GOALS ANALYSIS PROCEDURE

GUIDELINES FOR APPLYING THE GOALS ANALYSIS PROCESS

Albert E. Motley III, NASA Langley Research Center, Hampton VA.

Abstract

One of the key elements to successful project management is the establishment of the "right set of requirements", requirements that reflect the true customer needs and are consistent with the strategic goals and objectives of the participating organizations. A viable set of requirements implies that each individual requirement is a necessary element in satisfying the stated goals and that the entire set of requirements, taken as a whole, is sufficient to satisfy the stated goals. Unfortunately, it is the author's experience that during project formulation phases[1] many of the Systems Engineering customers do not conduct a rigorous analysis of the goals and objectives that drive the system requirements. As a result, the Systems Engineer is often provided with requirements that are vague, incomplete, and internally inconsistent. To complicate matters, most systems development methodologies assume that the customer provides unambiguous, comprehensive and concise requirements.

This paper describes the specific steps of a Goals Analysis process applied by Systems Engineers at the NASA Langley Research Center during the formulation of requirements for research projects. The objective of Goals Analysis is to identify and explore all of the influencing factors that ultimately drive the system's requirements.

Introduction

Goals analysis is predicated on the fact that no project operates in a vacuum; there are interfaces between the customer, the builder, and the environment,[2] or the rest of the world (figure 1). The participating organizations at each of these interfaces represent potential sources of goals and objectives that may influence the requirements of the system under development.

Figure 1. The Environment today[2]

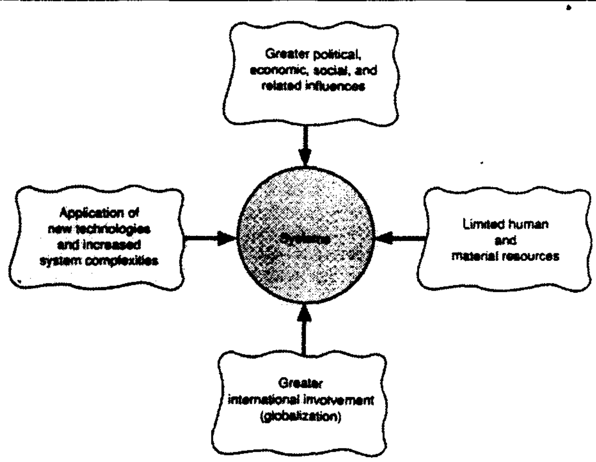


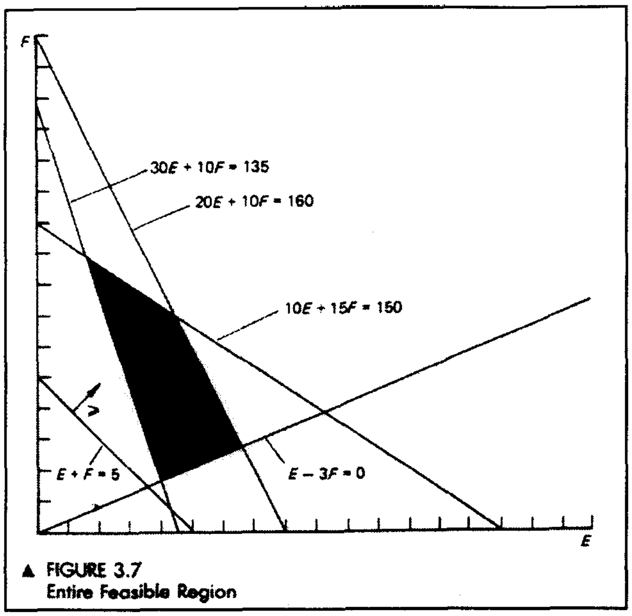
Figure 1.1. The environment today.

