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Production Process for Advanced Space Satellite System Cables/Interconnects

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Abstract

This production process was generated for the satellite system program cables/interconnects group, which in essences had no well defined production process. The driver for the development of a formalized process was based on the set backs, problem areas, challenges, and need improvements faced from within the program at Sandia National Laboratories. In addition, the formal production process was developed from the Master's program of Engineering Management for New Mexico Institute of Mining and Technology in Socorro New Mexico and submitted as a thesis to meet the institute's graduating requirements.

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CONTENTS

1. Introduction.....	7
2. Objective	9
3. Background.....	11
3.1. Current Processes.....	12
3.2. Problem Areas.....	13
3.2.1. Requirements/Specifications Problem Area	14
3.2.2. Requirements/Specifications Problem Area Example	14
3.2.3. Design Problem Area.....	15
3.2.4. Design Problem Area Example.....	15
3.2.5. Production Problem Area.....	16
3.2.6. Production Problem Area Example	16
3.2.7. Integration Problem Area.....	17
3.2.8. Integration Problem Area Example	17
3.3. General Problem Areas.....	18
4. Approach.....	19
4.1. Brain Storming.....	19
4.2. Cause and Effect Diagram	19
4.3. Force Field Analysis	19
4.4. International Organization for Standardization	20
4.5. Capability Maturity Model Integration for Development.....	20
5. Results.....	23
5.1. Cause and Effect Diagram	23
5.2. Current and Desired Outcome State	24
5.3. Process Modifications.....	27
5.3.1. Requirements	28
5.3.2. Functional Configuration Audit (FCA)	30
5.3.3. Physical Configuration Audit (PCA).....	31
5.3.4. Problems/Issues Feedback Loop.....	32
5.4. Work Breakdown Structure	32
5.4.1. Advanced Satellite System Cables/Interconnects WBS	32
5.5. Developed Process	37
6. Conclusion	41
7. References.....	43
8. Appendix A - Definitions.....	45
9. Appendix B – Abbreviations/acronyms.....	47
Distribution	48

FIGURES

Figure 1. Top Level Cables/Interconnects Business Workflow Process.	12
Figure 2. Problems Identified / Cause and Effect Diagram.	24
Figure 3. Force Field Diagram for Requirements/Specification Problem Area.	25
Figure 4. Force Field Diagram for Design Problem Area.	26
Figure 5. Force Field Diagram for Production Problem Area.	26
Figure 6. Force Field Diagram for Integration Problem Area.	27
Figure 7. Top Level Modified Cables/Interconnects Business Flow Process.	28
Figure 8. Work Breakdown Structure Chart.	36
Figure 9. Cable/Interconnect Business Work Flow.	38

1. INTRODUCTION

Many private sector companies in the manufacturing environment have established processes to design, produce, test, inspect, integrate, and deliver a multiple number of products. These companies are familiar with the tools and resources necessary to maintain a working production process. Some departments within Sandia National Laboratories (SNL) are not accustomed with these necessary concepts, resources, or tools to generate more than prototype quantities. SNL is responsible for the design, production, testing, and integration of 130 different system cables/interconnects for an advanced space satellite system. In addition, the design complexity of the system only adds to the challenges required to produce functional cables/interconnects for the entire system.

Currently, SNL is in the process of developing two advanced space satellite systems for national security purposes. One system is a second-generation follow-on to the first, but at this time, due to schedule slips in development of the first system, the systems are running in parallel; each in different stages of development. Initial planning was to have the second system beginning development following completion of the first, but considering the problems with schedule and cost, that is no longer the case.

SNL is a research and development (R&D) laboratory managed by Lockheed Martin Corporation for the United States Department of Energy (DOE). SNL has different processes that the laboratory utilizes based on its structure and business procedures. Due to the fact that the advanced space satellite system is a classified program, the project will be presented in a general format to avoid violating limitations that exist on the amount of information and detail that can be released.

2. OBJECTIVE

The advanced space satellite system projects at SNL generally have no well defined sequence, no requirements specified or how the cables/interconnects are to be integrated, the schedule has fallen behind, the performance of the product is not what it should be, and finally there is no clear process formalized for the production from start to finish. As a result of the complexity of the system cables/interconnects, a solid process is required to design, fabricate, test, inspect, and integrate each cable/interconnect. The objective of this project is to define a formalized production process for the program to increase the efficiency and delivery of high quality cables/interconnects.

3. BACKGROUND

The nature of SNL's environment and business processes focuses on research and development (R&D). This creates a disadvantage for the laboratory because the historic knowledge to implement a production based process exists in other areas within the laboratory, but they are not implemented into the program. SNL primarily produces prototypes of one or two for each system, on some occasions the laboratory will produce multiple copies of a design when it is necessary. Several problems have occurred because the process is not as formal, thus causing the project to suffer in many areas. In the R&D environment, design and development processes do not typically occur as they do in the commercial production sector. In the commercial production sector, from the initial start of the program a great amount of effort is put into defining and specifying requirements, making decisions for design and manufacturing methods, and modifying processes as the programs evolve. It is crucial that systems engineering methods and tasks are conducted from conception of a new product line to establish a solid structure for the overall process [1, 2, 3]. In the commercial production sector, multiple copies of a product are developed for the mass market; therefore, there is need for a solid process on which a company must depend on to ensure that customer demands are met. From the beginning of a project, companies spend a lot of time and money to define requirements, specifications, schedules, and design methods in order to establish communication lines between all contributors. All of this work is performed up front to help eliminate issues later down the line and to help deliver a better quality product.

Considering the R&D prototyping industry, processes are handled in a very different manner. In most cases, the customer requests a non-existent product in the amounts of one or two, which increases the risk of performance and uncertainty. Since the product is something that usually has never been developed before and taking into account the high level of risk, other companies tend to stay away from taking on such contracts. R&D facilities face limitations, so it is generally necessary for them to save time and money where it can to meet a very tight schedule and budget.

Currently one advanced space satellite system under development at SNL is in the integration stage and problems are being discovered with the system cables/interconnects. The project is seeing reoccurring problems that should not be seen at this time. The processes for developing the designs were not followed closely until significant problems caused the realization of how much else could go wrong. Because the process that SNL currently uses is not formally disseminated and utilized among all members of the team, many problems have occurred. A problem can be discovered in any stage of the process. Frequently when a problem is discovered, it is delayed to be fed back to the design engineer and CAD personnel to update the design drawings. Problems are sometimes fixed without updating the documentation, so when it is decided to build a second or third copy, it is built from the original design, and in the end the same problem is repeated.

3.1. Current Processes

In the early stages of development for the advanced space satellite system, the Cables/Interconnects Department did not exist. Later on in the development of the system, design engineers and management became aware of the fact that somehow the subsystems would have to interconnect with each other. Considering that outer space is the final operating environment for the system and the transmitting signals are highly sensitive, the complexity of the cables/interconnects increases proportionately. The idea of producing a cable/interconnect for the system appears to be a simple task, causing many designers and engineers to underestimate its importance. It is a critical component in the system. The cables/interconnects directly affect the system's functionality; if the cable/interconnect does not function, neither will the system.

