APPLICATIONS OF SYSTEMS ENGINEERING FOR ENGINEERS IN SMALL TO MID-SIZED COMPANIES

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ABSTRACT

Systems engineering (SE) is a primary integrator that enables cross-functional fields within engineering to work together and produce a product or system. Without a concise and practical guide for engineers to follow, it is difficult to adequately implement SE practices into the everyday engineering of products. This paper presents refined applications of systems engineering practices that could to be implemented in small to mid-sized companies by engineers themselves to efficiently design an effective system.

INTRODUCTION

Systems engineering (SE) can be informally and formally applied most fields because it can be interpreted simply as a management technique of everyday life as people interact with products, other people, and/or processes. Systems engineering allows for sufficient planning, adequate scope definition, and therefore an understanding and meeting of customer requirements that lead to innovative, low-cost, and high-quality products. The theoretical discussions that explain the processes of SE may be quickly endorsed by management, but the industrious engineer may struggle with understanding and applying the many SE processes into the designing of products and systems. This can be compared to the introduction of lean processes into a traditional manufacturing plant—it is important to first evaluate what is currently being manufactured and what could be improved.

Oppenheim, et al. [1] describes how "Lean Enablers for Systems Engineering" takes the traditional SE practices and combines them with lean principles to present a recommended checklist of "do's" and "don'ts." Also Sheard and Mostashari [2] discussed how condense SE principles with the purpose of being a useful source within the SE community. Rhodes et al [3] discusses how SE practices are transformed into leading indicators that present trends to help identify areas in need of scrutiny. As the customer requirements can change therefore one of the Value Principles is to "anticipate, accommodate and communicate changing customer requirements" [4]. As stated by Sheard and Mostashari researched and cited from other sources that "systems engineering (SE) has evolved without much of a formal or theoretical background for its practices; instead it has relied on experientially developed principles and heuristics" [2, 5].

The goal of the proposed applications of SE processes is based on the water and waste system deliverable of a company supplying to a commercial aircraft manufacturer. The following examples demonstrate how systems engineering should be implemented by engineers in this mid-sized company.

Requirements Foundation

One of the requirements is that pressurized water shall be delivered to the galley and lavatory sinks throughout the aircraft. The system engineer would then review the customer requirement and copy it onto the spreadsheet and analyze it by indicating understanding of the requirement as seen in Table 1.

In this example, the customer's requirement did not specify quantitative performance characteristics. As a result of analysis conducted during the preliminary design review, the system engineer would then define and create the supplier requirement: A system shall be defined to supply 4 GPM of water at a minimum of 30 PSI. The systems engineer will record this in the supplier requirements document with traceability to the original customer requirement as shown in Table 2.

Table 1. Requirements reviewed and analyzed

Customer Requirement		Supplier Analysis			Supplier Definition
Tracking Number	Description	Understood?	Feasible?	Concerns?	Addressed in supplier doc?
WS2575	Pressurize water shall be delivered to aircraft sinks in the gallies and lavatories	Yes	Yes	Pressure value not defined. Details of sink locations defined in customer ICD.	Yes - SCD8200-600 Req. No. 40

TABLE 1. Requirement redefined in the supplier specification control document

SCD8200-600		
Req. No.	Requirement Description	Customer Req. No.
40	System shall supply 4 GPM of water at a minimum of 30 PSI	WS2575

By completing the steps of reviewing, analyzing, and defining, the objective of requirements foundation is reached: Customer requirements are fully understood and defined at the supplier's subsystem level so that the systems engineer is ready for the next application of design framework.

Design Framework

The water system architecture is created by the systems engineer and based on previous programs where airline manufacturers desired water systems. The database should be maintained to store information on all project components. The information is laid out in a table format so that the various options can be compared, and the systems engineer can select what seems the most appropriate for their current customer as shown in Table 3.