The author believes the concept of Goals Analysis is analogous to the concept of Requirements Analysis. Where the latter establishes a trade space, or region of feasible

1 NPG-7120.5 Program and Project Management Process and Requirements, rev A, NASA, April 1998, p 18.

2 Blanchard, B. S., Systems Engineering Management, 3rd ed., Wiley-Interscience, 1991, figure 1.1, p 2.

Figure 2. Trade Space - Region of Feasible Solutions[3]



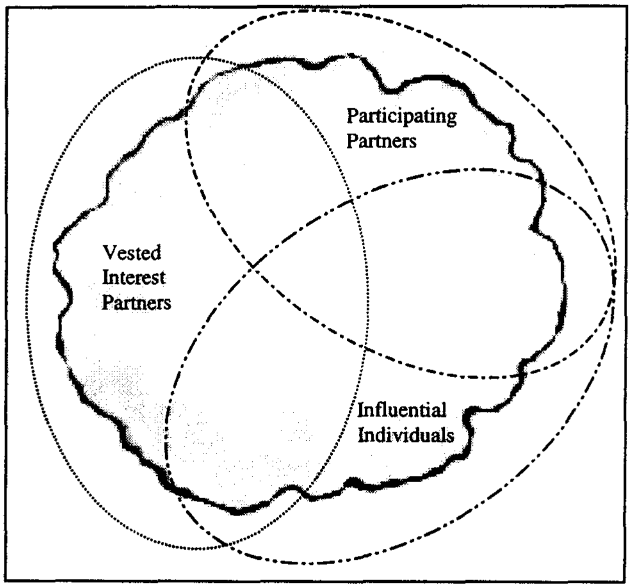
solution (figure 2),[3] the author suggests that the former establishes an *influence space* (figure 3),[4] or region of overlapping interests. It is the author's belief that the source of all requirements driving the system's design are captured within the goals and objectives that define the boundaries of a fully developed *influence space*.

It is also the author's belief that rigorous application of Goals Analysis, to seek out and explore all the interfaces and associated influence factors, will lead to better and more rapid requirements development and the minimization of requirements creep.

Why is Goals Analysis Needed?

It is the Systems Engineer's task to bring structure, in the form of a systems solution, to an inherently ill-structured and unbound world of human needs.[5] Most literature on the subject of Systems Engineering methodology illustrates the Systems Analysis and Development process as some form of flow diagram where the customer needs or requirements are an input to the process. While the process may contains steps to validate the customer inputs, seldom does the process include explicit steps to assist the Systems Engineer in developing and refining these inputs.

Figure 3. Influence Space: Region of Overlapping Interests.[4]



There is literature, such as that by Rechiten,[6] which provides useful Goals Analysis techniques. These techniques encourage the Systems Engineer to work with the customer to progress from problem statement to systems solution. Included are such processes as working the problem statement forwards, from problem to solution, and then working it backwards, from solution to problem. Another approach is to generalize

3 Eppen, Gould, and Schmidt, Introduction to Management Science, 4th ed., Prentice-Hall, 1993, figure 3.7, p 102.

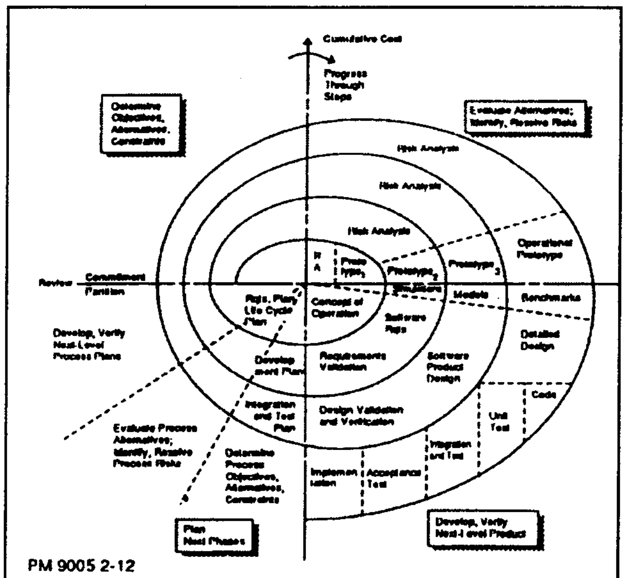
4 Motley, Albert, Goals Analysis Process, an internal document of the Systems Engineering and Controls Branch, NASA, May 1999.

