering approach applied is appropriate to deal with such complexity.

In this context it is useful to define the meaning of complex system used in this paper. As we are interested in development (including design) of a complex system we have chosen to use the complex system characterization of Rouse (2003) together with the successful engineered system characterization of Blanchard and Fabrycky (2011), because these concepts deal with most well-defined complex engineered systems. The kind of complex behaviour proposed by other authors (for example Mitchell, 2009; Sheard and Mostashari, 2009), presents the condition of no central control and a serendipitous pathway to the achievement of complexity which seems not to characterize complex man-made systems.

## 3. VALUE

There are many definitions of value, because it is a relevant concept for organisations in different sectors. The term value is used in many ways, depending on the point of view of who is analysing, the time, the place, the type of system.

Gallarza, Saura and Holbrook (2011) explained the concept of value through the perceived quality and perceived cost to promote customer satisfaction. Whilst this approach provides a comprehensive understanding to correlate quality, cost, value and customer needs, it nevertheless lacks a system's view.

In fact, value considerations have substituted the limited view on price and some research has examined the value of products, the value of buyer-supplier relationships and the value creation process (Lindgreen and Wynstra, 2005). According to Lindgreen et al. (2012) the importance of the buyer-supplier relationship to the creation of value is part of a discussion in marketing literature and supply chain management. Nevertheless extension of this concept could be applied to understand value creation inside the organisation, where many processes are developed and relationships need to improve to achieve the estimated value of the system.

Lawrence Miles in the early of 1940s proposed a basic value methodology based on functional analysis, which consists of an organised process to raise the value of a project and defines value as the ratio between the ability to perform a function by the cost to deliver this performance by the product (SAVE, 2007).

### 3.1. Value in System

According to Blanchard (2004), the system should be evaluated by the value as perceived by the consumer, considering two factors: economical and technical. SE–CMM (1995) introduced the concept of Systems Engineering functions to increase value and proposed that there is interrelationship among the engineering, project and organisation process areas. This is echoed by Buhl et al. (2011) who argue that a company needs to quantify the value contributions of individual activities, their interactions as well as for process, to implement value-based management. Subsequently, many organisations try to instill practices of system engineering that contribute high value in the development of complex systems.

Systems Engineering capability is the level at which the organisation can accomplish the essential elements of system engineering (ANSI - EIA, 2002). A path to achieve a highest level of capability Systems Engineering is through applying continuous progression regarding the organisation's capabilities or process performance, which could be promoted by applying a Systems Engineering capability maturity model (Becker et al., 2009).

Browning (2003) suggests that the most important impact on value in a product development process is the way you realize the activities and coordinate them, emphasizing that, in several circumstances, the origin of lack of value is more from doing "value-added" activities following a wrong approach than for doing "non-value-added" activities right. This puts the focus onto the actualisation of the processes rather than the definition of the processes themselves.

In Niazi and Ali Babar [2009], the relative "perceived value" of different practices of capability maturity model integration (CMMI) level 2 for process areas is identified; this means that one practice can be perceived by the organisation as more important than others. The practices help to show how to develop the process area to improve the maturity level of the organisation.

It is important to note that, according to the above, a high maturity level of Systems Engineering could be supported by "value-added" activities integrated with "perceived value" practices.

Focusing on what is value for the stakeholders will allow the Systems Engineering processes to be aligned in order to achieve a successful result (Patankul and Shenhar, 2010). They attempt to describe three different categories of value: to the customer, to the performing organisation and to the team. They present subgroups for each category of value as summarized in table I.

| Value to the Customer | Value to the Performing Organisation | Value to the Team |
|---|---|---|
| Operational Excellence | Market opportunity | Challenge and excitement |
| Modernization | Revenue and growth | Career prospect |
| Platform for future effort | Strategic positioning | Pride |
| Success enhancement | Organisational learning | Name and recognition |
| | Name and brand recognition | User benefits |
| | Relationship development | Networking |
| | | Incentive |

Table I. Subgroups for Each Category of Value. Based on Patanakul and Shenhar (2010)

