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Systems Engineering and Subcontract Management Issues

Alper Pahsa
Havelsan Inc.
Turkey

1. Introduction

One of the major problems that the Systems Engineering processes come across is how to deal with the subcontractors. Assuring the activities of subcontractors are convenient and compliant with the systems engineering standard procedures and criteria is an important for the systems engineering program management. One of the most challenging jobs for a systems engineering team is to understand the needs and requirements of the customer, the constraints and variables that are established and the limits of business conduct that are acceptable for the particular job under contract. This understanding should directly reroute to the people who work under the subject contract of the customer. All of the requests, criteria and generic standards of customer needs associated with the subcontractor are directly written in the subcontracts statement of work or tasking contract too.

The process of the dealing with the subcontractors is the responsibility of the systems integrators in order to ensure the whole systems engineering process is followed. The systems integrator has the responsibility of helping the subcontractor take functional point of view of the organization and of all procurement process. It is the responsibility of the systems integrator to aid the subcontractor in erecting a parallel technical auditing process.

So what does all of this mean to project management team responsible for issuing contracts and subcontracts that enable systems engineering team solutions to meet the requirements of the systems integration project? It should be clear that the unclear instructions as part of the subcontracts issued to subcontractors with metrics spelled out by which are able to gauge both technical and on-time performance should be clear.

Systems engineering teams incorporate this into the terms and conditions of the subcontracts. It must be careful to avoid the pass-through of non deterministic risk factors, as if the systems engineering team lose control of these once they are in the hands of others. Pass-through of known risk elements is natural, and a revision activity must be in place such that it is able to keep track of the progress in the resolving the items with the risk.

Systems Engineering Teams discussed how to implement and maintain an audit trail throughout the systems integration process and how to perform and record the details of the quality assurance process. Each of these activities carries special important on how it is implemented in systems integration approach with subcontractors that is engaged for assistance with the project or for procurement of hardware and software.

Just as the customer provides the facilities with a set of requirements that it believes to be representative of the actual needs of the user. The corporation must prepare a detailed set of valid requirements for subcontractors. Absence of strategic plan on the part of a subcontractor should result in imposition of the systems integration organization strategic plan, especially those parts that related to audit trail maintenance; risk identification, formulation, and resolution; and such management process and procedures as we feel are essential for satisfactory performance the contract or subcontract. In the following sections initially Systems Engineering process is explained. Secondly Program Management process is explained then the process of the subcontract management and the activities related to Issues with contractor and subcontractor management will be given. In this section a systems engineering and the program management teams' perspectives for subcontract management issues are explained. Then the concerns related to subcontractor management process are given and finally conclusion section is drawn for the subcontract management in sense of systems engineering process is given.

2. Systems engineering

Systems engineering defined as "An interdisciplinary approach to evolve and verify an integrated and life cycle balanced set of systems product and process solutions that satisfy customer needs. Systems engineering: (a) encompasses the scientific and engineering efforts related to the development, manufacturing, verification, deployment, operations, support, and disposal of systems products and processes; (b) develops needed user training equipments, procedures, and data (c) establishes and maintains configuration management of the systems; (d) develops work breakdown structures and statements of work; and (e) provides information for management decision making." Figure 1 displays the Systems Engineering process outline (David E. S. et al, 2006).

The basic Systems Engineering process needs successful products and/or process. It is largely an iterative process that provides overarching technical management of systems from the stated need or capability to effective and useful fielded systems. During the process, design solutions are distributed evenly to the stated needs through the constraints imposed by technology, budgets, and schedules (INCOSE, 2011).

Systems engineering should support acquisition program management in defining what must be done and gathering the information, personnel, and analysis tools to define the mission or program objectives. This includes gathering customer inputs on "needs" and "wants", systems constraints (costs, technology limitations, and applicable specifications/legal requirements), and systems "drivers" (such as capabilities of the competition, military threats, and critical environments). The set of recommended activities that follow are written for a complex project that meets a stated mission or goal, but the word "product" can be substituted to apply these steps to commercial products, for example (Associate CIO of Architecture, 2002),.