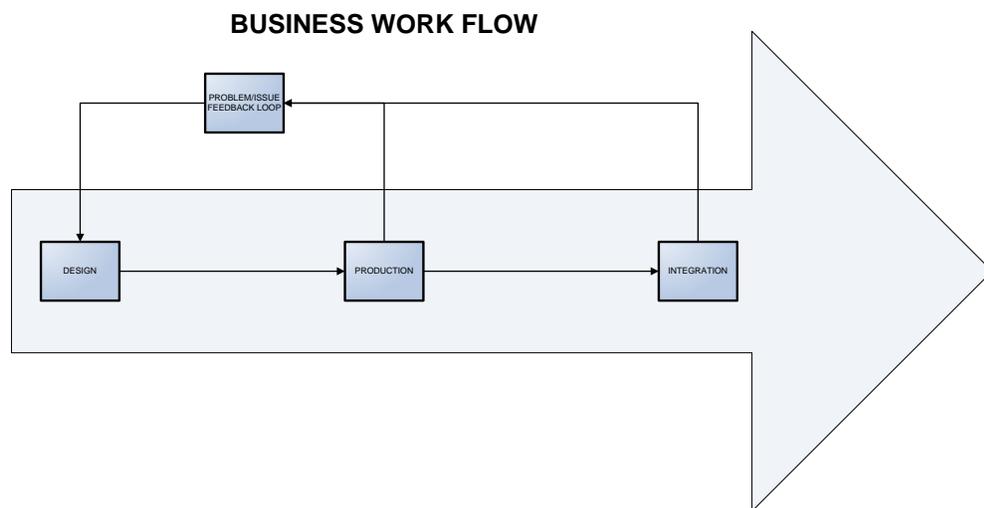


Figure 1. Top Level Cables/Interconnects Business Workflow Process.

Figure 1 illustrates the simplified top level process that has been used to produce cables/interconnects for the system. The process identifies three major phases. A planning stage for the program was not formally established, proposed, or introduced; instead each phase was created as the program was progressing. There is no well defined sequence within the overall process being rigorously followed, resulting in inefficiency throughout the team.

In the design stage of the process, the cable/interconnect may be designed according to a small amount of existing documentation created by the subsystem engineer. However, the design is created primarily from verbal conversations and meetings between the draftsman and the engineer. There is no formal process to document requirements for the design drawings of the system cables/interconnects. Within the design phase, once a drawing is created, there are informal design reviews only between relevant engineers, but not with the entire team. Formal design review meetings for drawings are not required for review. Comments and sign-offs are completed privately.

After several iterations of cable/interconnect drawings, the drawings are approved, signed off, and then moved into production. In the production phase, SNL works to kit the components and prepare paperwork to send to offsite manufacturers [4]. Once the parts kit and paperwork leaves SNL, there is little or no knowledge of the manufacturing process used to create the final product. If any problems occur or discovered during this period, the manufacturer only contacts the Sandia Delegated Technical Representative (SDTR), no other communication is conducted between the team and manufacturer. After the product is completed and received by SNL, with attached test data and documentation, it undergoes SNL's inspection, testing, and cleaning process [4, 2]. Generally, issues exist in this phase with documenting test and inspection results, which lead to inconsistent documentation history of product verification, validation, and approvals. Due to this fact, the documentation is not completed accurately [4].

During the integration phase in Figure 1, the clean cable/interconnect are installed and integrated onto the flight hardware in a class 100 clean room. Prior to the integration, the lead systems engineer writes an Assembly and Inspection Data Sheet (AIDS), which is a formal procedure for how to install the cable/interconnect onto the flight hardware. The AIDS procedures are the only formal process identified in this stage. There are no other formal processes in place for documenting problems discovered in the clean room or to assure that they are fixed in updated drawings. Many issues are overlooked without resolution or follow-on updates to the design drawings [5].

The tools and resources for how to identify, document, request changes, and/or implement corrective actions for discovered problems have always been available to the team, but have not typically been utilized. A feedback loop, in Figure 1, is in place to identify discovered problems. It is used to incorporate them back into the design phase quick enough to update and revise the existing cable/interconnect drawings [6]. In most cases, problems occur or are discovered in the Production and Integration phases; therefore, the feedback loop is initiated from those phases within the Business Flow Process of Figure 1.

At the program level, the cable/interconnect team is not recognized as a key contributor for the system or subsystem. The program does not consider the cable/interconnect team as a critical part. It excludes the responsible personnel along with their expertise, which is needed to assure that subsystems are interconnected properly with one another. The cable/interconnect team is left out of any critical discussions, design reviews, and decisions that are made at the system and subsystem levels. This exclusion of the cable/interconnect team causes important suggestions and opportunities for improving the design to be missed, not to mention the lack of communication that inevitably results in inconsistent outcomes.

3.2. Problem Areas

Problems have occurred and keep reoccurring multiple times across all phases identified in Figure 1. There are many causes for these problems. Many are consistent with problems that have been discovered; typically they tend to fall within the same categories

based on its definition and solution. The categories that exist for the problems are broken down and defined as follows:

3.2.1. Requirements/Specifications Problem Area

The system requirements frequently were not identified for the system prior to initiating the program design phase. At present, there are efforts to go back and define the system requirements for the system and subsystems. Many problems have developed due to the lack of effort put in at the beginning to identify the requirements and specifications. This has also created a great deal of risk and uncertainty for the design, production, and integration of a cable/interconnect [7]. Designs have been created based solely on the specific requirements that a single designer or engineer thinks are correct, rather than designing to what is required for the system design. Tight schedules and budget constraints that had been implemented for the program are to blame for this approach being accepted. No plan, structure, or process was identified prior to the initial kick off. Currently, the overall program is faced with schedule and budget issues within the process areas of designing, production, integration, and documentation.

3.2.2. Requirements/Specifications Problem Area Example

Prior to the design phase, as shown in Figure 1, the requirements and specifications should be identified. Theoretically, no design action should be taken any further without the completion of the requirements and specifications. In this example, the design, production, and integration of the system cables/interconnects had no requirements or specifications completed prior to the initial start of the designing phase. A particular problem that was created and later discovered during the integration phase, was a mismatch of the connection/mating between a cable connector and a subsystem connector on the flight hardware. The depth of the connector on the flight hardware subsystem was too deep for the connector on the cable to reach, resulting in only a partial mate. In another case, a similar problem occurred when the connector on the subsystem was penetrating too far through the hardware. The connectors on the subsystem and cable successfully mated, but because the connector over penetrated, a gap between the cable connector and the subsystem hardware was created. The gap then made it impossible for the screws on the cable backshells to screw into the tapped threads on the subsystem hardware. In different cases, problems are obvious to the point where two mating connectors are completely different types or of the same gender, resulting in an impossible mate.

The unsuccessful mate between the connectors was caused by the incorrect and inconsistent call out for the connectors' mechanical measurements on both the subsystem design and system cable design. Requirements and specifications identified prior to the designing phase are included on what is called an Interface Control Document (ICD). The ICDs capture two aspects, the electrical and mechanical requirements. The Control Document (CD) captures the electrical requirements and characteristics of the transmitting signals; the Mechanical Environment (ME) identifies the mechanical requirements and dimensioning. Having an ICD available eliminates problems for

misconnections between connectors. In this example, these problems could have been captured during the design phase in a design review or during the connector design. Currently in the system's cable/interconnect program at SNL, such documents are typically not available or simply do not exist.