5 Rechtin, Eberhardt, Systems Architecting - Creating & Building Complex Systems, Prentice-Hall, 1991, p 1.

6 ibid., p 54.

the problem statement then attempt to focus on specific problem solutions. A third technique is to explore multiple parallel problem solutions based on partial evidence of a solution's viability. A final suggestion is the use of analogies and metaphors to relate the current problem with previous system solutions. However, Rechiten is quick to point out that these techniques must be used with careful judgment and that they are best applied in cases where just "...a few leaps of imagination may bring the problem and solution together."[6] The author has found that techniques of this nature are generally not very useful when working with new, large, and complex problems.

Figure 4. Bomen Spiral Diagram[7]

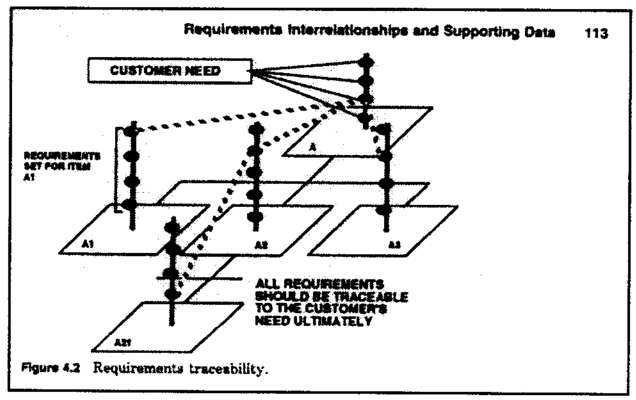


Boehm's (1988b) spiral model of the software process

Bohem's spiral model,[7] (figure 4) is perhaps one of the most frequently referenced illustration of the structured systems process. However, this model also assumes the requirements are given by the customer and not a product of the process. While the model's formulation steps include "determining the system objectives and constraints."[7] The author agrees with statements by Forsburg and Mooz that the specific role of systems engineering, and particularly the steps of a goals analysis process, in this model are obscured.[8]

Again, in the "Requirements Interrelationships and Supporting Data" diagram by Grady,[9] (figure 5) the customer's needs are illustrated simply as an input box to the diagram. No part of the process provides a structure for developing the needs.

Figure 5. Requirements Interrelationships and Supporting Data[9]



During the Systems Definition phase of the "Integrated Waterfall Model"[10] (figure 6), Sage assumes that the group developing systems requirements are "...sufficiently informed about the intended purpose of the new or modified system such that they can identify

7 Boehm, B.W. "A Spiral Model of Software Development," Software Engineering Project Management, IEEE Computer Society Press, 1988, pp 128-142.

8 K. Forsberg, and H. Mooz, "The Relationship of Systems Engineering to the Project Cycle," Proceedings of the First Annual Symposium of NCOSE, 1991, exhibit 4, p 58.

9 Gradey, Jeffrey O., Systems Requirements Analysis, McGraw-Hill 1993, figure 4.2, p 113.

10 Sage, Andrew P., Systems Engineering, Wile Interscience, 1992, figure 1.6, p 17.

Figure 6. Integrated Waterfall Model[10]

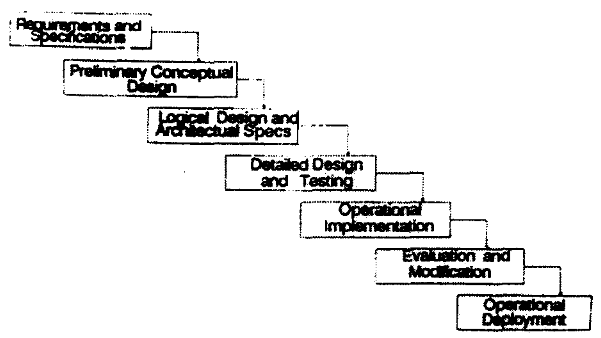


Figure 1.6. Systems Engineering Life-Cycle Phases

and develop the system level requirements in sufficiently complete detail..."[11] Again, no structured process or methodology is provided to assist in the development and definition of a Customer's needs into a set of system goals.