Based on the acquisition strategy, the technical team needs to plan acquisitions and document the plan in developing Systems Engineering Management Plan (SEMP). The SEMP covers the technical teams before contract award, during contract performance, and upon contract completion. Included in acquisition planning are solicitation preparation, source selection activities, contract phase-in, monitoring contractor performance, acceptance of deliverables, completing the contract, and transition beyond the contract. The SEMP focuses on interface activities with the contractor, including technical team involvement with and monitoring of contracted work. Often overlooked in project staffing estimates is the amount of time that technical team members are involved in contracting-related activities. Depending on the type of procurement, a technical team member involved in source selection could be consumed nearly full time for 6 to 12 months. After contract award, technical monitoring consumes 30 to 50 percent, peaking at full time when critical milestones or key deliverables arrive (Shamieh, 2011).

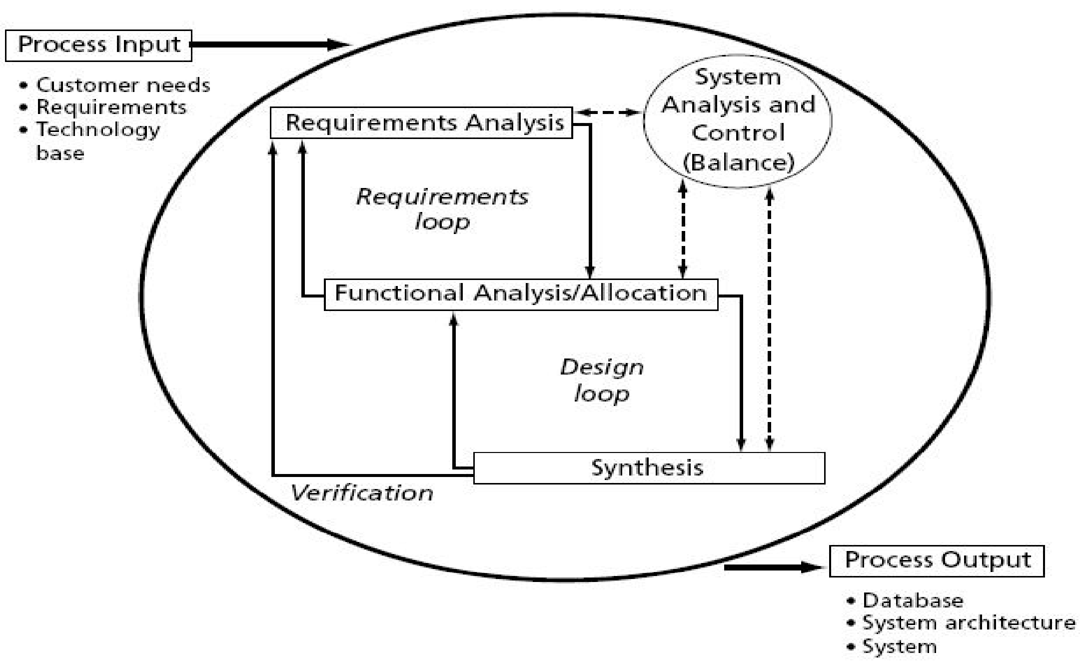

Fig. 1. Systems Engineering Process

The technical team is intimately involved in developing technical documentation for the acquisition package. The acquisition package consists of the solicitation (e.g., Request for Proposals (RFPs) and supporting documents. The solicitation contains all the documentation that is advertised to prospective contractors (or offers). The kkey technical sections of the solicitation are the SOW (or performance work statement), technical specifications, and contract data requirements list. Other sections of the solicitation include proposal instructions and evaluation criteria. Documents that support the solicitation include a procurement schedule, source evaluation plan, Government cost estimate, and purchase request. Input from the technical team will be needed for some of the supporting documents. It is the responsibility of the contract specialist, with the input from the technical team, to ensure that the appropriate clauses are included in the solicitation. All of the features related to solicitation are important for a subcontractor for fully understanding the content of the work that is aimed to realize. Figure 2 shows the process of the contract requirement development process (NASA, 2007).