3.2.3. Design Problem Area

SNL has well documented project processes for other areas in the laboratory, available to the program, but they have not been applied. Problems discovered in the design phase primarily arise due to the lack of a formal design review process. In other words, there is a lack of communication between subsystem leads and the cable/interconnect team. Ultimately, the team is faced with issues that could have been addressed if a formal design review was organized and conducted. In some cases, problems are discovered and corrective actions are issued. With the lack of a formalized documentation process, two different corrective actions may be issued and implemented for the same problem. In other cases, nothing is documented for a specific problem and then nothing is done to correct the problem. Later, the same problem will be recreated once an additional copy is made. Since the requirements have not been identified, the designer then has no choice but to design to informal requirements and specifications rather than designing to formal requirements and specifications that should have been established and outlined during the planning phase of the project.

3.2.4. Design Problem Area Example

Within the design phase, multiple design reviews, checks, and audits are conducted throughout the design phase of a cable/interconnect. They are used to verify and validate that the designs are complete and accurate, based on what the particular design engineer believes needs to be produced. In this example, the cable/interconnect designs already existed from an earlier satellite project, but since the follow-on project was almost identical to the previous project, the cable/interconnect designs were copied for the follow-on project. A committee was assembled to conduct Design Risk Assessments (DRA) with lead engineers, designers, systems engineers, and other experts who could represent and consult based on the various areas of a space environment operation. The purpose of conducting a DRA for each cable/interconnect was to review the existing design to identify risks that could arise by transferring these existing designs into the follow-on project. As each risk was identified, they were rated with the severity versus the likelihood of occurrence. A DRA was held for over 130 system cables/interconnects and then the list of appraised risks was documented. Later, a Change Control Board (CCB) was held, which consists of the program managers, lead engineers, lead designers, and the same experts who attended the DRAs. The CCB was assembled to determine a path forward for each identified high risk from the DRA. Once all approvals were agreed upon and signed off, all corrective actions were documented and then implemented into revised cable/interconnect design drawings.

Ideally, a cable/interconnect is produced and prepared to be ready for integration. During integration of a cable/interconnect, it was discovered that a dimension was incorrect and tolerances were too tight. Ultimately, the cable/interconnect could not be installed correctly onto the flight hardware. After the design was reviewed for documented changes, it was discovered that a corrective action, which was decided on in the CCB, was never implemented. The cable was fabricated as it was done for the previous project. After investigating the error that caused the corrective action from never getting implemented onto an updated design drawing, it was determined to be due to an inconsistent documentation process. The process failed to document changes and repairs discovered in the design review, which caused the approved change to never materialize. The inconsistency of the documentation process caused two different corrective actions to appear, the out dated corrective action and the most recent approved correct action. Of the two corrective actions that appeared for this specific cable/interconnect, the older corrective action over wrote the most recent correct action; therefore, the cable/interconnect was manufactured with the tighter dimension. The cable/interconnect could not be installed and a new revised cable/interconnect had to be built, pushing the schedule back nine weeks.

3.2.5. Production Problem Area

Problems that have previously occurred during the Cables/Interconnects Business Workflow process have a high probability of occurring during the production phase. Due to the fact that the cables/interconnects are manufactured outside of SNL, it has been difficult for the team to monitor the progress of the cables/interconnects during manufacturing. It has also been difficult for the team to correct any weak link in the actual manufacturing process. The cable/interconnects team has very little knowledge of outside vendors' manufacturing processes used to produce a product which leads to problems. Problems in this area range from incorrect use of connector genders, incorrect materials, uncertified space materials, wire gauge, cable sleeving, incorrect labeling, and inconsistent inspection and testing (QA) of the cable/interconnect. The manufacturer also performs insufficient testing, providing little or no test data, while their cleaning procedures frequently do not meet expectations.

3.2.6. Production Problem Area Example

Part of the production process includes preparation of the design documentation for the outsourced manufacturers to produce the cable/interconnect. The documentation is sent to the outside vendor for manufacturing; then the final product is received, inspected, tested, cleaned, and prepared for integration at SNL. In this example, two cables/interconnects were sent to the manufacturer for fabrication. The two designs were almost identical, with only slight differences. The only difference between the two cables/interconnects was the configuration of several connector pins that are used to set address bits on the system, once integrated. Ideally, these few pins should be shorted together each with a specific configuration, which represents a unique address setting for the two cables/interconnects. The designs did capture the difference in configuration correctly, but the final product was delivered to SNL with both cable/interconnect pin

configurations manufactured exactly identical. The cables/interconnects did go through inspection and passed quality assurance (QA) at the manufacturer site. Once delivered to SNL, the cables/interconnects went through another set of inspection and test processes. The cables/interconnects passed all inspections and tests, both at the manufacturer site and at SNL, so the cables/interconnects were signed off as “Ready for Integration.” The cables/interconnects were integrated into the system. During system tests, errors began to arise; however, engineers and technicians could not determine the cause of the problems. After 250 man-hours of testing and debugging, it was discovered that the address bits of the system were set incorrectly because the pin configuration on the connectors was incorrect. After all this, the pins were finally configured correctly to set the address bits as they should have been set, and the cables/interconnects passed the system tests successfully.

In another example, a set of pins on a connector of a cable/interconnect was contaminated with an odd and unknown substance. The cable/interconnect also passed various inspection and tests at both the manufacturer site and SNL. The cable/interconnect was then signed off as “Ready for Integration” and installed onto the flight system. The cable/interconnect contaminated the entire system and resulted in time lost to clean and decontaminate the system.

The cause of the problems identified resulted from a poor systems design, and an inconsistent and informal process from both the manufacturer and SNL. Not much is known about the processes, procedures, and the level of QA performed offsite at the manufacturers, but at SNL there is no formal process for the production phase. The lack of identifying and formalizing a process can result in extreme schedule slips, additional costs, and other potential consequences.

3.2.7. Integration Problem Area

During the integration phase is most likely that a problem will be discovered rather than created. In this phase, it is common to discover problems. Problems are usually created in the earlier phases prior to integration because there is missing detail or incorrect design requirements and/or specifications. Several negative results may occur. First, from the integration point of view, problems that arise usually range from a misconnection due to the use of incorrect connectors, incorrect cable length to contamination on wires and/or pins of the cables/interconnects. All result in unsuccessful installation. Second, for the problems that are discovered during the integration phase, there are no formal processes in place for writing up and documenting any of these anomalies. Sometimes the anomalies are not documented, addressed, or fed back to the designers. The designers need to be aware of these discovered anomalies so an appropriate corrective action can be initiated and updated in the revised design drawing [5].

3.2.8. Integration Problem Area Example

The process to document and create an action to feedback these anomalies to the design team is not as formal as it's really needed. At times the anomalies get lost or are never

considered for revisions. The result of this weak link in the process has also been identified as cause for recreating problems. The tools and resources are not utilized to document anomalies so eventually the problems never get considered. The drawings never get updated to reflect a correction for a discovered problem [5]. Action items are not initiated to correct a discovered problem. The second or third time that the drawing is sent out for manufacturing, the problem is recreated only to be found once again during the integration phase.

3.3. General Problem Areas

Other problems that occur are related to improper documentation processes for problems and the subsequent execution of their corrective actions. The team has been faced with great challenges on how to document a problem, find a corrective action, and finally how to implement the corrective action into a new revised design. The team would simply correct the problem on the actual cable/interconnect by modifying it “on the fly”; however, when this method was used, typically, the change was never documented and the design drawings were never updated to reflect the modification or the fix. Later, when that same cable/interconnect was sent out again for multiple copies, the team would be faced with the exact problems that they have seen previously. A great amount of time and money has been spent fixing problems that should not have occurred the second time around.

