Using system engineering on an aircraft improvement project

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ABSTRACT

A complete system engineering process is applied to a pilot project that will determine the initial deployment of the system engineering process for future projects. It was a challenge to complete the entire systems engineering process to include project team utilisation of system engineering tools in such a short time span. Therefore, systems engineering products had to be useful and productive to the project. The system requirements definition, quality function deployment (QFD) evaluation, trade study, risk identification and risk mitigation processes were completed in a timely manner and assisted in the system eequirements, system design and preliminary design reviews successfully.

1.0 INTRODUCTION

A system engineering process improvement task was initiated on the C-17 programme in 1996. In the beginning the experience described by LaBudde[1] was encountered. Traditionally, the project will take the incomplete customer instructions to immediately start physical design. Engineering department was organised under traditional disciplines, i.e., mechanical, electrical, avionics, airframe, software, etc. Each engineering discipline will start its own design without a central co-ordination. Although there is a project manager, his or her job is to steer people to march to the schedule. They will pay a big price in cost overrun and schedule slip due to design problems and design iterations. It will be even more costly and schedule penalty if there are re-works at the assembly and manufacturing phase. It is difficult to introduce a layer of engineering on top of this structure. Turf battles are sure to ensue.

The C-17 is the mainstay in airlift in this new century. The incorporation of airdrop capability improvements was critically important. From defining requirements, engineering design, fabrication, assembly, flight test and retrofit to the field aircraft would have to be completed by the year of 2000. This presented a challenge to the integrated product team (IPT) organisations to achieve first-time quality under an accelerated schedule. Airdrop capability improvement was one of a few performance improvement projects to apply the complete systems engineering process. Development of team members understanding of systems engineering applications was necessary and added additional challenges to the systems engineering implementation. If the systems engineering process was not well executed by the entire team, the outcome would be viewed as a worthless activity.

In summary, the challenges were:

- A short time span of project design life cycle.
- A first-time break-through implementation of full spectrum of systems engineering.
- Team members learning systems engineering on the job during design phase.
- Progressively understanding the customer requirements during design phase.

2.0 REQUIREMENTS

A timesaving technique to meet the accelerated schedule was the employment of a matrix for recording both requirements and verification methods. The requirements were allocated to the corresponding functions. The matrix is called requirements allocation sheet (RAS).

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Table 1
Airdrop capability improvement requirements

No.	Requirement	Verification Requirement	Method
1.0	***Performance***		
1.1	**SS 3.2.1: Performance Characteristics** The C-17A shall perform the operational mission profiles described in Section 10.	**AVS 3.2.1.1: Maximum Payload Mission** Verification of the mission performance requirements shall be determined by analysis of the flight test data of a C-17A test aircraft, which incorporates pertinent production design features, using approved performance computation procedures. The mission gross weights used in computing the climb, acceleration, and cruise shall be determined in accordance with Paragraph 50.1 of the System Specification, plus the deliverable payload, plus reserve fuel at destination.	Test and analysis
		SS 4.2.2.3: Performance Characteristics The specified performance capabilities of the C-17A shall be verified by analysis of the flight test data during the FSED program.	Analysis
1.2	**SS 3.2.1: Performance Criteria** Performance computation rules and criteria are specified in Section 50.	Same as above.	Same as above
1.3	**SS 3.2.1.1: Maximum Payload Mission** The air vehicle shall have a maximum payload of 167,531 pounds. ***SEE CONSTRAINT # 2***	Same as above	Same as above

For a C-17 performance improvement (PI) project, a programme task plan (PTP) was required to be written. There were strategic brigade airdrop (SBA) requirements included in this project. It was, however, far from a complete set of system requirements.

Fortunately, C-17 has an existing top-level system specification; and the second level air vehicle specification and fabrication specification. Many of the system requirements pertaining to the airdrop system were extracted from these specifications. The new and derived requirements were added to the system requirements list. The verification requirements associated with each requirement were also listed along with the verification method. System RAS was developed. There were 75 requirements identified for the airdrop mission under the categories of performance, airdrop, cargo airdrop, platforms and recovery system, logistic rail system, loadmaster panel, anchor cable system, mission computer, supportability, producibility, safety, human factors and training. As it can be seen that these requirements covered not only design but also manufacturing, operations, training and product support. At the onset of the project activities, the team members involved consisted of applicable engineering disciplines, supplier management, manufacturing, human factor, and product support, etc. The systems engineering process insured that the design, manufacturing and product support requirements were considered from day 1 and not wait until later during the project progress. One of the RAS sheet was shown in Table 1. This sheet was belonged to the performance category. It was numbered as 1.0. requirements 1.1 under performance was extracted from system specification paragraph 3.2.1, performance characteristics. The corresponding verification requirements were also extracted from the system specification. It was shown in the remark column that this requirement satisfied performance requirement no. 1. There were five performances requirements. The performance requirements were considered as customer requirements. requirement No. 1.3 satisfied constraint No. 2 that was 'the current C-17 maximum payload capability cannot be changed.'

