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Requirements Traceability in Systems Engineering for Large-scale Systems Development

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ABSTRACT

This paper presents results from a computer-aided systems engineering application to system development projects. RDD-100 version of ALC Inc. was used in this work. The framework adopted in the study takes a unified approach to the system design and the process management associated with it, thereby coherent and full traceability between them is maintained. Conventional system engineering process supported by the tool is adopted in the system design. On the other hand, the same tool is also used to the systems engineering management to get full traceability between system design data and engineering management data. It is greatly helpful in managing many sub-contractors in the sense that the traceability can help identify the sub-project responsibility as well as the objectives of the project in coordination with interface requirements. We conclude with the advantage and limits of our unified approach.

1. INTRODUCTION

Today's defense systems represent a typical example of large-scale multi-disciplinary system, consisting of mechanical, electrical hardware, electronics, control, information, communication technology etc., that must exercise configuration and requirement management. Not only the requirements dictate the contracts with the suppliers but also becomes the basis of the project execution, system integration, and testing. It provides the basic specification of development activities. This paper summarizes the results of using RDD-100, a systems engineering tool, to establish requirement traceability and development process management in performing any technology development program.

As a result of the study, the segmented systems engineering data including requirements, component information, WBS, projects, and organization information etc. that existed with minimal documentation were organized into a reusable form of RDD-100 database with traceability among data. Additionally, new data model and schema was proposed and built along

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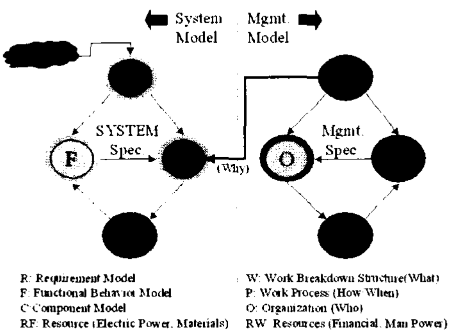
with a management framework.

2. THE UNIFIED SYSTEMS ENGINEERING FRAMEWORK

Why unified framework? Any system development program that manages and oversees various subsystem suppliers and performs systems engineering activities needed the visibility and traceability of the contracted work and systems requirements as well as of the system design and project management data. Accordingly, the purpose of the study was to develop a unified systems engineering data concept and structure that use a single tool to manage both system design results and development processes.



[Figure 1] Abstract data model of the unified systems engineering

Systems Engineering Data Model. Figure 1 represents a single systems engineering data model built to organize a system development program and system design data using RDD-100 computer aided systems engineering software. The left-hand side of the picture depicts system-level design data model while the right-hand side shows the systems engineering management related data model in a symmetric form. System model divides into four elements of System Requirement (R), Functional Behavior (F), Component Model (C), and Resources for Function (RF) consumed or produced during the execution of each function.

Systems engineering management data model demonstrates a similar form of WBS (W), Organization (O), Process (P), and Resources for work (RW) needed to perform each task.

This data model provides element-level mutual interrelationship since all high-speed rail system design data can be traced each other. Finally the resultant database serves as *"systems engineering knowledge base"* essential for enterprise knowledge management and *reusability.*

Systems Engineering Process. Systems engineering process in this study signifies the sequence of development activities to produce system specifications and process specifications. A reverse engineering approach is typically used to determine system specification since the majority of system development programs these days involve the evolutionary improvements. The process specification was obtained based on the system specification. An iterative process at each hierarchy level of the system produces a gradually detailed model. More detail is given in the following sections.

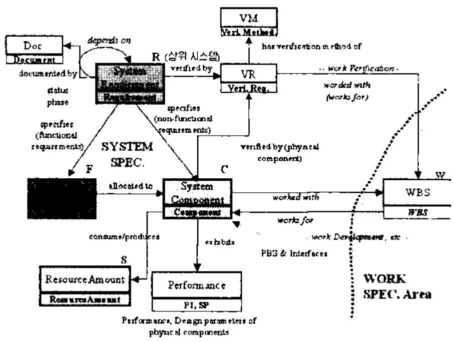
3. SYSTEM-LEVEL DESIGN FRAMEWORK

System-level Design Data Model. System design data model is an abstract model for various data obtained from *systems design activities.*

The data structure of RDD-100 implementing system design data model depicted in Fig. 1 is called a data schema shown in Fig. 2. Data schema consists of data element types and relationships as well as directional links and reverse links. For example, requirement elements have the data structure to describe a treestructured system requirements showing the relationship between the requirements of upper-level and lower-level using "incorporates" link (ALC 1996).