We will restrict our analysis to that from the perspective of the supplier organization on the value creation process whilst acknowledging that value is being created on several dimensions related to the system. This is because the onus of creating value, even if not wholly within the remit of the developer, can nonetheless not be fully abdicated by them. In this paper we propose there are 3 main dimensions (in orange colour in figure 2) to observe when focussing on value in the development of a system of interest (SOI) from the perspective of the supplier organisation:

1) Technical value in the system of interest; that is, the characteristics primarily stemming from the technology and performance of the system of interest

2) Value in the supplier's organisation due to the development of the system of interest; that is the value acquired by the organisation in the process of developing the system of interest

3) Value that the development of the system of interest represents to any supersystems that it is a part of; that is how effective the system of interest is in all application scenarios and use cases

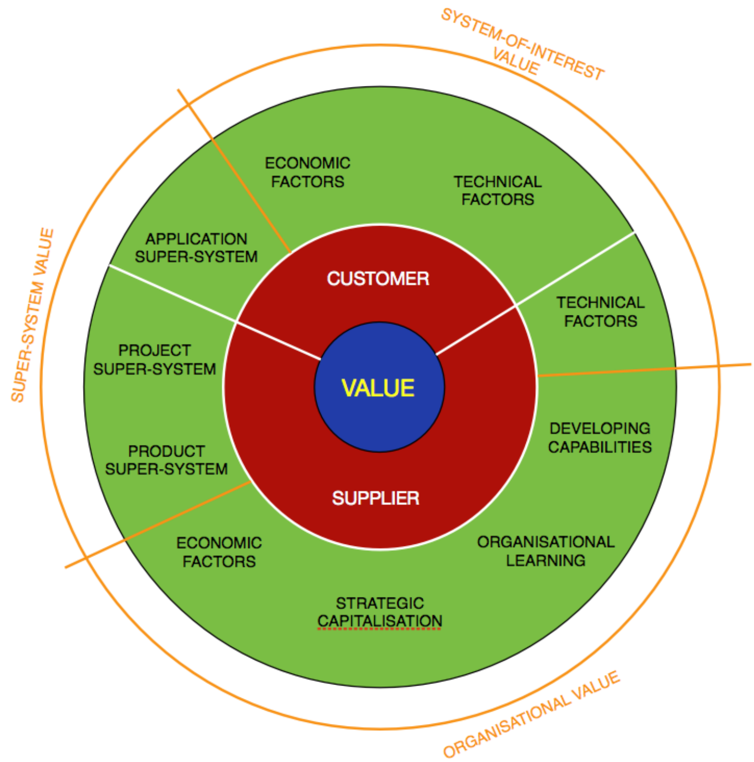


Figure 2: Customer value through the complex system suppliers' lens.

At this point, some distinct ideas have been illustrated, which pose, among other things, the following research questions:

- How to improve the value achieved in complex engineered system?
- How can Systems Engineering improve the value in complex engineered system?
- How to align the value to the stakeholders with the Systems Engineering process?

In this paper we hypothesise that by using the UCLse Principles of Systems Engineering as a guide, and with knowledge of the values perceived by the various stakeholders, that appropriate tailoring of a systems engineering methodology can be made to increase SE maturity and, by extension, those values.

## 4. RESEARCH DESIGN

Previously the UCLse group published a primary study about the UCLse principles and a number of practices were presented based on the experience of MSSL projects. Thus the objective of this empirical research (see figure 3) was to amplify the list of practices that fall within the UCLse Principles and understand the UCLse principles as a way of achieving value in complex systems.

From September to December 2012 20 interviews were conducted. Interviewees voluntarily participated in this study in a self-selecting sample. There are 6 participating companies in our sample of research.

This research seeks to identify perceptions and experiences of practitioners about Systems Engineering practices that give benefits to achieving a high maturity SE capability level and therefore value. The participants are from different companies and the data collection occurred in four episodes.