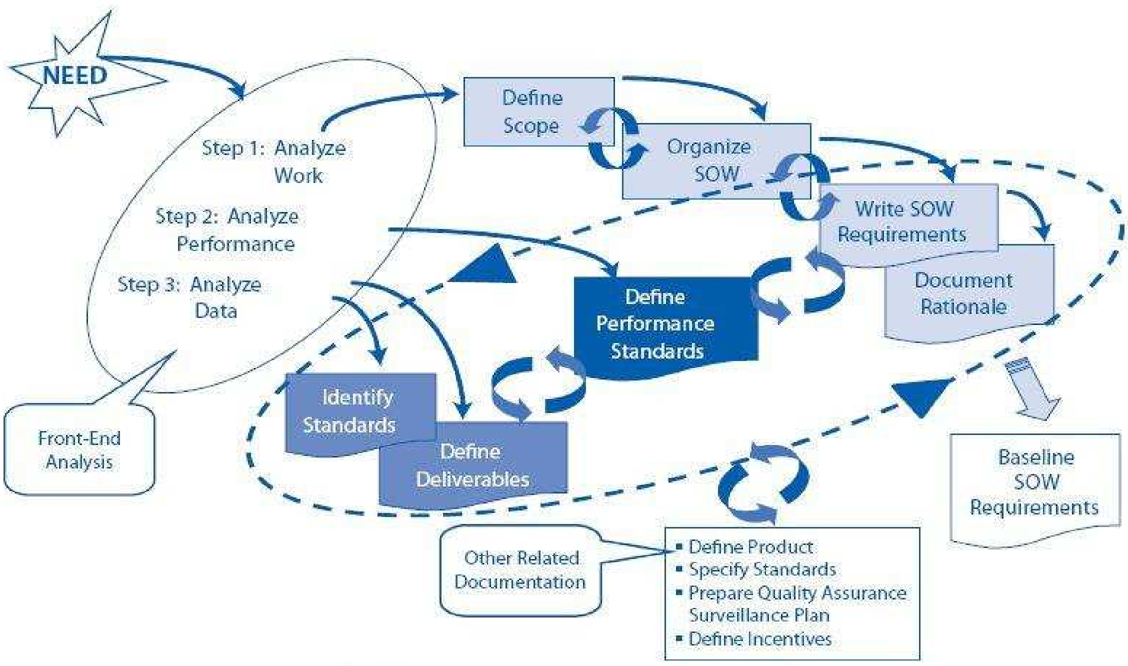

Fig. 2. Contract Requirements Development Process

3. Program management

Program management has been defined as "the management of a series of related projects designed to accomplish broad goals, to which the individual projects contribute, and typically executed over an extended period of time". Program management is very different from corporate administrative management that involves an ongoing oversight role. Program management usually has the more specific task of completing a project or set of projects for which there is a common goal and a finite termination point. The program manager has the responsibility of planning the project, controlling the project's activities, organizing the resources, and leading the work within the constraints of the available time and resources (Associate CIO of Architecture, 2002).

Project planning involves mapping the project's initial course and then updating the plan to meet needs and constraints as they change throughout the program. In the planning process, an overall plan, called an "acquisition strategy," is formulated by analyzing the requirements; investigating material solutions (designs); and making technical, cost, and performance trade-offs to arrive at the best solution. A formal acquisition plan details the specific technical, schedule, and financial aspects of a specific contract or group of contracts within a specific phase of a program. Functional plans detail how the acquisition strategy will be carried out with respect to the various functions within the program (i.e., systems engineering, test and evaluation, logistics, software development). Schedules that are continually updated are used to ensure that various milestones along a timeline are being met. Budgeting, another aspect of project planning, involves developing an initial cost estimate for the work to be performed, presenting and defending the estimate to parties responsible for budget approvals, and expending the funding.