It was believed, by some team members, that there were no tools or resources available for them in order to capture and document the problems. The team was not familiar with the process used to keep the design drawings updated to reflect the documented anomalies and/or problems. After an investigation of the processes within the department, it was discovered that all the needed resources and tools were already in place and available to the team. Part of the team had little knowledge of the tools or resources, but most did not have a good grasp of how to implement them into their daily work. The lack of knowledge and under utilized available tools and resources by the team resulted in creating and recreating unnecessary problems; problems that should have been corrected the first time.

4. APPROACH

The brain storming process, cause and effect diagram, and force field analysis tools were used to pin point issues and help address solutions. The ultimate starting point to identify and analyze problems was to begin conducting interviews. Members from the team who hold ownership over a process or part of a phase were identified and interviewed individually. The interviews helped gain information with reference to each process phase and analyze current procedures that are used. Some team members had already established their own working processes and procedures that were built upon the family standards of the International Organization for Standardization (ISO) and the Capability Maturity Model Integration (CMMI) guidelines. All the information was collected from the interviews and analyzed with the brain storming process, cause and effect diagrams, and force field analysis tools. Keeping the needs and standardized guidelines in mind, the gained information was integrated into one working process that will be used by the entire cables/interconnects team.

4.1. Brain Storming

In order to implement a business workflow process, the business process across all phases had to be understood. With the team's cooperation, a brain storming process was initiated with individuals from the different process phases: Design, Production, and Integration. In addition, the ideas of management, outside manufacturers, systems engineering, and records retention were considered in the brain storming process. Ideally, the focus of the brain storming process was to engage in discussion about how current operations needed to be adjusted and about how awareness of problems was leading to contradicting outcomes. The brain storming process consisted of a series of interviews throughout the team in the different process phases.

4.2. Cause and Effect Diagram

A cause and effect diagram was utilized and generated from the brain storming process. The diagram is a basic problem-solving tool that visually represents a relationship between symptoms and their root causes. It is used to explore all the potential or real causes that result in a single effect. The interviews conducted in the brain storming process only identified the problem, but the causes and effect diagram narrowed down to the cause of a certain event.

4.3. Force Field Analysis

A force field diagram is a model built on the idea that there are forces which both drive and restrain change. The diagram has two halves: the left half contains the forces driving the desired change, and the right half contains the factors resisting the change. A vertical line represents the present state and the far right states the desired outcome. The analysis helps to identify the forces around a given issue and encourages an action plan that strengthens the drivers and reduces the resistance. During the brain storming process,

problem areas were identified along with the desired state; along side the driving and restraining factors.

4.4. International Organization for Standardization

The International Organization for Standardization publishes the family of standards known as ISO 9000, which represent the guidelines for good quality management practices in business processes. The ISO 9000 family of standards also incorporates the ISO 9001:2000 standard, which implements a frame work for a program's processes from a systematic approach. These standards are considered as part of the process developed with the focus of quality and its management [8]. Various processes existed throughout the team, which were built upon these standards. In developing the formalized process, the ISO 9000 family of standards was used as a basic guideline for its structure.

4.5. Capability Maturity Model Integration for Development

The Capability Maturity Model Integration (CMMI) is a process improvement model for the development of products and services. CMMI is used as a guideline to develop and improve the process by considering the following areas: Requirements Development, Technical Solution, Product Integration, Configuration Management, and Process and Product Quality Assurance. Considering each section, the formal Cable/Interconnect Business Workflow process was developed and implemented [9].

Requirements Development (RD) – The purpose of section RD is to produce and analyze customer, product, and component requirements. There are three areas to consider for the requirements development: customer requirements, product requirements, and analysis and validation of requirements. The customer requirements consider the needs of the customer and those of the appropriate stakeholders. Once the customer requirements are established, they can be refined into the product requirements. The product requirements encompass and provide further development for the product and engineering. Finally, the analysis and validation of the requirements in all areas is conducted to define, derive, and ensure understanding of the requirements that have been established [9].

Technical Solutions (TS) – The purpose of section TS is to design, develop, and implement solutions to requirements. All that is taken into consideration for a product, product components, and product lifecycle processes are the solutions, designs, and implementations; in some cases it may include all or some of these aspects. The primary function of TS is to place the focus of the process on the following:

-Evaluating and selecting solutions that many satisfy a group of requirements all together. This may be considered as design approaches, design concepts or preliminary designs.

-Developing details for the design drawings for a selected group of solutions. This may include details needed for manufacturing or implementation of a product or a product component.

-Finally, Implementing as a product or a product component [9].

Product Integration (PI) – The purpose of section PI is to assemble the product from the components, ensuring that the integrated product functions properly when delivered to the system. The objective of this area is to achieve a complete product integration through a definite integration process, sequence, and/or procedures in combination with product component assemblies. Most importantly is the management of interfaces of the product and its components that will ensure proper compatibility among those interfaces. Since the management of interfaces plays a critical role for PI, this detail needs a great amount of attention and consideration. The objectives and practices fall within three main areas: preparing for product integration, ensuring interface compatibility, and finally assembling and delivering of the product and/or product components [9].

Configuration Management (CM) – The purpose of section CM is to establish and maintain the integrity of work products using configuration identification, configuration control, configuration status accounting, and configuration audits. In some areas, the project and organization decides which work areas need to be subject to configuration management as well as the amount of control needed. The main outline considered falls within the established baselines for the project, tracking and controlling tasks and changes, and establishing the reliability of the products [9].

Process and Product Quality Assurance (PPQA) – The purpose of section PPQA is to provide staff and management with objective insight into processes and associated work products. The PPQA supports the delivery of high-quality products and services provided by all team members, manufacturers, and management at all levels of understanding of the process with feedback on the work products and designs. By considering the practices of PPQA, it will help to reduce the amount of duplicated efforts in the work and issues of the product [9].

5. RESULTS

To produce one single cable/interconnect requires a great amount of effort from team members. The complexity of the system directly affects the design complexity of the cables/interconnects. Various processes exist for different specific tasks and responsibilities. The lack of requirements and specifications has added to the challenge of correctly designing a cable/interconnect. Furthermore, the lack of communication between the different team members has contributed to the challenge of producing an operable cable/interconnect. A number of team members are only concerned with what they are doing; only worrying about their own processes [6, 10, 11]. Other associates are overworked to the point that they do not have time to do documentation for which they are responsible or to share critical information with the rest of the team. There are many different working areas within the team that make up a cable/interconnect due to the number of different parts and pieces. It is very hard for everyone in the team to acknowledge and understand all tasks at hand. The team is in need of a formal cables/interconnects business workflow process that the entire team can utilize and refer to, regardless of their area of responsibility and expertise.

In management, the challenge to obtain full cooperation from the team, which must engage in and accept unknown change, is recognized as highly difficult. Associates within the team and the program have had a makeshift process, which each one has developed, incorporated, and become familiar with during their time working on their individual, assigned tasks and responsibilities. Considering this fact, it is known to be a great challenge to establish a working relationship, by which to engage in learning, sharing, and understanding each team member's work, ideas, and processes [1, 2, 3, 12]. To reduce the amount of resistance from the team to accept change, it helped to have a team member with an unbiased point of view analyze the problems. The team was more willing to cooperate with someone they knew was not there to criticize or force new changes upon them. On the contrary, the team was happy to know someone was there to help improve the process, formalize informal processes, evaluate recurring problems, and find solutions. Problems that have been occurring with the business process of the cables/interconnects were well known and discussed throughout the team. The team was not surprised to hear of the efforts being made to change current operations and respected the efforts put forth. They understood the importance and difficulty of the challenge that someone would have to accept. Rather than resisting, team members were willing to give up time from their busy schedules. Ultimately, they were aware that they would be the ones to benefit by the outcome. A formalized process would help complete the tasks with the rest of the team efficiently and with less effort. The team's cooperation has helped establish a solution for the problems the program has experienced regarding the Cables/Interconnects Business Workflow process.