Finally, in Blanchard's "Software Life Cycle" model,[12] (figure 7) the entry block is titled "Identification of the Need" with an associated statement in the text that reads "this information is generally included in a software requirements specification."[13] This portion of the text does include a reference to Functional Analysis from a previous section in the book, but that topic deals primarily with the translation of systems requirement into detailed design criteria. The very next block on the diagram jumps directly into "Systems Conceptual Design" with no provision or mention of Goals Analysis.

The lack of readily available methodology, or specific process steps, to perform goals analysis is not a criticism of the work published by the authors referenced in this paper but rather an observation by this author of the need to push Systems Engineering methodology further back into the lifecycle process to the very first inception of a system's need by the Customer.

Figure 7. Blanchard Software Life Cycle[12]

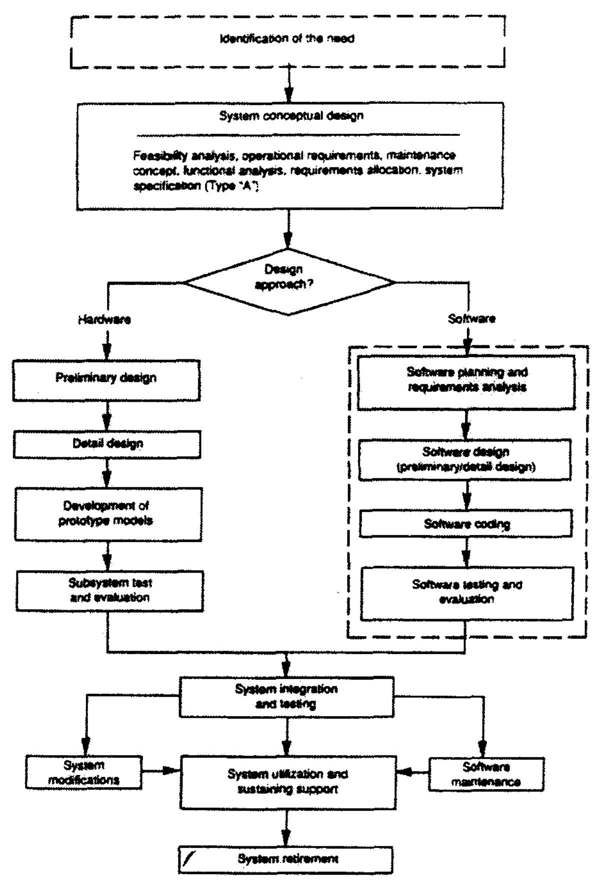


Figure 3.25. Software life cycle.

121

Goals Analysis Process.

Typically, at the inception of a new project, the customer has already identified a set of top level goals that he/she believes are necessary to fulfill a perceived needs. The engineering group accepts these goals, then develops a system concept to fulfill the needs.

Paramount to the success of any undertaking is the clear and coherent statement of what is to be accomplished. Without a concise statement of the goals, there is very

11 Sage, Andrew P., Systems Engineering, Wile Interscience, 1992, figure 2.3, p 49.

12 Blanchard, B. S., Systems Engineering Management, 3rd ed., Wiley-Interscience, 1991, figure 3.25, p 121.

13 ibid., p 121.

little chance of establishing direct linkage between the customer's needs and the system designed to satisfying those needs. Unless this linkage is clearly established then it is all too easy to "... make an error of the third kind - solving the wrong problem."[14]

The Goals analysis process outlined in the remainder of this paper is designed to help the customer fully explore all the factors that influence the perceived system's need and to articulate the most general top-level goals and objectives. The process also helps the engineering group understand the influencing factors driving the goals, which ultimately flow down to a quantifiable set of performance requirements for the system to be developed.

As the architecture of the systems concept is refined and detailed, subsequent iterations of the Goals Analysis Process allows for development of lower and lower levels of system requirements, which tie directly to project upper level goals.