Since this is an improvement project to an existing aircraft, the existing equipments and subsystems cannot be altered. The hardware that was not allowed to change were constraints, for example, cargo floor, logistics rails, logistic lock, and loadmaster control panel, etc. cannot be changed. The new hardware systems for improvement have to be compatible with this existing hardware (constraints). There were 11 constraints.

The Air Force System Project Office (SPO) arranged two joint Army/Air Force meetings to define the customer requirements. These two meetings were held after the design had started. Therefore, the customer requirements were developed and updated as design progressed. This presented a challenge since the design would be modified on top of the compressed schedule. Systems engineering can help maintain detailed requirements documentation to trace the chaning requirements.

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3.0 QUALITY FUNCTION DEPLOYMENT

A time-proven method for quickly converting requirements into a design is QFD[2]. The system requirements had been derived and related to performance requirements and constraints. The next step was to generate design requirements. An anchor cable support assembly was one of the design items for the project. The project team consisting of members from several IPT organisations had several brainstorming sessions to derive the design requirements from system requirements. The design requirements have to be explicit and measurable. The team generated 17 design requirements pertaining to the anchor cable support design.

The QFD method was employed to correlate design requirements with system requirements and calculate weighting for each design requirement. The EXCEL based spreadsheet application was developed on a matrix format. The QFD matrix is shown in Table 2. The first column contains the system requirements, which are related to the anchor cable support design requirements. The second column is the weight assigned to each system requirement by the customer. The weight is scored from 1 to 5 and 5 is the most important. The customers were given instructions about the scoring ranking. It is subjectively determined by customers. The subjectiveness is acceptable since they are customers and have the prerogative to do so. The top row lists 17 design requirements. The team scored the relationship between design requirements and system requirements as follows: Strong is five points; Medium is three points and Weak is one point. All the team members have to participate in the scoring sessions, especially, the subject matter experts (SMEs), such as, design domain knowledge, reliability, human factor, safety, etc., are required to attend if the scoring is related to their areas. The scoring criteria could be developed like the ones shown in Table 3. But it would be an immense job to define 697 (41 customer requirement rows × 17 design requirement columns) scoring criteria for this QFD evaluation. The scoring was, therefore, dependent on the judgment of SMEs. It took several scoring sessions to go over the 697 scorings. It was very time consuming. The validity of the results solely depended on the SMEs and the consistency in scoring. The relative importance between the design requirements is shown by weight percentage. When the weight percentage is normalized with the highest percentage weight, the relative weights between the design requirements were displayed in the last row in the range of 1 to 5.

4.0 TRADE STUDY

The widest possible range of distinctly different design alternatives had been identified through brainstorming sessions. They had been screened based on their projection to meet the design requirements. A second screening was performed on the basis of schedule and budget constraints. There were six candidate design alternatives that had been identified to meet all the design requirements. Design 1A is a short arm added to the existing aft arm and an outboard forward arm; Design 1B is the same as the Design 1A except it has an inboard forward arm; Design 2A is an aft multi-mission arm with an outboard forward arm; Design 2B is the same as the Design 2A except it has an inboard forward arm; Design 3 is an aircraft centerline mounted arm; and Design 4 is an aft dual arm and an outboard forward arm.

The next step was to choose the best design alternative from the design requirements. The weight for each design requirement was obtained from the QFD evaluation process. The team decided that the ones with weights less than two would not be considered in the evaluation.