Control of the project's activities is primarily concerned with monitoring and assessing actual activities and making sure they align with program goals. Monitoring involves conducting program reviews, measuring actual costs with planned costs, and testing incremental aspects of the program. It also includes managing the internal aspects of a program (e.g., the current contract) and monitoring external organizations (Government etc.) that may have a stake in the program's outcome. From time to time, a program assessment is needed to determine if the overall requirement is still being addressed, adequate funds are available, the risks are being managed, and the initial acquisition strategy is sound. Leading the work, given time and resource constraints, involves not only the previously mentioned tasks, but also directing that tasks be carried out and maintaining consensus within and outside the program. The program manager must give direction to his or her organization and take direction from organizations outside of his or her direct control. Maintaining a consensus requires making sure that the competing goals of internal and external organizations remain in balance and are working toward the desired goal (David E. S. et al, 2006).

There exists an agreement between the systems engineer and the contract management team. Systems engineer supports the development and maintenance of the agreement between the project office and the contractor that will perform or manage the detail work to achieve the program objectives. This agreement has to satisfy several stakeholders and requires coordination between responsible technical, managerial, financial, contractual, and legal personnel. It requires a document that conforms to the acquisition regulations, program product breakdown structure documentation and the systems architecture. The figure given below shows the contractual process (David E. S. et al, 2006):

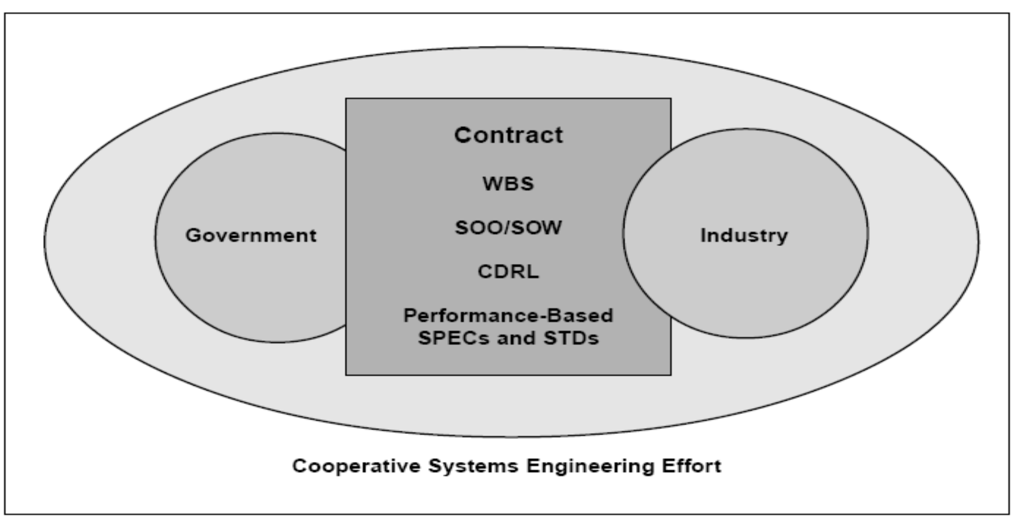

Fig. 3. Contractual Process

The role of technical managers or systems engineers is crucial to satisfying these diverse concerns. Their primary responsibilities include:

- Supporting or initiating the planning effort. The technical risk drives the schedule and cost risks which in turn should drive the type of contractual approach chosen,
- Prepares or supports the preparation of the source selection plan and solicitation clauses concerning proposal requirements and selection criteria,

- Prepares task statements
- Prepares the Contract Data Requirements List (CDRL),
- Supports negotiation and participates in source selection evaluations,
- Forms Integrated Teams and coordinates the government side of combined government and industry integrated teams,
- Monitors the contractor's progress, and Coordinates government action in support of the contracting officer (Global Intergy Corporation, 2002).

4. Subcontracting in System Engineering program

When a Systems Engineering program/project includes a contracting service/product, a challenge is occurred in the Systems Engineering people minds: "Do it in our company or purchase it?" As "everything is program/project…", it is always seem to Systems Engineer team that the option of doing the service/product in the company would be more manageable and cause less trouble. In fact this option is an illusion and reinforced by closed project/program contracting experiences. These experiences are large and were not successful and over which the system engineering process had little control.