Participants in the Goals Analysis Process

The following people, or organizations, should participate in the Goals Analysis Process: the Program or Project Manager, the Lead Systems Engineer, the Systems Engineering Support Team, representatives from the Customer, representatives from the User group, representatives from Engineering Management, and representatives from each of the identified Partners.

Identification of Partners.

The first step in establishing the boundaries of the *Influence Space* is the identification of partners. For the purpose of this paper, a partner refers to any individual or organization that is participating in the project or has an interest in the project's final results. The relationship between the project and the partner can generally be classified into three categories: Vested Interest Partners, Contributing Partners, and Influential Independent Partners.

Vested Interest Partners are those individuals or organizations who have a strategic stake in the project. In other words, the strategies they have incorporated into future plans are dependent on, or affected by, the success of the project. Vested Interest Partners are generally the source of objectives that must be accomplished by the systems under consideration.

Contributing Partners are those individuals or organizations who are involved with the project but only from a current business perspective. In other words, the success or failure of the project does not affect the strategies of their future plans (aside from the failure of any given business venture affecting an organizations future plans). Contributing Partners are generally the source of constraints that limit the bounds of viable solutions for the system under consideration.

Influential Independent Partners are those individuals or organizations that have the ability of affect the project, but they are not involved from a current business perspective or from a strategic future perspective (partners of this type are often known as political friends or foes). Advocacy from Influential Independents may come at a price; that price often takes the form of additional objectives for the system to accomplish. Opposition from Influential Independents often takes the form of additional constraints that further limit the bounds of viable solutions for the system under consideration

It is quite possible that any given partner may fall into more that one classification. This is not a problem as the classifications are actually just constructs to assist the customer in exploring and identifying

14 Rechtin, Eberhardt, Systems Architecting - Creating & Building complex Systems, Prentice-Hall, 1991, p 53.

potential partners in a way that may not have been readily apparent.

A technique for helping the customer identify partners is to ask questions such as:

- "Who does the Customer want to know about this project?"
- "Who does the Customer want to participate in this project?"
- "Who might want to know about what the Customer is doing?"
- "Who will the project, or the final results, affect?"

The process of identifying Activity Partners should result in a listing of individuals and organizations that may/will/should be involved with the planning, development, implementation, and operations of the system under consideration.

Establish the Metrics for Ranking the Partners

Once the Partners have been identified they must be sorted in relative priority or significance of the partner to the project. Such a sorting requires a set of metrics for ranking each partner. The significance of each metric must be in terms of value to the customer or influence over the project. Several different criteria may be used in sorting the partner list. For example, one sorting may be by funding source. In other words, the most likely or the largest funding partner would be ranked higher on the list. A second sorting order may be by technical expertise. In other words, the partners with the critical technical capabilities or skills would be ranked higher on the list. Another possibility is to sort the partners by political advocacy. In other words, the most influential political advocates or foes would be ranked higher on the list.

Generally, a project can identify several different metrics for sorting the partner list, each offering a new insight as to the relative value of each partner to the project.

Outputs: Weighted listing and description of each metric to be used.

Ranking Each Partner's Relative Importance to the Project

In this step, the list of Activity Partners is sorted in accordance with the metrics just developed. The reason for ranking partners at this stage of the analysis is often difficult to understand, but doing so now will prove invaluable during subsequent steps when resolving priority issues between partners becomes important. At this point it may be convenient (for future requirements tracking and flow down purposes) to assign unique identification numbers or letters to each partner.

Outputs: Partner list ranked according to the metrics.

Document the Current Situation

This is the process of establishing and documenting the status quo. It is important to seek out and solicit support from those individuals most experienced in the technical fields related to the project. Research, to establish a complete understanding of the current situation's status and how it evolved, is the key to this step. Benefits of this step include a deeper understanding of the problem and lessening the possibility of duplicating previous efforts.

The narrative of this Current Situation Document should delineate both the positive and the negative aspects of the status quo.[15] Developing this narrative is best accomplished through group interaction with representatives from all project Partners.