This is the first break-through implementation of full spectrum systems engineering implementation. It was also under compressed schedule. The execution was not perfect as expected. The stowage accommodation requirement was neglected during the QFD evaluation and it would not have time to include it to perform additional QFD evaluation. The team members determined that this design requirement could not be ignored; therefore, this design requirement was added to the list for trade study and a weight was assigned. In normal systems engineering practice all the design requirements should be included; otherwise, repeat the process to include the missing requirements. The team had sessions to define scoring criteria against the remaining design requirements. The criteria are shown in Table 3. After the scoring criteria had been defined, the team had more sessions to score each alternative against the design requirements. The weighted sum for each alternative is shown in Table 4. Design Configuration 4 had the highest percentage. Although the scores between Design Alternative 4 and Design Alternative 2A were very close, a parametric sensitivity analysis might be needed.

The trade study was presented in preliminary design review (PDR). Please note that per systems engineering technical review, a system design review (SDR) should be performed prior to the PDR. Again, due to the compressed schedule and limited budget, the SDR was not preformed. However, all the possible risks had been identified and mitigation plans were developed. Please refer to Section 3.0 Risk Identification and Section 6.0 Risk Mitigation. The team members unanimously agreed that Design Configuration 4 was the optimum candidate from the technical and cost point-of-view. During the PDR customer concurred with the design choice and decision. Therefore, it was concluced that a sensitivity study was not required.

5.0 RISK IDENTIFICATION

The risks of meeting the mission objectives of airdrop capability improvements were typically known as programmatic risks. Programme risk management[3] was an organised and systematic decision-making process that identified risks to achieve programme goals. The risk identification and mitigation was conducted from the beginning to the end of the project including flight test phase.

The risk management presented here was a highly effective technique for an accelerated project schedule. The risk identification worksheet was distributed to team members including the customer since everyone could identify risk. The risk identified was discussed in the team meeting and had to be concurred by team members before it was formally identified as a risk item. The identification worksheet contains the risk description, source of risk, consequence if risk is realized, risk ranking and risk reduction options. A 5×5-grid block formed by ‘consequence’ on the *X*-axis and ‘likelihood’ on the *Y*-axis defines the risk ranking. The five levels of likelihood and five levels of consequence are defined in Tables 5 and 6. The team members will need to clearly understand the definition of each level. Then each team member will use his or her judgment to assess the Likelihood and Consequences levels for each identified risk. It is naturally that different individuals have different judgment. The final risk ranking will have to be conducted in a team meeting to reach a unanimous decision and agreed by all team members. There were 11 risk items formally identified. Five were high-risk items; three were medium-risk items and three were low-risk items. One of the identified risks is shown in Table 7.

6.0 RISK MITIGATION

There are five risk mitigation strategies: avoidance, transfer, control, assumption, and research and knowledge. Control is the basic design approach is unchanged, but the design details are modified to reduce the risk. Avoidance is to intend to eliminate the situation or condition that produces the risk. Transfer is to shift responsibility of a task to someone more capable of

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Table 2
Airdrop capability improvments QFD matrix