However, it is already known that small or large project/programs there are many benefits of subcontracting the program/project. These benefits caused by purchasing the service/product from the product that is already available. Because of the lack of information or interest in a certain technology, carrying out a program/project without subcontracting external services/product, many problems would frequently occur for the program activities. Moreover, it must be well known that the training to hire outsources is important.

The reasons for failing in subcontracting activities are started with lack of a well-defined process to guide the systems engineering team. Purchasing services/product, despite being a rather routine task in program/project manager's life, is a high-risk endeavour and, usually, an empirical activity. Nonetheless, there are many items are bought during the program life cycle (De Mello Filho, 2005). When the program management acquisition team purchase hardware or some material, they are performing a search procedure for certain characteristics that will be evaluated during the acquisitions. This procedure or acquisition activity is defined in classical engineering terms as the procurement process.

5. System Engineering integration roles for subcontract management

When a project being managed by the primary contractor requires a wide range of skills and experience, it may require subcontracting with other companies. It is the prime contractor project manager's responsibility to ensure that the teaming partners and subcontractors are held to the same quality standards as the prime contractor as specified in the Project Plan.

- Statements of work for the subcontractors must clearly reflect the project requirements and state what activities and reviews are expected in their performance. Primary activities that the prime contractor will address with subcontractors include:
- Acceptance criteria.
- Subcontractor Project Plan, Quality Plan, Quality Assurance Plan.
- Quality assessments of subcontractor performance.
- Subcontractor assessments, audits, preventive and corrective action plans (Associate CIO of Architecture, 2002).

The systems integrators company teams such as the systems engineering and contract management have the responsibility of helping the subcontractor take a functional point of view of the organization and of all procurement efforts.

It is the responsibility of the systems integrator to aid the subcontractor in grows a parallel technical auditing process. In addition to interaction matters already discussed, there are several other points to be made (U.S. DoT, 2009). These include the following items:

No favoured treatment for specific vendors. It is only human perhaps for clients and systems integrators to have favourite vendors. These are companies or individuals within certain companies that have provided excellent service in the past. Perhaps a previous acquisition more than met specifications or was unusually trouble-free. Sometimes a particular marketing organization has gone the extra mile to be of assistance in an emergency. It is only natural under such circumstances that this favourable past impression might bias the client or systems integrator. Indeed, the concept of the favoured client is a common one in the private sector. But this attitude is illegal and improper in government procurements. We want to emphasize here that we are not talking about collusion or conspiracy to defraud the government. It is entirely possible that, on occasion, biased behaviour could benefit the government. That is of no matter. It is illegal and not to be condoned.

Timely, Accurate Client Reports. Technical personnel, engineers, computer scientists and the like, tend not to support active, timely reporting on progress to clients. They follow the mushroom growers to client interactions-"keep them in the dark and cover them with manure." That approach may work when things are moving well, but it runs the risk of forfeiting client confidence in troubled times. It seems better to report progress accurately and in a timely fashion, so that if slippages occur they are minor when first mentioned. Naturally the systems integrator should make every effort to stay on schedule, and if the schedule slips or a problem surfaces, the systems integrator should present the recommended solution at the same time the problem is first mentioned.

Prudential Judgement. Suppose the systems integrator has reason to believe that the client is unable or unwilling to handle setbacks in an objective manner. The parable of the king who "killed messengers who brought him bad news" would not remain current in our folklore if it did not have a basis in reality. Thus, reports of delays and difficulties should be brought to the attention of top management rather than directly to the client. This is the sort of prudential judgement call that should be handled by the top management within your organization rather than someone at the operating level. It is suggested that the matter be brought to the attention of top management within the organization as soon as possible and in a calm, factual manner.

Management of subcontractors is of special importance for systems integration involving large, complex engineered systems. It is highly likely that multiple subcontractors will be employee by the prime contractor. Prudent management of these subcontracts is critical to the success of the systems integration program (Grady 1994, 2010).