Requirement Model (R). In many systems engineering projects, in spite of the established systems engineering process, it was discovered that the requirement management and traceability task could not be performed easily without improving the process. Because of the evolutionary development nature of the industrial products, a reverse systems engineering process is required to retrieve the upper-level system requirements from the top-level system design specifications. As a result, requirements process results in many leaf-node-requirements and many incomplete requirements that are not usually addressed by the existing system design specifications. These new requirements are classified as critical issues requiring further attention and special review.

Functional Behavior Model (F). The most significant area of behavior analysis in many systems arises in electrical and software subsystem areas. The increased application of automaated system stresses the capacity and safety issues greatly and the electrical or software subsystem deserve extensive behavior analysis for optimal system design. The system level productivity and safety requirements needs to be decomposed into several subsystems areas.

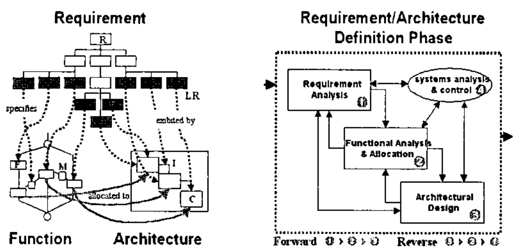


[Figure 2] Brief schema of the design elements and its relation to WBS element.

Component Model (C). Component objects are used to represent system architecture model. Due to its top-down modeling approach, the component architecture demonstrates a tree structure. Based on the identified components and the associated interfaces, the component model was built. A reverse engineering process can easily yield component architecture for existing portion of the legacy system. A complex model can be built by considering the interfaces surrounding those subsystems that includes the changes or improvements

Using the system design model and schema as described above, the requirement model (R), the function model (F), the component model (C) are obtained and managed through RDD-100 tool.

Reverse Systems Engineering. As shown on the right hand side of Fig. 3, RDD-100 supports the forward engineering process of iterating requirements analysis, functional analysis, and architecture synthesis. (Martin 1997).



[Figure 3] Forward and reverse engineering process(right) and final form of the system-level design database (left)

Since other than those areas of the system to be improved, the rest of the subsystems mainly remain unchanged from the legacy system. For this reason and the evolutionary nature of the industrial system development, the entire system level requirements database in a CASE tool are not usually available to any technology development program. Therefore, the system level requirements and the engineering processes needs to be retraced from the results of the detailed design adopting a reverse engineering process (Martin 1993, Park 1999).

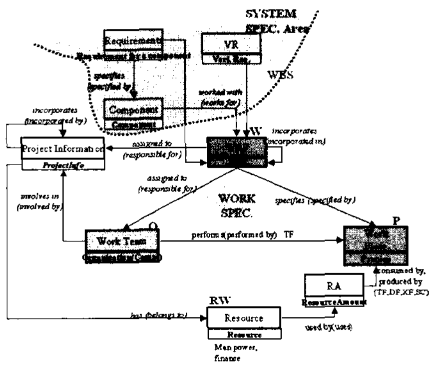
Accordingly, a reverse engineering process of bottom-up approach must be performed utilizing system specification document and PBS to retrieve system architecture and subsystem interfaces. Functional and performance requirements were obtained subsequently from this process as shown in the design database of Fig. 3 (left).

Benefit. The main advantages of the database obtained from this study are the requirements and configuration management with traceability, the reusability of the database, and the report generation capability provided by the tool which exhibits a great deal of productivity and convenience upon design changes and improvements.

4. SYSTEMS ENGINEERING MANAGEMENT

Engineering Management Data Model. Since Many subsystem contractors support any system development program, data models can be established to support the suppliers' activities and to consistently manage those tasks in pursuing to meet the prescribed system requirements. As mentioned earlier, the process management model demonstrates a symmetric structure of the system data model (recall Fig. 1).

Fig. 4 shows more details of the RDD-100 core schema relevant to the process management data briefly shown in Fig. 1. Both organization and workflow models as well as the resource model surround the WBS that has attribute defined as project information. Each WBS is assigned to a work team and the project information specifies the resource assigned to the WBS. Upon the completion of each WBS task the assigned resource is consumed. WBS can be traced from either a system requirement or from an architecture component.

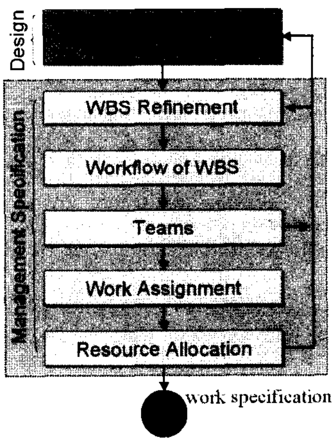


〔Figure 4〕 Core schema of engineering management data and its relation to the design data.