Table 3. Component database tool for the architect step with the design framework application

Part Number	Component	Customer	Input Criteria	Performance Description	Weight
38000-501-201	Compressor	A380	104-122 VAC 400 Hz	7 SCFM at 40 PSIG outlet and 11	25 lbs
9631200-0001	Compressor	E170	109-115 VAC 389-420 Hz	1 SCFM at 30 PSIG outlet and 10	6.0 lbs
77000-600	Water Pump	B787	115 VAC 360-800 Hz	4 GPM at 30 PSI min	6.5 lbs

Also recommended within the architect step is performing trade studies. An example of a trade study for the collection of waste water is depicted in Table 4. Based the importance of the design requirements indicated by the assigned weights and the independent storing criteria, option number two for the retention via an interface valve and routing to the waste tank is the recommended result of this trade study. An example of a WBS for the water system to be created by the systems engineer is illustrated in Figure 1. The information inputted into the WBS dictionary is a snapshot of some of the important technical data. With a database that contains the WBS and links all the WBS dictionaries within the system, it will be easier to keep track of dependencies amongst the components. By completing the steps of architecting, evolving, and structuring, the objective of design framework is reached: The system is designed optimally to reduce the likelihood of reworking after production is launched and to eliminate the risk of recalling system components after the system is delivered to the customer.

Table 4. Trade study analysis for gray water collection.

Trade Studies for Gray Water Collection

		Option #1		Option #2	
Design Requirements	**Wt**	**RS**	**WS**	**RS**	**WS**
1. Maturity of technology	3	5	15	1	3
2. Number of system components	4	1	4	5	20
3. Weight of Gray Water	5	5	25	1	5
4. Effects on aerodynamics	5	1	5	3	15
5. Cleanliness/Maintenance	3	1	3	5	15
6. Potential for clogging	3	1	3	5	15
7. Control and power consumption	4	1	4	3	12
8. Environmental concerns	3	1	3	5	15
Total	30	16	62	28	100
Normalization	150		41%		67%

Option #1: Discharge via Drain Mast
Option #2: Retention via Interface Valve and Waste Tank

	Score Criteria		
Design Requirement	5	3	1
1. Maturity of technology	Over 30 years of service experience	Over 10 years of service experience	No service experience
2. Number of system components	3	2	1
3. Weight of Gray Water	Decreases as flight goes on	Remains the same as flight goes on	Increases as flight goes on
4. Effects on aerodynamics	Change to fuselage improves aerodynamics	No effect to fuselage skin	Protrusion of mounting on fuselage skin causes drag
5. Cleanliness or Maintenance	Cleans adjacent components and systems	No effect on adjacent components and systems	Stains adjacent components and systems
6. Potential for clogging	Clog needs clearing after greater than 2000 flights	Clog needs clearing between 500 to 2000 flights	Clog needs clearing after less than 500 flights
7. Control and power consumption	Less than 50 Watts	Between 51 and 99 Watts	Greater than 100 Watts
8. Environmental concerns	None - Gray water is retained until it can be properly disposed	Minimal - Gray water partially leaks to the atmosphere	High - Gray water is dumped into atmosphere

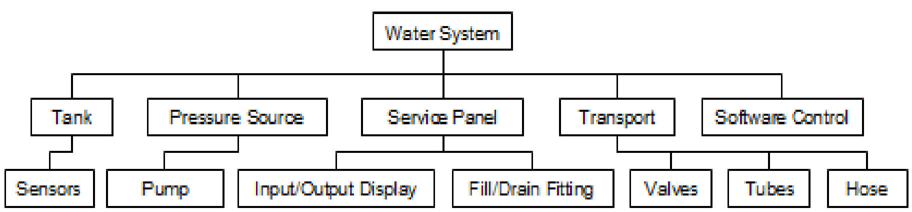

Figure 1. WBS for the supplier's water system.