5.1. Cause and Effect Diagram

A cause and effect diagram to find root causes (Figure 2) was completed with the list of problems that were identified throughout the team. Figure 2 lists the key problem contributors that lead to the end results of: schedule slips, additional resource

consumption, additional costs, and inoperable cables/interconnects [5, 13]. Most of the problems were common among all team members and were heard repeatedly, regardless of the individual's specialty. Some problems were more specific to one area, but overall most were generic problems that were seen throughout the team.

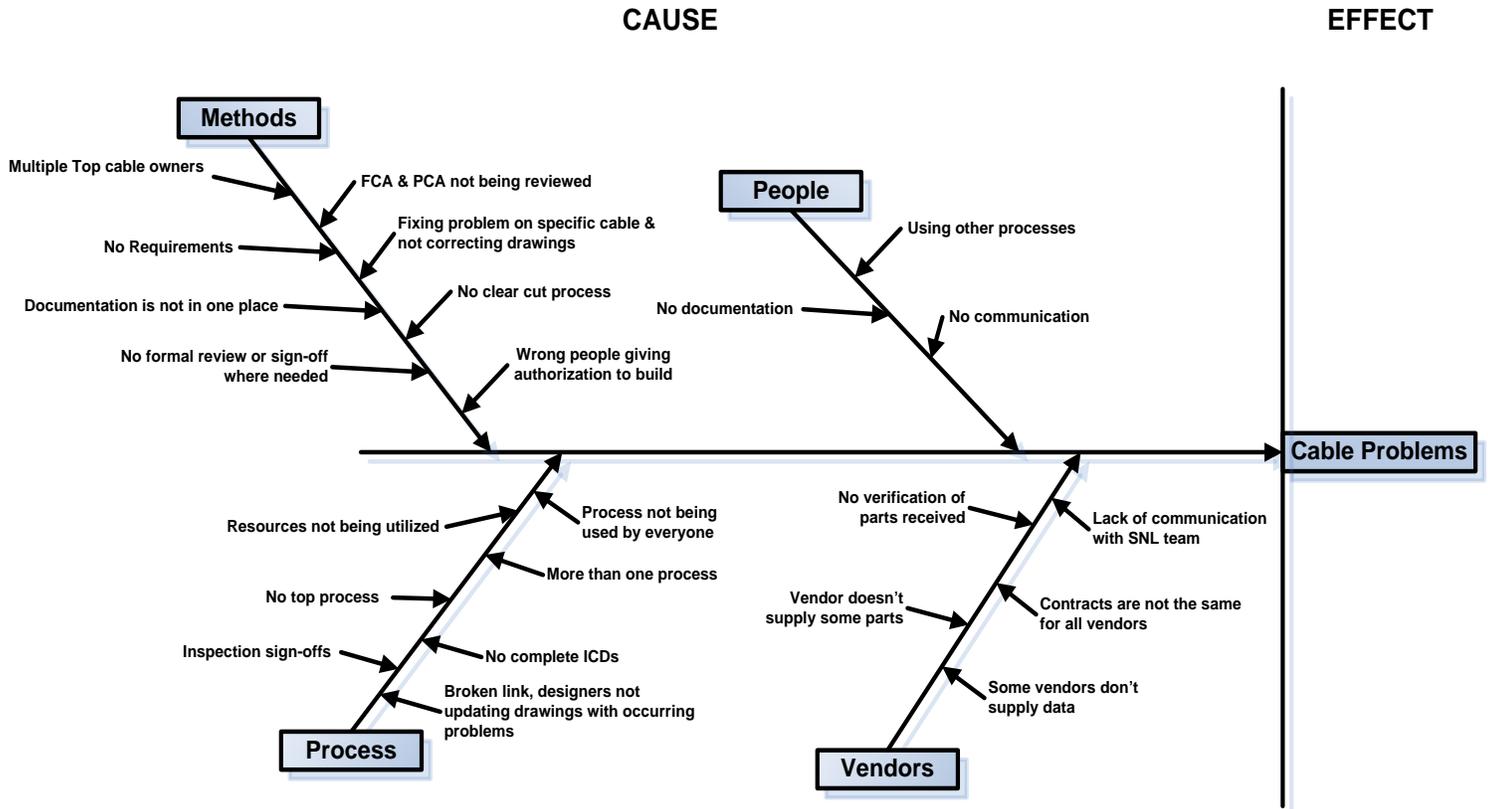


Figure 2. Problems Identified / Cause and Effect Diagram.

The outcome of the brain storming process was very positive, accomplished because the team cooperated and acknowledged that the program is in great jeopardy. On a daily basis before the brain storming session, team members were faced with reoccurring problems that were seen multiple times. It was very discouraging for them because no efforts had been made to find solutions to the problems. By including the team in the brain storming process, it helped to give them a “voice,” a sense of ownership, and reassured them that their work is important. Ultimately, involving the team in the brain storming process will help reduce resistance to accept major changes in processes once the plan is implemented [13].

5.2. Current and Desired Outcome State

To improve the current state or provide solutions, it is necessary to define current problems so the desired outcome state can be achieved. In order to define the current problems in the different areas of the process, the team members that deal with the problems on a direct day-to-day basis were solicited to participate to achieve the desired

outcome. The four different areas that were defined previously for the requirements/specifications, design, production, and integration were analyzed to establish the correct current state and then to determine the desired outcome for that specific area. To achieve this task, a force field analysis was used to help establish decisions and to implement improvements within the current process.

Requirements/Specifications Problem Area

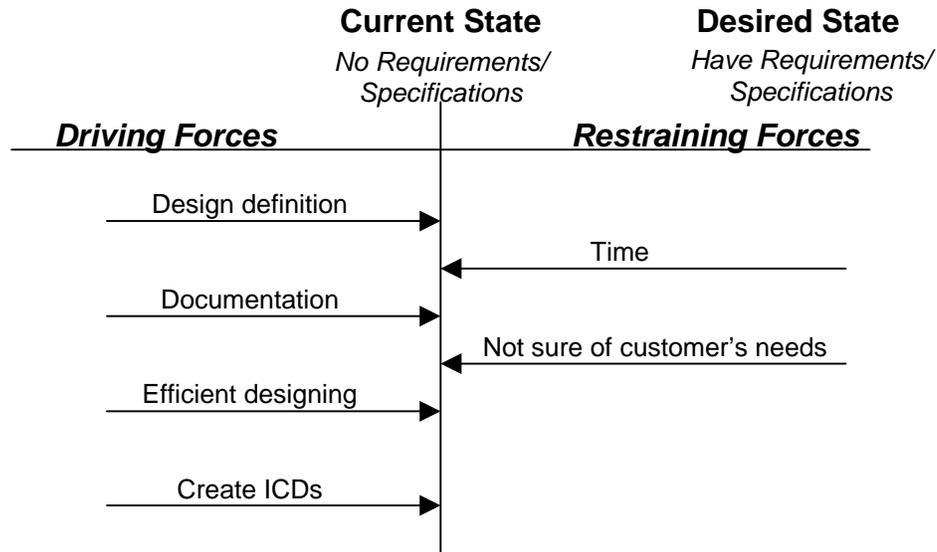


Figure 3. Force Field Diagram for Requirements/Specification Problem Area.