WBS-Centered Project Management (W). Those activities performed within a WBS can be justified by their contribution toward the objective of the WBS. Each WBS has justification why it needs to be performed. Therefore, each WBS must have traceability within the system model to answer to the question of 'why'. In the process management model, the traceability serves as the link between WBS and the system component model.

Fig. 5 represents a process of defining work from the system specification. Since the systems engineering process is to define the system design specification, as the system specification gets more concrete, the iteration activity gets in more detail to define the needed tasks.

Workflow Management (P). While the WBS shows what task must be accomplished, the workflow defines the input, the sequence of work steps, and the output information. The details of work within a WBS item gets described in natural language while the workflow model represents its behavior in a mathematical form. The modeling for the sequence of work and schedule utilizes the Behavior diagram of RDD-100.



〔Figure 5〕 Engineering management specification process

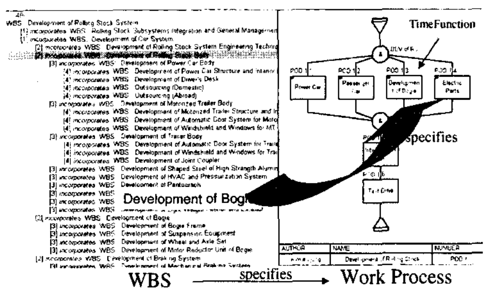
The advantage of using the workflow model is to express the sequence of work and the input and output relationship that is unavailable from the WBS model. Additionally, through the use of Dynamic Verification Facility (DVF), one can exercise 'what-if' analysis, which can simulate the overall schedule change scenarios when there is work delay problem in a critical path.

Fig. 6 shows the relationship between a WBS element and the workflow example. There must be one-to-one matching relationship between the tasks of a WBS element and the workflow model. Furthermore, an output obtained from a task within WBS becomes an input to another task.

As a task is modeled in a hierarchy the work sequence, input and output, and the execution time can be retrieved if the workflow model is examined in detail.

Organization (O). Organization describes the responsible party executing each task defined in the WBS element. It uses the component modeling facility in RDD-100 with some modifications. In a typical project application, the decomposition is accomplished up to the team level of each subsystem WBS leaving the further details to the responsibility of the subsystem WBS.

Resource for Work (RW). Resource is required to model the allocated budget, manpower, and facilities when a WBS element was assigned to a responsible organization. Initial allocation of the resource gets re-allotted to perform each task. The resource model can be used to analyze the budget using the dynamic simulation facility of RDD-100.



〔Figure 6〕 Example of traceability from WBS to the workflow

Project Management. Those tasks within a WBS element relevant to the total system acquisition must be performed to execute the work process in a single batch of process, work authority, and needed resource. This unit was defined as a project. In a large-scale system, a typical project is unable to accomplish all required tasks within a single WBS element. Several lower-level WBS elements can be used to accomplish the overall task. For example, the systems engineering task deserves as a single WBS element that can be assigned to a project. Accordingly, some task under a WBS element can be performed as a lower-level allocated task item.

5. DISCUSSION

Merits. The most advantage achieved by an integrated management of both systems design data and process management data comes from the ability for easy traceable management and the reusability of the database. Additionally, all of the system design data could be collected and captured by using the tool and the data model presented in the study. The benefit of the database to support the future configuration management for improvements and routine maintenance is incalculable. Furthermore, it provides the foundation to facilitate any changes in the specification can be analyzed and reflected.

Limits. The application of the process management data for detailed project schedule management using RDD-100 may not be advantageous over the use of other specialized schedule management tool such as MS-Project that provides various options in data display. However, it was sufficient for the kind of need to manage only the top-level schedule in many program applications.

6. CONCLUSION

An application of the systems engineering tool using a unified data framework to manage both system design data as well as the development process data demonstrated a successful management of a typical large-scale development program data. Much of the system level program data existing in many different forms can be collected, captured, and organized in a traceable form of single database. As a result, the traceability for system requirements was established and an efficient development process was setup for any development programs.

It was learned that a reverse engineering process was more appropriate to build the system design database in the case of the evolutionary nature of the industrial system development. RDD-100, a system design tool, can be successfully applied to organize the top-level program control data.

The data model framework and the database built from this study will play a significant role in performing system interface management, integration, and verification work to follow later.

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