INTERFACE REINFORCEMENT

The systems engineer releases an Interface Control Document for the water pump that notes the properties of the material at the physical interfaces and also calls out the coupling interface to connect to the adjacent water plumbing tubes. Analysis of material compatibility should be performed amongst subcomponent interfaces and also at the external boundaries of the system which interface with other systems at the customer and should be maintained via lists with information on the type of material, finish, and process specifications used for each subcomponent. By completing the steps of identifying, evaluating, and maintaining, the objective of interface reinforcement is reached: Components interface and operate together to seamlessly function as one system.

Verification and Validation Assessment

An example of verification and validation of water plumbing for an aircraft is illustrated in Figure 2. A diagram for each requirement can be used to assess whether proper verification has been performed throughout development and if validation has been checked at the system level.

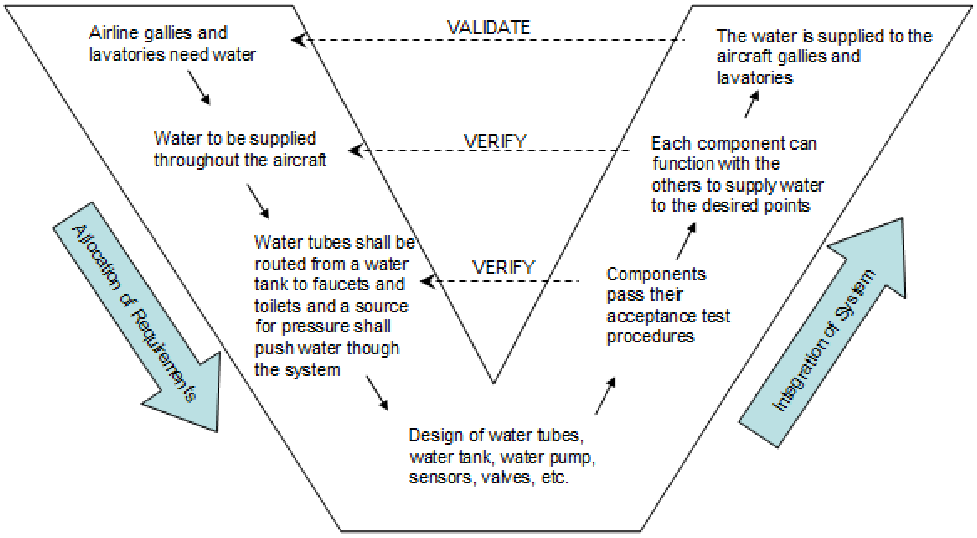

Figure 2. A verification and validation diagram can be used for each requirement

Since verification and validation is an iterative task, it is to be reapplied to all of the proposed applications. For example, another column is to be added to the matrix to indicate the assessment of verification and validation, to record the method that the requirement was accomplished, and to include the document that contains the objective evidence. By indicating that the requirement is met, the current design is verified. Verification and validation testing should be conducted before the system is delivered to the customer. Figure 3 is a model of a check valve installed in a test fixture that is to be used in vibration testing.

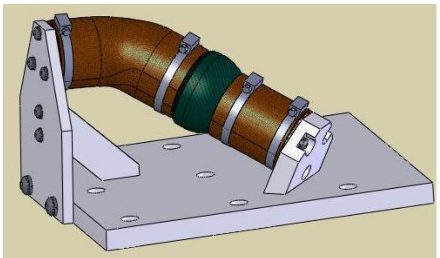

FIGURE 3. Vibration test fixture for a check valve designed with identical aircraft physical interfaces

CONCLUSION

A structured breakdown of the system is laid out in order to focus on the component level design. A framework for the design of the system is created. In parallel, another method for technical application is to establish interface reinforcement. Interfaces are identified and evaluated. Maintenance of interfaces includes both ensuring the current design but also preparing for variant updates. The fourth application method presented is for use throughout the systems engineering process. Verification is to be performed by the systems engineer to ensure that all design requirements are met. The systems engineer performs validation at the system level to guarantee that the verified requirements satisfy all customer needs. The concise applications presented are intended to be applied to any engineer's project so that systems engineering practices can be put to use, although a limited number of methods were advised.

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