The current state of the requirements/specifications problem area has been recognized and agreed on by the team. Little or no requirements and specifications exist or have been identified for the program. A force field analysis is conducted for this problem area in Figure 3. The desired state for the requirements/specifications problem area is to establish and define requirements and specifications for the program [13].

Design Problem Area

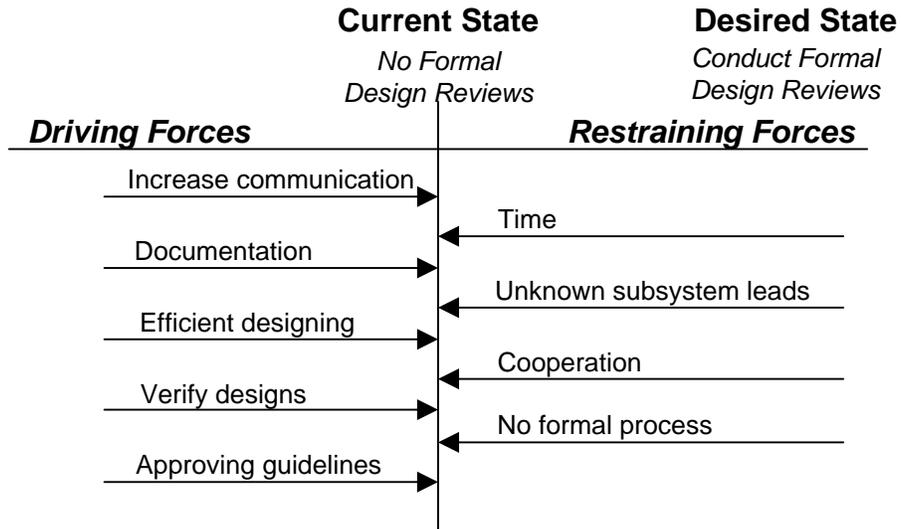


Figure 4. Force Field Diagram for Design Problem Area.

The current state of the design area is known throughout the team as having no formal design review process. Currently, only informal design reviews exist, but the process does not explicitly specify when these reviews are necessary or when they should typically occur. A force field analysis is conducted for this problem area in Figure 4. The desired state for the design problem area in Figure 4 is to establish and implement a formal design review process for the program [13].

Production Problem Area

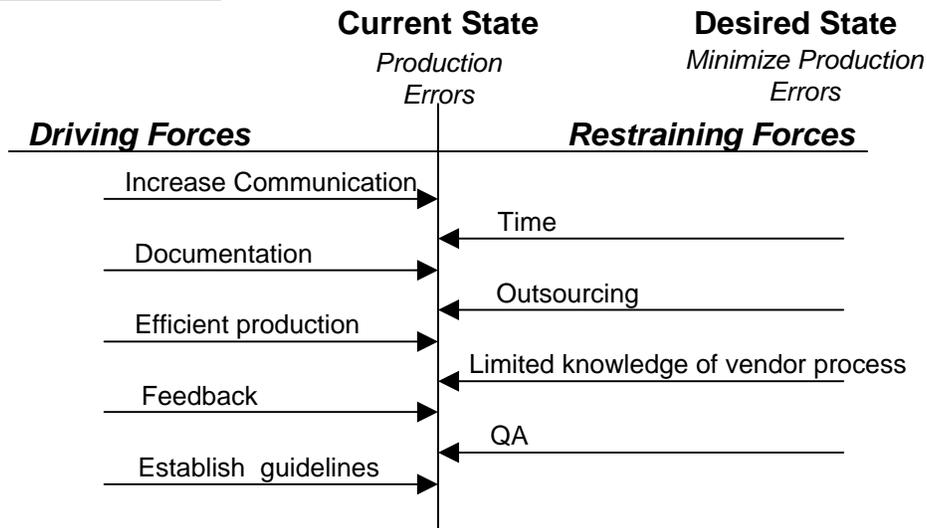


Figure 5. Force Field Diagram for Production Problem Area.

The current state of the production problem area is known throughout the team for having production related errors. Currently, the designs are sent off-site for manufacturing. Little is known about the process used at the off-site locations, so it has become difficult to monitor progress for the fabrication of the system cables/interconnects. The force field analysis is conducted for this problem area in Figure 5. The desired state for the production problem area is to eliminate error and become knowledgeable of the process at the off-site locations [13].

Integration Problem Area

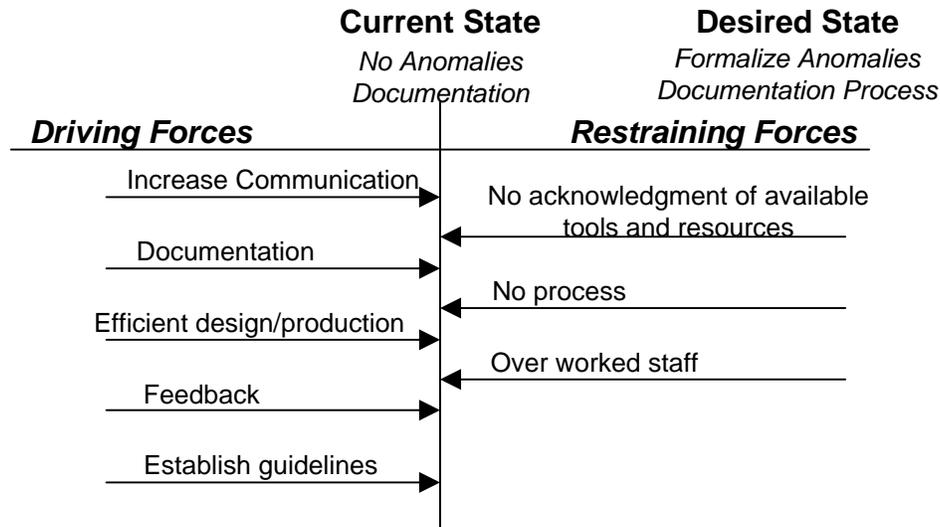


Figure 6. Force Field Diagram for Integration Problem Area.

The current state of the integration problem area is known throughout the team for having no formal process to use, to document anomalies that are discovered in the clean room during integration. Currently, if the team is fortunate, the discovered anomalies are documented if and when the lead integration systems engineer remembers and has time to document them. The integration systems engineer is over loaded and has to prioritize tasks. With a formalized process to document anomalies, it would help to reduce the work load and also assure the team that proper procedures are in place to capture any anomalies that should arise. The force field analysis is conducted for this problem area in Figure 6. The desired state for the integration problem area is to establish a formal process to document discovered anomalies [5, 6, 10, 13].

5.3. Process Modifications

Figure 7 represents the top level Cables/Interconnects Business Workflow Process with the restructured modifications (identified by red boxes). The process in Figure 1 was the initial informal process that existed within the program, but was rarely considered in some cases. Each process block, identified in the red boxes in Figure 7, has been implemented in the formal process and has been carefully examined to help reduce problems by solving the reoccurring problems seen within the process [4].