RELATIONSHIPS

■	STRONG	5
▤	MEDIUM	3
□	WEAK	1

Requirements	Weight	1.0 Anchor Cable Support Subsystem	1.1 Minimum Weight Growth	1.2 Load Factors for Weather	1.3 Release Load Sequentially	1.4 Airdrop Customer Platforms	1.5 Support Clearance	1.6 Compatible with Structure	1.7 Size of Cable	1.8 Cable Load	1.9 Maintainability & Reliability	1.10 Safety Design	1.11 Clean Air Amendment	1.12 Perform DFMA & DFR	1.13 Use Common Hardwares	1.14 MP&P Complies w/MIL-STD	1.15 Design Dwgs Comply w/DPS	1.16 Interchangeable & Replace	1.17 Human Factor Design	
			Design Requirements																	
1.0 Performance																				
1.1 Characteristics	3		□					▤												
1.2 Criteria	3																			
1.3 Max Payload	4		□							□		□								
1.4 Del Payload	2		□																	
1.5 Cargo Comp	1					□	▤	□												▤
1.6 Cargo Comp	1		□	□		□	▤	□												▤
1.7 Mission Cong	1										□									
2.0 Airdrop																				
2.1 Airdrop	3			■																
2.2 Subsystem	5		□					□												
3.0 Cargo Airdrop																				
3.1 Cargo Airdrop	1				■			□				□								
3.2 Load Limit	1											□								
4.0 Platform/Pallet & Recv																				
4.1 Pallets	3					□														
4.3 Platform	3					■														
4.4 Dual Row Airdrop Sys	5				■	■														
4.7 Ctr of Gravity Limits	3		□																	
5.0 Logistic Rails/Locks																				
6.0 Loadmaster Panels																				
7.0 Anchor Cable System																				
7.1 Anchor Cable Support	5		□	□			■	■		■	□	□	▤	□	■			■	□	
7.3 Operation of Winches	1																		□	
7.4 Cargo Clearances	5		□	□		□	■	□												
7.5 Maximum Size	1		□	□		□	□		■		□								□	
7.6 Anchor Cable Load	3		▤	■	□	□	□			■										
7.7 Retriever Winch Pos.	1																		□	
8.0 Mission Computer/CIP																				
9.0 Supportability																				
9.1 Reliability	3			□	□	□				□	■									
9.2 Maintainability	3						□	□			■		▤	■	□			□	□	
9.3 Maintenance Access	3						□				■			□	□			□	□	
9.4 Maintenance Level	3										■			□				□		
9.5 Servicing Points	3										■									
9.6 Rel Centered Mainten	1										□									
9.7 Maintenance Ladder	1										▤									
9.8 Maintenance	1										▤				▤					
10.0 Producibility																				
10.1 Producibility	3													■						
10.2 Design & Construct	1						□								■		▤			
10.3 Mat, Proc & Parts	3			□		□							■			■				
10.4 Workmanship	1																■			
10.5 Interchange & Repl	3																	■		
11.0 Safety																				
11.1 Safety Design Crit	5			■	■	□	■	■	■	■	■	■					▤		▤	
11.2 Safety Des Criteria	5			■	■	□	■	■	■	■	■	■					▤		▤	
12.0 Human Factors																				
12.1 Human Factors	3		□									□							■	
12.2 Design Guidance	3																		■	
12.3 Human Factor Eng	3																		■	
12.4 HFE Guidelines	3																		■	
13.0 Training																				
13.1 Training	3				▤														□	
Raw Weight			41	98	95	70	117	100	55	97	139	64	39	41	39	15	38	49	113	1210
Weight %			3.4	8.1	7.9	5.8	9.7	8.3	4.5	8	11	5.3	3.2	3.4	3.2	1.2	3.1	4.05	9.34	Tot
Weight 1-5 Scale			2	4	4	3	4	4	2	4	5	2	1	2	1	1	1	2	4	11
																				Max %

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Table 3
Scoring criteria

Design Requirements	5	3	1
1.1 Minimum Weight Growth	< 10 lbs.	10 - 20 lbs.	> 20 lbs.
1.2 Load Factors for Weather	Qual by similarity	Some common analysis	New analysis
1.3 Release Load Sequentially	No entanglement	Possible entanglement	Definite entanglement
1.4 Airdrop Customer Platforms	Accept all types	Accept most types	Accept few types
1.5 Support Clearance	> 6 inches		< 6 inches
1.6 Compatible with Structure	Use existing location	New location w/minor mod	New loc w/sig mod
1.7 Size of Cable	Use existing size		Different cable size
1.8 Cable Load	Use existing load		Higher than the exist load
1.9 Maintainability & Reliability	Same or better	Minor difference	Significantly difference
1.10 Safety Design	Total compliance	Partial compliance	No compliance
1.12 Perform DFMA & DFR	Simple for MA & R	Moderate complex	Complex for MA & R
1.16 Interchangeable & Replace	Total int & repl	Partial int & repl	No int & repl
1.17 Human Factor Design	Easy to operate	Mod efforts to operate	Difficult to operate
1.18 Stowage Accommodation	No add'l provision	Modify stowage	New stowage