Outputs: Current Situation Document.

15 Walters, J. Milam, ESSM Goals Analysis Effort, an internal document of the Systems Engineering Office, NASA, April 1991, p 1.

Develop the Issue Base

The purpose of this step is to identify the issues of each Partner in reference to the system under consideration. These issues become the basis for each of the systems goals or subgoals. A good place to start is by exploring the Strategic Plans of each Partner. The Systems Engineer must work with each of the Partners to identify supporting and conflicting elements within their plan relative to the system under consideration. It is helpful to ask questions such as "How will the system under consideration support or hinder the Partner's future activities?" Each issue should be assigned a unique identification number or letter that is a composite of the originating Partner's identification. This will be important for future requirements tracking and flow down purposes.

Avoid the use of compound statements. Try to decompose the issues such that each statement relates to a single issue and each issue is contained in a single statement. Decomposing the issues into basic statements will simplify the latter process of consolidating redundant issues and converting issues into Goals Statements.

Outputs: Summary report describing the issues each partner has with the system under consideration.

Consolidation of the Issue Base into the System's Issue Table (the "Super Set" of Issues)

The objective of this step is to consolidate the common or shared issues so that each issue is listed only once. Often, the issues of different partners will partially or fully overlap. If all the issues were represented in graphical form, the results would be a large and complex Venn diagram.

If the contents of the Issue Base have been properly developed into basic statements, then consolidation is almost a clerical level task that can be accomplished by a single individual. However, if the issues have been expressed as compound statements, then consolidation will be a very difficult task that requires the entire team to accomplish.

A useful technique is to generate a table of issues (similar to the "what" axis of a QFD Correlation Matrix).[16] Be sure to include a column for mapping issues back to each and every partner sharing that issue. Also, each issue listed in the table must be uniquely identified. When two or more partners share the same issue, it is often convenient to adopt the issue identification of the highest ranked partner. This helps reduce the "proliferation of identifiers" and helps to maintain tracking and flow down of the issues from the source partners.

Outputs: A System's Issue Table that lists each unique issue.

Prioritize the Systems Issue Table

This is perhaps the most difficult step in the Goals Analysis Process. The customer, in concert with the Partners, must agree to the priority order of the System's Issue Table. In general, the issues of higher ranked partners receive higher-ranking priority, but this is not always the case. The Systems Engineer should anticipate significant negotiation and compromise between the partners before an iteration of this step is completed

Outputs: A prioritized System's Issue Table.

Develop Preferred Future

The Preferred Future describes the combined Partners' view of the system upon successful completion of the project. This view must include the interfaces and how they operate. It is frequently prefaced by a "Vision Statement," a description of the desired accomplishments in relation to other efforts.

16 QFD Awareness Training, Quality Education and Training Center, Ford Motor Corporation, 1989, p 26

This provides a clear understanding of where the efforts are pointed and what can be expected upon completion of the project. This portion of the analysis can be very helpful in solidifying required constituencies. Minimally, the narrative should contain all the positive aspects described in the Current Situation as well as corrections to all the negative aspects.[17] Ideally, development of this narrative will stimulate ideas that are strides beyond the current situation. Care should be taken to prevent description of an idealized future that is unrealistic from the expected cost and schedule constraints as well as to prevent over achievement of the actual needs. However, no plans should be discounted in the early iterations of Goals Analysis, since those that are overly optimistic will be removed through validation and in subsequent iterations.

Outputs: Preferred Future Document.

Generate Goals and Objectives Statements

In this step the issues of the Systems Issue Table are translated into Goals Statements. Each issue is rewritten into an objective statement such that accomplishing that particular objective will resolve the issue. Again, try to avoid the use of compound statements. Try to keep each statement a single Goal and each Goal a single statement.

All the Goals and Objectives generated directly from the System's Issue Table are known as the root set or the set of imposed System Goals and Objectives. All the Goals and Objectives generated later in the process, for the purpose of providing logical continuity in the formation of a Goals Tree, are known as derived Goals and Objectives.