The first research population consisted of 8 mid-career systems engineers, from a company in the United Kingdom (UK) with an average of 8 years of work experience. The participants were from the defence sector and were receiving a course about System Engineering Management.

During the 1st day of the course after an explanation about the UCLse Principles, the open questions to the first group were conducted. Since the Principles were taught in the course during the lecture, we assumed that all participants had one identical minimal level of knowledge of these principles. Consistent with the tacit knowledge approach, the eight invited participants, based on their experiences, were divided into two groups, each one with four participants, and asked to discuss and identify valuable practices in SE, which using the UCLse Principles as a guide.

The participants of the second group were 5 systems engineers from companies across the UK with an average of 5 years of work experience.

The third sample was collected during the delivery of a course in a UK company that is a leader in complex systems development. On the fourth day of the course, after hearing about the principles for more than 6 hours and discussing them, a group of 4 experienced delegates was asked to answer which practices were must valuable in Systems Engineering projects and how to correlate these practices with the UCLse principles.

The last group was from a major transport company, which manages transport services across a city with a population of about 7.5 million people. The data collection was conducted in the same way as happened with the first and the third group using face to face open questions with 3 practitioners.

All these answers were noted down and evaluated for differences and similarities. If the same practice was cited by more than one group, it just appears once on the final practices list. The result is illustrated in table II.

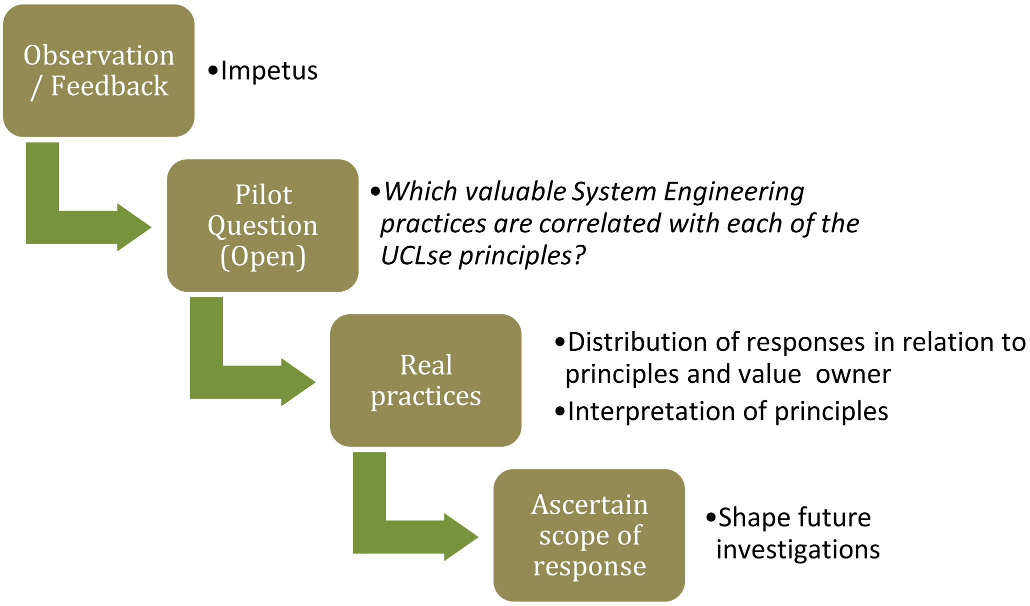


Figure 3: The organisation of our empirical research.

## 5. RESULTS AND DISCUSSION

### 5.1. Practices to Support UCLse Principles

In order to achieve value in complex systems it is necessary to considerer different stakeholders. UCLse principles contribute to delivering value to the customer, maximizing the worth delivered to the system, to the organisation and to the supersystem. Understanding UCLse principles, it is possible to think of Systems Engineering from different perspectives and to analyze how to build good practice, to improve the Systems Engineering process in such way as to achieve the most value from the complex system.