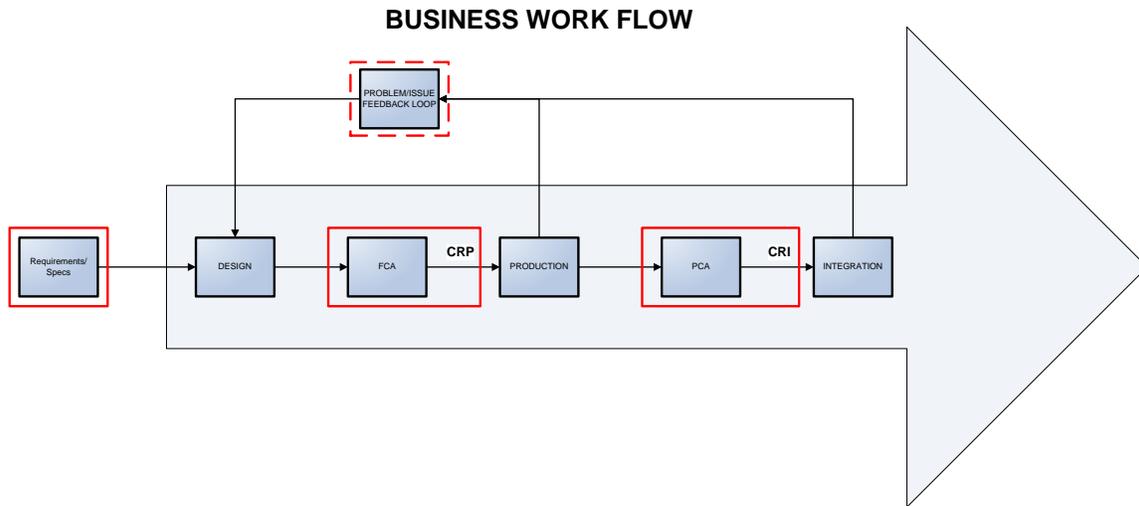


Figure 7. Top Level Modified Cables/Interconnects Business Flow Process.

5.3.1. Requirements

In general, requirements play a key role in identifying the program's structure; without the requirements there is no framework for design engineers and technicians to reference or to fall back on. Better yet, there is no structure of the overall program. For this project, the lack of requirements has been identified as the major cause of failures that have occurred and that continue to occur. The program has failed to identify ALL requirements. In some cases, design engineers and technicians were working from ideas and not from formalized requirements and specifications.

The red box around the requirements/specifications process block, in Figure 7, signifies that the process has been modified to implement these changes. In order to begin improving the program and stop the cycle by which problems are recreated over and over, the requirements and specifications have begun to be identified. Formalizing the requirements has also been identified in the process as mandatory in order to continue through the process and onto the next phase, the designing phase [13].

Necessary requirements have been identified for the following areas [14, 15, 16]:

-Performance requirements

- Electrical continuity and resistance
- Optical continuity
- Electrical insulation resistance/dielectric withstanding voltage
- Bandwidth
- Signal loss
- Voltage drop
- Strength

-Interface requirements

- Mechanical
 - Connectors
 - Physical envelope
 - Range of motion
 - Rate of motion
 - Drag load
 - Mounting
 - Routing
- Signal and Power Interface
 - Connectivity
- Optical Interface
 - Precision Cleaning
 - Particulate Generation
 - Outgassing

-Environmental Requirements

- Electrostatic
- Thermal vacuum
- Vibration, shock, and acoustic loads
- Radiation

-Design Constraints

- Design Life
 - Moving Assemblies
 - Environmental degradation of optical fibers
 - Environmental degradation of dielectric materials
- Mechanical Design Margins
 - Fatigue
 - Strain
 - Lay
- Reliability
 - Failure rate model
 - Crimp joint reliability
 - Solder joints
 - Metal whiskers
- Weight
- Electromagnetic Compatibility (EMC)
 - EMC Design
 - Cables
 - Terminations

In addition, electrical and mechanical Interface Control Documents (ICDs) are created for all the subsystems in the program. An ICD is a document that describes the interface to a system or subsystem. The ICD describes the inputs and outputs of a single system and may also describe the interface between two systems or subsystems. The purpose of the ICD, in this case, is to communicate all the possible inputs to all the potential outputs

from each subsystem. In the electrical ICDs, the critical detail and data that is communicated between subsystems is the signal characteristics. In the mechanical ICDs, the critical detail and data that is communicated is the dimensional characteristics for the connectors/connections, which enable the transfer of all the electrical signals between subsystems. ICDs open the communication channels for the team to be aware of the level of characteristics for each subsystem that interconnect with each other. The information of what is expected to be received from one subsystem and what is anticipated to be output onto another subsystem, will help reduce the conflict of mismatch when it comes to integrate the subsystem together [1, 3, 7, 17].

5.3.1.1. Requirements Desired Framework

The desired framework for the requirement is to follow something similar to the CMMI-DEV Requirements Development. The framework is a guideline to develop requirements in three areas: customer requirements, product requirements, analysis and validation of requirements. The customer requirements consider the needs of the customer and those of the appropriate stakeholders. Once the customer requirements are established, they can be refined into the product requirements. The product requirements encompass and provide further development for the product and engineering. Finally the analysis and validation of the requirements in all areas is conducted to define, derive, and ensure the understanding of the established requirements. During the development of the requirements in all three areas, it is ideal to involve the relevant stakeholder to give them a sense of the development and ensure proper definition for the requirements [9].

5.3.2. Functional Configuration Audit (FCA)

In Systems Engineering, it is ideal to conduct various audits and reviews to approve designs. The system engineers validate that the designs have been created correctly and have met the requirements that have been established at the beginning of the program, during the planning stage. Throughout the life of a program, it is common to see multiple formal audits/reviews. In this project, a FCA is being established and formalized. Conducting this audit is mandatory in order to proceed onto the next phase within the process, the production phase. The red box in Figure 7 signifies that the workflow has been modified to implement the FCA into the business flow process. A FCA is a formal, independent audit intended to provide a high degree of assurance to a project in the sense that the design development of a hardware configuration item has been completed satisfactorily, and that all requirements have been met by the design. The FCA is conducted with an audit of a product with the technical requirements versus associated validation artifacts. The audit identifies the technician's documentation concerning a product that can be used to confirm its satisfactory development. Once the design is validated against all the requirements, a Certified Ready for Production (CRP) is approved and issued. A CRP is a letter or certificate issued by Quality Assurance, certifying that a cable/interconnect has successfully completed the product development process and is ready for production. A CRP cannot be issued without correcting deficiencies or accepting associated risks by the project management. Once a CRP is

issued and approved, the product can proceed to the next phase in the process, the production phase [18].

5.3.2.1. FCA Desired Framework

The desired framework for the FCA is defined by a number of different guidelines and/or specifications from the United States Department of Defense (DoD), the United States Department of Energy (DOE), the Institute of Electrical and Electronic Engineers (IEEE), and the International Standards Organization (ISO). The FCA is structured from these various standards to establish an audit that will support the program for the specific quality assurance of the product. The checklist is the guideline against which the cables/interconnects are audited and reviewed. The audit is continually performed until the cables/interconnects are 100% compliant with the checklist. In addition, the basic structure is modeled after the CMMI-DEV Process and Product Quality Assurance by which the objective of quality assurance evaluations is provided to the program. Those that are independent of the production of the cables/interconnects use a combination of these methods to evaluate against the design criteria [1, 8, 9].