There are a number of key activities that must be completed by the systems integrator to assure integration of the products provided b the subcontractors prior to test and delivery of the final configuration. Some of the more important activities that must be accomplished include the following (Grady 1994, 2010):

- Organize overall team support for the subsystems integration and test activity, including personnel from various subcontractors.
- Validate incremental deliveries as these are made by subcontractor.
- Prepare the various subsystems for the test and evaluation prior to integration to assure performance meets the stated specifications.
- Integrate hardware/software (HW/SW) subsystems from subcontractors with systems developed by the corporation and legacy systems.
- Monitor test activity and assure that all tests conform to the systems testing regimens agreed to by the client.
- Provide for both Alpha and Beta site tests.
- Conduct necessary post-test activities to review outcomes with all concerned parties.
- Conduct formal reviews and review documentation.
- Provide for failure recovery and error correction in the event subcontractors are unable to meet design specifications.

The corporation must be able to demonstrate that it has gone about its business in a legal, objective, unbiased fashion. In large procurements it is often the case that outside contractors will be let for validation and verification and to develop and administer an audit trail relative to the prime contractor. The necessity for an external enterprise to create and follow a technical audit trail arises not so much from the need to respond to potential procurement difficulties as it does from a need to be able to demonstrate that an objective and unbiased procurement process was utilised. In the figure given below systems integration acquisition strategy is given (INCOSE, 2004):

Systems Integration Acquisition Strategy	
Specification Component	Auditing Component
I. *Functional Architecture Concept*	*Validation Test Document Conceptual Discussion of:*
Establish the general technical capabilities (i.e., the client functional needs).	1. Traceability 2. Conflict resolution 3. Risk analysis and management 4. Consistency 5. Ambiguity evaluation 6. Testability 7. Constraints 8. Feasibility
II. *Technical Architecture Plan*	*Validation Test and Audit Plan*
Define the configuration categories.	For each configuration category, name and describe the relevant characteristics that delimit the requirement.
III. *Technical Component Specifications*	*Validation Test and Audit Implementation*
Define and select the configuration components.	For each configuration component, set down explicit functional and quantitative tests.
IV. *Contract(s)*	*Establish the Operational Requirements for Validation and Audit*

Fig. 4. Generic Technical Acquisition Strategy for a Systems Integration Viewpoint

The Validation Test Document will contain a conceptual discussion of items such as the following (NASA, 2007):

- Traceability
- Potential conflicts and resolution procedures
- Risk analysis and management
- Consistency of requirements
- Potential ambiguities in evaluation procedures
- Testability

1. *Traceability.* The fundamental requirement for the auditing component is traceability. This is classic requirement in all of engineering and in scientific efforts. All work must be written up on a regular basis in a laboratory notebook, dated signed, and witnessed. In engineering construction only registered professional engineers inspect and approve drawings. This seems to be a reasonable precaution when lives may be at stake when using the finished product. While the traceability and validation aspect of computer software is not as formal and rigid as in conventional engineering, the trend is undoubtedly in that direction.
2. *Potential Conflicts and Resolution Procedures.* At the Validation Test Document level, we do not identify specific technical conflicts and their solutions. At this highest level we expect only to see outlined the recommended procedure for resolving technical conflicts. This procedure should be formal, with a special form to be filled out if the conflict is not resolved at the first level discovered. Informal resolution of potential conflicts is the purpose of frequent peer reviews of the systems while it is under construction. Yourdon (1988) recommends this in his data flow method of design. But the idea of frequent peer reviews is a general tool and should be adopted in some form of team design and analysis. Peer review meetings should probably occur at least weekly, with any conflicts not resolved at that time being written up and forwarded to the first level of management. This should not be viewed as an additional burdensome administrative load; rather, it is simply what a group leader would do automatically in a management-by-exception environment.
3. *Risk Analysis and Management.* Risk analysis and management is also derived to the subcontractor from the systems integrator. Risk analysis and management process should be thought to the Subcontractors and with frequent peer reviews and coordinated meetings risks should be identified and managed to resolve.
4. *Consistency of Requirements.* Consistency of requirements would seem to be essentially similar to the previous issue of conflict resolution procedures and it may be taken as so if convenient. We separate the two simply to indicate that consistency of requirements can be checked at the general level, whereas conflicts sometimes occur in an unfortunate application of requirements that are not necessity inconsistent in them.