| **UCLse Principles break down in practices** | **UCLse Principles** | | | | |
|---|---|---|---|---|---|
| | **I** | **II** | **III** | **IV** | **V** |
| Adoption of appropriate tools/ practices (DOORS/ SYSML) | | | | | X |
| Appropriate people buy-in at reviews | | X | X | | |
| Appropriate base lining | X | | | | |
| Capture best practices in a center of competence | X | | | | |
| Brainstorming | | X | | | |
| Workshops | | X | | | |
| Break down silos | | | X | | |
| Bring in consultants to have new perspective | | X | | | |
| Business user groups | | X | | | |
| Clear scope | | | X | | X |
| Communication | | X | X | X | |
| Consider upgrades from the start | | | | | X |
| Continuous process improvement | X | | | X | X |
| Costing and schedules in work package management | | | X | | |
| Cycle between embedded Project Management (PM) in project team and central PM team | | | | X | |
| Effective Design Reviews | | X | | X | |

| | | | | | |
|---|---|---|---|---|---|
| Engineering buy-in to PM constraints | | | | X | |
| Flown down of ethos | X | | | | |
| Form project team at early enough stage | | | | | X |
| Full team at kickoff meeting | | X | X | | |
| Higher management buy-in | | | X | X | X |
| Include SEMP in the project plan | | | | X | |
| Integrate the system with other system in the supersystem | | | X | | |
| Integrated project team meetings | | X | X | | |
| Inter disciplinary team management | | X | X | X | |
| Investigate failures' root causes from different domains | | X | | | |
| Learn from individual mistakes | X | X | | | |
| Lessons learnt process/ database | X | | | | |
| Look for ways to improve the process | | | | X | |
| Register changes to the process | X | | | | |
| Mix people experience in the team | X | | | | |
| Open discussions in business management level | | | | X | |
| Newsletters | X | | | | |
| Peer reviews | X | | | | |
| Personal development reviews/ skills matrix | | | X | | |
| Progress meetings | | X | | | |
| Use proof of concept (modeling, mock-ups, …) | | | | | X |
| Complete and refined requirements | | | | | X |
| Right level of awareness/ involvement of stakeholders | | | X | | |
| Risk management | | | | X | X |
| Staff briefings- next project milestones and current status | | | | X | |
| Stage reviews | X | | | X | |
| Systems engineering management plan | X | | | | |
| Systems engineers to define and flow down requirements | | X | X | X | |
| Tailoring process | X | | | | X |
| Create mentoring opportunities | X | | | | |
| To look for trends to anticipate problems | | | | | X |
| Understand the typical life cycle | | | | | X |
| Presenting possible solutions at user meetings | | | | | X |
| User/ client understanding | | X | | X | X |
| Create and maintain a project wiki | X | | | | |

Table II. Practices to support UCLse principles: I, Principles govern process; II, Seek alternative systems perspectives; III, Understand the enterprise context; IV, Integrate systems engineering and project management; V, Invest in the early stages of projects.

Having the data points, we considered that many practices support more than one of the UCLse principles. For example, the practices of communication, continuous process improvement, higher management buy-in, inter disciplinary team management, systems engineers to define and flow down requirements and user/ client understanding, each promotes three UCLse principles. Based on these findings, it is possible to identify the top practices derived from the UCLse principles which are practices frp, Table II that are related to three UCLse principles. The subsequent section discusses in more detail the top practices identified.

principles.

#### 5.1.1. Communication

To establish and maintain communication (we believe this to entail information flow, timeliness, frequency, relevance, integrity of data, etc.) that permits all participants of the project to know what they need to do, when and why and understand how their part of the system interacts with the system as a whole. This human interface is one of the most important tasks of the project system engineer (Kossiakoff, 2011).

The communication could be conducted in different ways such as, newsletters, wiki, workshops. It may involved informing others about the project status, sharing knowledge of changes, problems and lessons learnt that improves understanding of the whole project. In the same way, it could improve knowledge of the whole organization, allowing better alignment of the project goals with the enterprise objectives.

In addition, it promotes a good environment to deal with the differences between project management and Systems Engineering, because each one knows more about the challenges and efforts of the other and in this way to look to minimize compromises.