Possibly the most critical facet of any project is the correct and concise statement of the top-level goal(s). The exact wording of this objective is crucial and must be very carefully considered. Generalization of the top-level goal is designed to take the problem addressed by the system out of its narrow context and explore more general considerations. In other words, what is the **real** problem? The primary method of achieving this generalization is a rigorous questioning of the stated top-level goals. Typical considerations include:

- Why is the goal stated this way?
- Are there underlying goals not brought to light which affect the wording, i.e. politics, personal agendas, etc?
- Is the stated goal truly the objective or a means of achieving some other objective?

The purpose is to guard against a technically acceptable system that is infeasible for other reasons and to assure that the true objective is pursued.[18] Included is consideration of those directly or indirectly affected by the project. This may be accomplished in part by listing the political advantages of meeting the goal as well as possible drawbacks of pursuing the goal. If opposition from the Partners, in particular from the Influential Independent Partners, appears unmanageable, then a modification of the goals may be in order.

The most effective method of performing this step is an interactive group session. Brainstorming[19] [20] and Brainwriting[21] are good methodologies to follow. The main point is that all inputs are heard and considered.

17 Walters, J. Milam, ESSM Goals Analysis Effort, an internal document of the Systems Engineering Office, NASA, April 1991, p 2.

18 ibid., p 1.

19 deBono, Edward, "Lateral Thinking - Creativity Step by Step, Harper & Row, 1970, p 149.

20 Adams, James, Conceptual Blockbusting, 3rd ed, Addison-Wesley Publishing, 1986, pp 134 - 137.

21 Wycoff, Joyce and Richardson,Tim, Transformation Thinking, Berkley Publishers Group, May 1995.

Outputs: Concise and understandable top-level Goal Statement(s) and "root set" of imposed System Goals and Objectives.

Partner Value Considerations

An area rarely considered in goal development is the values of concerned and affected Partners. This issue is included to amplify and articulate the underlying personal goals contained in the Goal Statements and Preferred Future Document. Paramount for consideration are the values of partners with decision authority over continuation of the project[22]. This should lead to a reiteration of the potential advocate/foe list and the reevaluation of the reasons for their support/opposition. The purpose of personal goals and values that are unrelated to accepted project goals should be removed in this step. The considerations are designed to resolve unstated, non-technical conflicts contained in the top level goal and vision statements for the project.

Output: Conflict resolution of non-technical issues.

Develop the Goals Tree

In this step, the top-level goal developed in the previous step is decomposed and mapped into subgoals of narrower scope. Subgoals are objectives, which if accomplished, assist in satisfying the next higher level goal. Typically, the major subgoals of the project will become the top-level goal for project support organizations. For example, if a subgoal of the project is to maintain instrument temperature to within 5° K, this may become the top-level goal for the thermal-control organization. The expansion of goals may be terminated when a given subgoal is measurable. When a subgoal is capable of being indisputably judged as satisfied, that branch of the hierarchy requires no more definition or decomposition.[23]

Individual subgoals are arranged into a hierarchical representation. This is easily accomplished by writing each goal statement generated from the Systems Issue Table on a card and arranging them so that each lower level assists in the accomplishment of the next higher level. As the development progresses, the lowest level goals are expanded further by discussion with the cognizant organizations. When gaps occur in the diagram, where *imposed goals* (or goals generated from the Systems Issue Table) are insufficient to provide a logical flow between levels, then *derived goals* (or goal statements generated during the analysis process strictly for the purpose of maintaining logical continuity) must be synthesized and inserted. Progressing in this manner assures that every objective by project personnel, even on the lowest level, is directly tied to the project's top level goal.

The result of this effort is a graphical hierarchical representation of the project goals, which contains technical and non-technical requirements at the terminating branches. The representation takes the approximate form of an organizational chart. One output of the effort is a set of technical requirements for the project. The tree may also provide information that affects non-technical requirements such as cost and schedule.[24]

Two useful tests on the structure of the Goals Tree are: 1) to ask if each individual goal on a given level is a necessary element to fulfilling the next higher level, and 2) if all the goals as a set on a given level are sufficient to fulfill the next higher level. Additional decomposition and expansion are required until the goals of each level can pass these two tests.