(a) Potential Ambiguities in Evaluation Procedures. In effect, a conflict is an error of omission. It is almost impossible to write a set of specifications for complex systems that is totally without conflict and ambiguity. Be that as it may, it is the job of systems integrators to produce a set of specifications that reduce ambiguity to a minimum, while at the same time remaining within the bounds of reasonableness as far as complexity goes.

(b) Testability. Testability is an absolutely necessary attribute or feature of a specification. If a specification is not testable, it is not really realistic. It is the job of the installation team or the validation component of the systems integrator effort to require a feasible test scheme for

each proposed specification. Some specifications can be validated or tested by simple observation. One can count the entry ports or disk drives or what have you. But other specifications are intrinsically impossible to complete until after final installation and break-in of the systems. The second level of the audit component is the Validation and Audit Plan. At this level the generic Validation Test Document produced in the first phase is refined and sharpened. For each configuration category, name and describe the relevant characteristics that delimit the requirement.

Then in the third audit component, Validation and Test audit Implementation, for each configuration component set down explicit functional and quantitative tests. At the fourth and final audit level, within the contract request for proposal, establish the operational requirements for validation and audit.

(c) Audit Reports and Sign-off. It is known how the auditing process proceeds. The procedures just discussed above establish the requirements for a complete audit trail, but only if the requirements are actually followed. Often, in practice, reality is far from the theoretical ideal. For example, program evaluation and review technique (PERT) and critical path method (CPM) charts are merely useless impedimenta if not maintained on a timely basis. We also know that documentation sometimes lags production by several cycles. Similarly, audit reports and sign-off will not be kept up to date and functional unless management insists. This is especially so in dealing with subcontractors and one can see why this is so. A subcontractor is paid to produce one or more deliverables. Paper records of any kind seem to some subcontractors to b a non functional and unnecessary.

For each of the activities, components "at risk" are identified, the risk aspects are analysed, the steps to avoid the risk and the ensuing consequences are taken, and management of the risk initiated, an internal processes and procedures are developed to address components at risk. In addition, the risk detection and identification plan is modified to incorporate similar occurrences of such risk, if these are not already to address components at risk. In addition, the risk detection and identification plan is modified to incorporate similar occurrences of such risk, if these are not already included in the plan. The risk management plan, as part of the overall strategic plan for the systems integration program, begins wit an analysis of the requirements at the onset of the program to ascertain if there are requirements statements that could jeopardize successful completion of the program (NASA, 2007).

The risk management plan continues with risk assessment for each of the phases of the systems integration life cycle. One of the most vexing problems in risk management is the early identification of potential causes of risk. This is especially true in the development of large, complex life-support systems and for large systems integration programs that are heavily dependent on the integration of legacy systems and newly developed requirements. What has made this problem particularly difficult has been necessity of using qualitative processes in an attempt to identify risk areas and risk situations. Risk detection and identification should commence with the issuance of requirements and the development of specifications. It is often assessing the risk assessment process is delayed until development of systems designs or even until procurements of major subsystems. This is fundamentally an untenable situation, since by this point in a program, investments of resources and personnel have been made, designs have been developed, and it is much too late to achieve an economical and efficient recovery without significant rework. This impact and ripple effect due to program elements at risk becomes known only after discovery of the nature and character of risk, thus jeopardizing the entire development program (Grady, 1994, 2010).

Consider the instance of systems and hardware and software requirements that may be at risk. If these requirements are found to be ambiguous, in conflict, incomplete, or changing too much (Requirement volatility), they may be considered to be a cause of risk to successful completion of the program. Any of these sources may in and of itself, be sufficient to jeopardize the entire program if not resolved.