#### 5.1.2. Continuous process improvement

Any successfully completed project has processes and tools which contribute most to the achievement of the project's goals and objectives. These should be identified and disseminated to other projects.

Davenport (1993) presented some features of continuous process improvement, such as the following: process is the main unit of analysis; demanding a measurement system for process performance; and needs a high level of organizational and behavioural changes.

A path to facilitate the dissemination of this practice is to have a database that can be used by project teams, but the process and rationale for doing this should be institutionalized.

The project team needs to know where to look for examples of best practice in the organisation, which comes not only from your projects but also from different places such as universities, other organisations and professional associations.

#### 5.1.3. Higher management buy-in

Management commitment and involvement has strong influence for any successful project, because, among other things, it needs provision of appropriate resources. INCOSE (2011) pointed out that the management commitment to quality is reflected in the strategic planning of the organisation and it tends to provide guidelines to understand how other approaches are useful for the organisation, because it is a way to communicate to everyone in the organisation what is seen as important.

#### 5.1.4. Inter disciplinary team management.

Derry et al. (2001) suggested that interdisciplinary teams are groups of people with a strong sense of shared purpose and definable membership, including members from different fields.

Focusing on people, the project team requires different competencies, characteristics and attributes. Therefore, the provision of different approaches improves the system engineering management maturity. In a complex system, development of interdisciplinary teams would promote an appropriate competency in the responsibility layer. Tishler (1996) stated that the quality of the system development team is one of the main factors critical to the success of projects.

#### 5.1.5. Systems engineers to define and flow down requirements

Frank et al. (2011) indicate that if the engineers have a good capacity for engineering systems thinking - CEST, there is a good condition to implement the core tasks for the stages of the life cycle. Assessing the engineering systems thinking of the project team could improve the skills development of understanding customers' needs and transforming them in users' requirements.

Systems engineers promote the understanding of the whole system to specialists of different domains, which facilitate the management of tradeoffs and brings together several approaches to contribute to the improvement of the system.

#### 5.1.6. User/ client understanding

Sometimes it is difficult to know what clients/ users want. When the users are willing to be involved in the project and discuss their needs, requirements management becomes easier; this should drive the project management and Systems Engineering teams to cooperate. It is generally agreed that the project begins when user needs are received and resources are committed to a project. At that point, it is helpful to improve the user-supplier relationship (INCOSE, 2011).

## 6. CONCLUSIONS

We will summarize the advantages to achieving value in complex systems considering the UCLse principles.

According to Emes et al. (2012), UCLse principles support a way to achieve long-term value to the enterprise when developing the complex system. Considering the experience of the practitioners it is possible to identify several good practices for the development of complex systems, aligned with the UCLse principles.

We have introduced an interpretation of Value that contains greater breadth (figure 2) than others found. We believe this conceptualization at Value supports and extends the UCLse principles of Systems Engineering Management and that it provides a framework for more sustainable and ethical industrial activitiy by introducing a consideration of supersystems related to the system of interest. At the moment that consideration is limited to 'product', 'project' and 'application' supersystems but it can be extended further to all relevant supersystems. Indeed, that is one area where we are doing further work.

The main point of the discussion is to recommend the UCLse principles as a guide, which could be broken down into practices adapted to each specific situation and to all systems related to the complex system to be engineered.

Most of the practices used by the practitioners that fall within the UCLse Principles focus firstly, in improving the value to the system and secondly, in adding value to the supplier organisation. But there is a lack of practices to develop the value to the supersystem as already expressed which might indicate the need for another principle. When interpreting these findings, a discussion about the capacity for engineering systems thinking should be considered (Frank et al., 2011), which suggests extending the systems' view to apply it recursively throughout the development and throughout the systems' hierarchies.

To conclude, the UCLse principles are a guide and should promote the development of practices tailored for each kind of complex system. If the practitioners understand the contributions of the UCLse principles, it is possible to create a supportive environment to cultivate good practice and increase the value acquired by the system development and its application.

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