Table 4
Trade study for anchor cable support design

		Des. 1A		Des. 1B		Des. 2A		Des. 2B		Des. 3		Des. 4	
Design Requirements	Wt	RS	WS	RS	WS	RS	WS	RS	WS	RS	WS	RS	WS
1.1 Minimum Weight Growth	2	3	6	3	6	3	6	3	6	1	2	3	6
1.2 Load Factors for Weather	4	5	20	5	20	5	20	5	20	1	4	5	20
1.3 Release Load Sequentially	4	5	20	5	20	5	20	5	20	3	12	5	20
1.4 Airdrop Customer Platforms	3	5	15	5	15	5	15	5	15	3	9	5	15
1.5 Support Clearance	4	5	20	1	4	5	20	1	4	1	4	5	20
1.6 Compatible with Structure	4	5	20	5	20	1	4	1	4	5	20	5	20
1.7 Size of Cable	2	5	10	5	10	5	10	5	10	1	2	5	10
1.8 Cable Load	4	5	20	5	20	5	20	5	20	1	4	5	20
1.9 Maintainability & Reliability	5	3	15	3	15	5	25	5	25	1	5	3	15
1.10 Safety Design	2	5	10	5	10	5	10	5	10	5	10	5	10
1.12 Perform DFMA & DFR	2	3	6	3	6	3	6	3	6	5	10	3	6
1.16 Intgerchangeable & Replace	2	1	2	1	2	1	2	1	2	1	2	3	6
1.17 Human Factor Design	4	3	12	3	12	5	20	5	20	3	12	5	20
1.18 Stowage Accommodation	2	1	2	1	2	3	6	3	6	1	2	1	2
Total		54	178	50	162	56	184	52	168	32	98	58	190
Normalization	220		81%		74%		84%		76%		45%		86%

achieving the desired result. Assumption is to assume the risk is usually limited to low risks or cases where no acceptable mitigation and research and knowledge is to develop a new technology, concept, process, etc.. This option may also include simply increasing the knowledge pool by consulting experts in the field. Assumption was used for low risk items. It is simply accepting the likelihood and the consequences associated with a risk's occurrence.

A risk summary worksheet was used for tracking the mitigation action/event for each risk area. The action description, schedule,

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Table 5
Likelihood definition

Level		Your Approach and Process
1	Not Likely	Will effectively avoid or mitigate this risk on standard practices
2	Low Likelihood	Have usually mitigated this type of risk with minimal oversight in similar cases
3	Likely	May mitigate this risk, but workarounds will be required
4	Highly Likely	Cannot mitigate this risk, but a different approach might
5	Near Certainty	Cannot mitigate this type of risk; no known process or workarounds are available

Table 6
Consequences definition

Level	Technical	Schedule	Cost
1	Minimal or no impact	Minimal or no impact	Minimal or no impact
2	Minor performance shortfall, same approach retained	Additional activities required; able to meet key dates	Budget increases or unit production cost increase < 1%
3	Moderate performance shortfall, but workarounds available	Minor schedule slip; will miss need date	Budget increase or unit production cost increase < 5%
4	Unacceptable, but workarounds available	Program critical path affected	Budget increase or unit production cost increase < 10%
5	Unacceptable; no alternatives exist	Cannot achieve key program milestones	Budget increase or unit production cost increase > 10%

success criteria and new risk level if successful were shown on the worksheet. It also provided the latest mitigation status for each risk area. It was updated in the weekly project status meeting. An example is shown in Table 8. This worksheet summarised the risk mitigation plan for identified Risk Nos. 1, 4 and 5. In this particular case one mitigation plan would mitigate three identified risks. It can be seen from Table 9 that the risk would be mitigated through a series of events in chronological order. The mitigation option was indicated for each mitigation event. There were scheduled and actual completion dates for each event. The risk levels can be seen as waterfall being mitigated from high to low. The worksheet was used as a living document and updated as mitigation progressed.

A programme risk mitigation report for this project was developed. It was a report in approximately 30-page long. It included purpose and scope, risk description, risk mitigation strategy, mitigation approaches, action plan and risk mitigation tracking. The appendices contained templates for risk identification and mitigation, and the identified risks and their mitigation plans for high and medium risks for this project. This program risk mitigation report was a living document for this project.

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Table 7
Risk identification worksheet No 1

Risk Identification Worksheet No. 1
Logistic Lock Capability

1. Potential Risk Description: The currently designed logistic locks are controlled from the Loadmaster Forward Control Panel and the logistic pallet panels, right and left side. When the release of locks is activated from the panels even though all locks in a pallet/platform position will release simultaneously, there is a time differential between locks in different pallet/platform positions. When two or more pallets/platforms are closely-spaced loaded on the same logistic rail during dual row airdrop operations, the time differential between the locks in different positions will create a possibility that the aft pallet/platform will be locked when it is hit by the forward pallet/platform. This will cause a combination of loose and jammed pallets/platforms condition when the locks are released.

2. Source of Risk: Use the existing design of logistic locks which were originally designed for combat offload. The dual row airdrop operation was not a requirement when the C-17 logistic lock was designed.