6. Issues related with subcontractor arrangements

In the ideal world, a systems integrator group that has systems engineering management and program management group manages its subcontractors, each subcontract contains all the right requirements, and resources are adequate. In the real world, the technical team deals with contractors and subcontractors that are motivated by profit, subcontracts with missing or faulty requirements, and resources that are consumed more quickly than expected (Grady 1994, 2010). These and other factors cause or influence two key issues in subcontracting:

- Limited or no oversight of subcontractors and
- Limited access to or inability to obtain subcontractor data.

These issues are exacerbated when they apply to second-(or lower) tier subcontractors. Scenarios other than those above are possible. Resolutions might include reducing contract scope or deliverables in lieu of cost increases or sharing information technology in order to obtain data. Even with the adequate flow down requirements in (sub) contracts, legal wrangling may be necessary to entice contractors to satisfy the conditions of their (sub) contracts. Activities during contract performance will generate an updated surveillance plan, minutes documenting meetings, change requests, and contract change orders. Processes will be assessed, deliverables and work products evaluated, and results reviewed (De Mello Filho, 2005).

Systems engineering companies, who use an internal pool of technical resources to develop the entire program/project in their organization, need independent control and audit to their process. System's owners who select to use their internal resources and capabilities of their organization to perform the development process should obey the Systems Engineering Management process defined a Systems Engineering Process guidebook such as "INCOSE System Engineering Handbooks". Internal agreements in the organization should be written and signed between the customer and the systems development team as though they were procured from the outside. Moreover there should be independent review (by another division such as quality control assurance teams, agency, or independent consultant) of products and activities. In fact the development is done internally, an independent review team is recommended to provide a sanity check on the development process. This will create a healthy and clear perspective in the project and help to identify and manage project risks (De Mello Filho, 2005).

If the company uses an independent subcontractor in their development program/project then the control on the subcontracted service is performed by the contractor system integrator. Independent control of the system integrator carries the same responsibility as the independent control/audit of the consultants or agencies that use to select internal system development resources in the program/project development. However subcontracting a service/product then brought different problems with itself. Distributing the Systems Engineering process of the system integrator to the subcontractor, sharing the program schedule and program risks related to the subcontracted activity to the subcontractor are the important headlines in the subcontract activity.

7. Conclusion

One of the major problems that the Systems Engineering processes come across is how to deal with the subcontractors in order to assure activities of subcontractors are convenient and compliant with the systems engineering standard procedures and criteria. One of the most challenging job for a systems engineering team is to understand the needs and requirements of the customer and the constraints and variables that are established and the limits of business conduct that are acceptable for the particular job under contract. This understanding should directly reroute to the people who work under the subject contract of the customer. All of the requests, criteria and generic standards of customer needs associated with the subcontractor are directly written in the subcontracts statement of work or tasking contract too.

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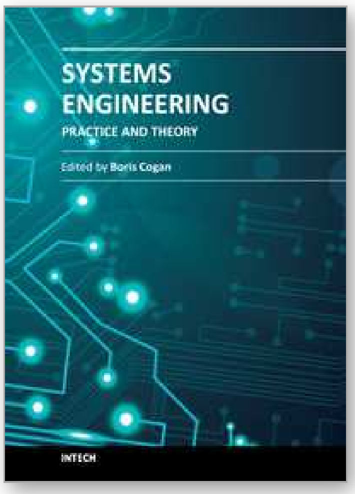

Systems Engineering - Practice and Theory

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The book "Systems Engineering: Practice and Theory" is a collection of articles written by developers and researches from all around the globe. Mostly they present methodologies for separate Systems Engineering processes; others consider issues of adjacent knowledge areas and sub-areas that significantly contribute to systems development, operation, and maintenance. Case studies include aircraft, spacecrafts, and space systems development, post-analysis of data collected during operation of large systems etc. Important issues related to "bottlenecks" of Systems Engineering, such as complexity, reliability, and safety of different kinds of systems, creation, operation and maintenance of services, system-human communication, and management tasks done during system projects are addressed in the collection. This book is for people who are interested in the modern state of the Systems Engineering knowledge area and for systems engineers involved in different activities of the area. Some articles may be a valuable source for university lecturers and students; most of case studies can be directly used in Systems Engineering courses as illustrative materials.