Output: Goals Tree

---

22 Walters, J. Milam, ESSM Goals Analysis Effort, an internal document of the Systems Engineering Office, NASA, April 1991, p 2.

23 ibid., p 3.

24 ibid.

Validate

At this point, the process departs from earlier subjective considerations and becomes objective.[25] The outputs of previous steps are now scrutinized. Through editing, selection, comparison, etc., a validated version of the work to date is produced. Where criticism was previously discouraged, it is now invited. The purpose is to decide which facets of the work truly belong, which may be deleted, and which insures that a logical flow down has been developed.

Output: Validated version of work to date

Iterate the Process

Much of the power of the systems approach comes from the idea of iteration by one-pass analysis.[26] This allows the individual steps to be performed at a general level during the early iterations, then defined in further detail during subsequent iterations. Also this enables incremental refinement of the output for each step as understanding of the entire system, gained through repeated iterations of the process, is continuously improved.

Output: Improved Goals Analysis

Conclusions

This paper has described the specific steps of a Goals Analysis process applied by Systems Engineers at the NASA Langley Research Center. Projects that apply this process to the early phases of a research project will improve their understanding of factors influencing the project and perhaps lead to better requirement development with a reduced chance of requirement creep. The outputs of a Goals Analysis will provide excellent input for a Requirements Analysis process such as Quality Functional Deployment (QFD).[27] But that is a topic for another paper.

Acknowledgements

Although this paper was not co-authored, credit must be shared with my predecessor, Mr. J. Milam Walters, for his efforts at formalizing the Goals Analysis Process applied to developing space flight projects at the NASA Langley Research Center.

References

[1] NPG 7120.5 Program and Project Management Process and Requirements, rev A, NASA, April 1998.

[2] Blanchard, B. S., Systems Engineering Management, 3rd ed., Wiley-Interscience, 1991.

[3] Eppen, Gould, and Schmidt, Introduction to Management Science, 4th ed., Prentice-Hall, 1993.

[4] Motley, Albert, Goals Analysis Process, an internal document of the Systems Engineering and Controls Branch, May 1999.

[5] Rechtin, Eberhardt, Systems Architecting - Creating & Building Complex Systems, Prentice-Hall, 1991.

[6] Boehm, B.W., "A Spiral Model of Software Development," Software Engineering Project Management, IEEE Computer Society Press, 1988.

[7] K. Forsberg, and H. Mooz, "The Relationship of Systems Engineering to the Project Cycle," Proceedings of the First Annual Symposium of NCOSE, 1991.

[8] Gradey, Jeffrey O., Systems Requirements Analysis, McGraw-Hill, 1993.

[9] Sage, Andrew P., Systems Engineering, Wile Interscience, 1992.

25 Walters, J. Milam, ESSM Goals Analysis Effort, an internal document of the Systems Engineering Office, NASA, April 1991, p 4.

26 ibid.

27 Sullivan, L. P., "Quality Function Deployment - A System To Assure That Customer Needs Drive The Product Design And Production Process," Quality Progress Magazine, June 1986, pp 39 - 50

[10] QFD Awareness Training, Quality Education and Training Center, Ford Motor Corporation, 1989.

[11] Walters, J. Milam, ESSM Goals Analysis Effort, an internal document of the Systems Engineering Office, NASA, April 1991.

[12] deBono, Edward, Lateral Thinking - Creativity Step by Step, Harper & Row, 1970.

[13] Adams, James, Conceptual Blockbusting, 3rd ed., Addison-Wesley Publishing, 1986.

[14] Wycoff, Joyce and Richardson,Tim, Transformation Thinking, Berkley Publishers Group, May 1995.

[15] Sullivan, L. P., "Quality Function Deployment - A System To Assure That Customer Needs Drive The Product Design And Production Process", Quality Progress Magazine, June 1986.