3. Consequence If Risk is Realized: It will result in a potentially hazardous(no-release) condition due to loose pallets/platforms. Aircraft damage is possible. Aircraft CG may be affected if a jam occurs near the aft end of the aircraft.

4. Risk Ranking:

Likelihood		1	2	3	4	5
Consequence	**T**	1	2	3	4	5
	S	1	2	3	4	5
	C	1	2	3	4	5

T: Technical
S: Schedule
C: Cost

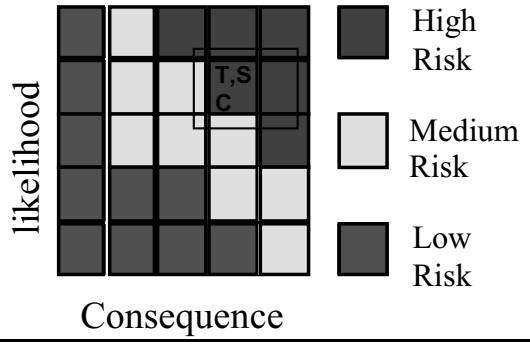


Table 8
Risk summary worksheet

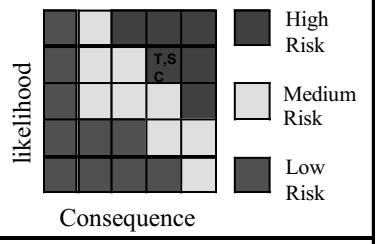
Program Risk Summary Worksheet

Risk Title Logistic Lock System Mitigation for Risk ID 1, 4 & 5

Description of Risk
Time differential between locks, deck angle limitation for lock and deck angle definition of dual row cause uncertainties to achieve desired lock release capability

Statement of Basic Cause
Original design of logistic system is for air land transport or combat off-load. Definition in logistic lock capability is required in achieving dual row airdrop.

Consequence if Risk is Realized
It will result in loose and jammed pallets/platforms and cause damage to the aircraft



Risk Reduction Plan

Action/Event	Date			Success Criteria	Risk Level if Successful	Comments
	Scheduled	Actual	Option			
Define confidence levels for different deck angles	07/18/97	07/18/97	Research & Knowledge	Deck angle 90% confidence and 90% reliability is defined	High	
Limit the deck angle for DRA to less than x.x°	08/08/97	08/22/97	Control	Complete the study and determine the limit for deck angle	High	
Complete T/WR	9/12/97	9/12/97	Transfer	Identify all the test requirements	Medium	
Develop test matrix	8/25/97	9/11/97	Control	Test matrix developed	Medium	
Evaluate test data	11/4/97	11/4/97	Control	Test data evaluated and concluded	Medium	
Develop acceptable procedure for Dual Row Airdrop	05/15/98	07/10/98	Control	Acceptable procedures for DRA developed	Low	

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7.0 CONCLUSION

The entire process presented here was completed in four months. The risk mitigation was a continuous process. The project personnel were able to learn systems engineering process on the job during the progress of the project. In addition, the team members were able to be adaptable to the changing customer requirements. This is due to good requirements traceability and systems engineering documents. Risk management process also helped in this regard. The systems engineering process implemented resulted in clear system requirements derived from customer requirements and constraints; the associated verification requirements; and the requirements tree from top-level to second level and down to the project level. The system requirement review (SRR) was completed successfully. The design requirements were derived from the system requirements and ranked with customer input through the QFD evaluation process. Results from the QFD matrix were then flowed down to trade studies to select the optimum design alternative. Risks were identified systematically and thoroughly. The system engineering products contributed to the satisfactory completion of the system design review (SDR) and the preliminary design review (PDR). The risk mitigation was carried out formally with an initial implementation plan and also tracked by risk summary worksheet.

REFERENCES

1. LABUDDE, E.V. Barriers to bringing system engineering into the commercial market place, 1997, INCOSE proceedings, Los Angeles.
2. DOUKAS, L. A spreadsheet implementation of QFD and systems engineering approaches to support concurrent engineering, 1997, INCOSE proceedings, Los Angeles.
3. ELAM, R. Risk management implementation in a product team environment, 1997, INCOSE proceedings, Los Angeles.
4. McDonnell Douglas Aerospace. *Risk Management Standards Practice*, 1997, MDC 96A0088, Missouri.
5. JACKSON, S. Using the theory of constraints to examine the change approval process, 1998, INCOSE proceedings, Vancouver.

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