5.3.3. Physical Configuration Audit (PCA)

Just as the FCA was identified, from a Systems Engineering point of view, the PCA is similar to a FCA. The red box in Figure 7 signifies that the workflow has been modified to implement the PCA into the business flow process. A PCA verifies that an “as built” configuration item conforms to the technical documentation that defines it. Performing this audit is generally required prior to the formal delivery of a product. The PCA document is intended to provide a record for the audit that is verified against the physical requirements and the product specifications. The PCA is initiated once the product is received from the outside manufacturer. Once the built product is verified against all the physical requirements, a Certified Ready to Integrate (CRI) is approved and issued. The CRI is composed of the FCA, the CRP, and the PCA. Without the existence or approval of any of these formal documents, a CRI will not be approved and issued. Once a CRI is issued, the product can proceed to the next phase in the process, the integration phase [19].

5.3.3.1. PCA Desired Framework

Similarly to the FCA, the PCA framework is also structured after the same specifications and guidelines. In addition to the specifications used to build the framework for the FCA, the PCA also utilizes a guideline from the National Aeronautics and Space Administration (NASA). The NASA standard, NASA ISD PCA, checklist is utilized during the audit and is continually performed until the cables/interconnects are 100% compliant with the checklist. Those that are independent of the production of the cables/interconnects and that are independent of the FCA process for the cables/interconnects use a combination of these methods to evaluate against the design criteria [9].

5.3.4. Problems/Issues Feedback Loop

The Problems/Issues Feedback Loop is identified in Figure 7 with a dotted red box, which represents the fact that the process already had those tools and resources in place, but improvements and modifications have been implemented as well. The improvements that have been made help the existing process to better capture and define the best corrective action for a discovered problem. The first improvement to the process was to make the team aware of the tools and resources that are available to them. Most of the team members believed there was a broken link in this area of the process, which led to the lack of having corrective actions for problems. This documentation process needs to be used to identify and record anomalies as they occur and provide solutions that will lead to a modification and/or improvement of the final product [5, 6, 10].

5.4. Work Breakdown Structure

The Work Breakdown Structure (WBS) is the hierarchical breakdown of the work necessary to complete a project. The WBS created for the cables/interconnects design, production, and integration processes identified in Figure 7 also incorporates other areas such as tooling, systems engineering, integration support, and project management. The identified WBS elements are product-oriented rather than functionally- or organizationally- oriented. Each WBS element is identified to represent work products such as hardware or data. The WBS is organized to identify the technical objective of the project and is broken down to provide the elements that are necessary to consider for the design, production, and integration of the cables/interconnects of the system [1, 2, 3, 12].

The product-oriented WBS is organized to provide structure for project status reporting, including schedule, cost, workforce, technical performance, and integrated cost/schedule data. The scope of the statement of work and specifications for contract efforts is also defined through the WBS. In addition, the WBS provides an outline and vocabulary that describes the entire project and helps define a more complete business flow process [1, 2, 3, 12, 20]. The outline WBS is defined as follows:

5.4.1. Advanced Satellite System Cables/Interconnects WBS

- ASSC. Cables

- ASSC.1 Production

- ASSC.1.1 Contracting (including in-house)

- ASSC.1.1.1 Purchase Orders/Agreements (DATA)

- ASSC.1.1.2 Production Reports (DATA)

- ASSC.1.1.3 Deliveries

- ASSC.1.1.3.1 Hardware Configuration Item (HW)

- ASSC.1.1.3.2 Product Data Package (DATA)

- ASSC.1.2 Tooling

- ASSC.1.2.1 Design (DATA)

- ASSC.1.2.2 Fabricate (HW)

- ASSC.1.3 Kitting

- ASSC.1.3.1 Procurement Planning and Reporting (DATA)
- ASSC.1.3.2 Stock Long-lead items (HW)
- ASSC.1.3.3 Stock balance of BOM (HW)
- ASSC.1.3.4 Kits
 - ASSC.1.3.4.1 Fabrication Kits (HW)
 - ASSC.1.3.4.2 Integration Kits (HW)
- ASSC.1.4 Receiving
 - ASSC.1.4.1 Inspection (DATA)
 - ASSC.1.4.1.1 Failure/Non-Conformance (DATA)
 - ASSC.1.4.1.2 Corrective Action (DATA)
 - ASSC.1.4.2 Test
 - ASSC.1.4.2.1 Test Equipment (DATA/HW)
 - ASSC.1.4.2.2 Test Report (DATA)
 - ASSC.1.4.2.3 Failure/Non-Conformance (DATA)
 - ASSC.1.4.2.4 Corrective Action (DATA)
 - ASSC.1.4.3 Burn-in (DATA)
 - ASSC.1.4.4 Cleaning (DATA)
 - ASSC.1.4.5 Packaging (DATA/HW)
- ASSC.2 Components
 - ASSC.2.1 Select Item Drawings (DATA)
 - ASSC.2.2 Component Qualification
 - ASSC.2.2.1 Component Qualification Plans (DATA)
 - ASSC.2.2.2 Component Qualification Records (DATA)
 - ASSC.2.3 Qualified Parts List (DATA)
 - ASSC.2.4 Inspection Plans (DATA)
 - ASSC.2.5 Non-conformance/Failure Evaluation Reports (DATA)
- ASSC.3 Verification and Qualification Testing
 - ASSC.3.1 Test Plans and Procedures (DATA)
 - ASSC.3.2 Test Item Production (DATA/HW)
 - ASSC.3.3 Test Equipment (DATA/HW)
 - ASSC.3.4 Test, Evaluation, and Reporting (DATA)
- ASSC.4 Integration Support
 - ASSC.4.1 Physical Interface Definition
 - ASSC.4.1.1 Cable Routing
 - ASSC.4.1.1.1 Three-Dimensional Mockups (DATA/HW)
 - ASSC.4.1.1.2 Three-Dimensional Modeling (DATA)
 - ASSC.4.1.2 Cable Mass Effects
 - ASSC.4.1.2.1 Mass Models (DATA)
 - ASSC.4.1.2.2 Testing (DATA/HW)
 - ASSC.4.1.3 Cable Installation
 - ASSC.4.1.3.1 Assembly and Inspection Data Sheets (DATA)
 - ASSC.4.1.3.2 Integrated Harness Assemblies (DATA/HW)

- ASSC.4.1.3.3 Dry Runs (DATA)
- ASSC.4.1.3.4 Planning (DATA)
- ASSC.4.1.3.5 Activity Reporting
 - ASSC.4.1.3.5.1 Status (DATA)
 - ASSC.4.1.3.5.2 Failure/Non-Conformance (DATA)
 - ASSC.4.1.3.5.3 Corrective Action (DATA)
- ASSC.4.1.4 Subsystem/System Test (DATA)
- ASSC.5 Design
 - ASSC.5.1 Engineering
 - ASSC.5.1.1 Conceptual Design (DATA)
 - ASSC.5.1.2 Preliminary Design (DATA)
 - ASSC.5.1.3 Final Design (DATA)
 - ASSC.5.1.4 Update Design (DATA)
 - ASSC.5.1.5 Drawing Tree (DATA)
 - ASSC.5.1.6 Build-To Unit Configuration (DATA)
 - ASSC.5.1.7 Non-conformance/Failure Evaluation Reports (DATA)
 - ASSC.5.1.8 Corrective Action (DATA)
 - ASSC.5.2 Drafting
 - ASSC.5.2.1 Production Drawings (DATA)
 - ASSC.5.2.2 Status Reporting (DATA)
- ASSC.6 Systems Engineering
 - ASSC.6.1 Technical Requirements (DATA)
 - ASSC.6.2 Design Reviews (DATA)
 - ASSC.6.3 Change Control Boards (DATA)
- ASSC.7 Project Management
 - ASSC.7.1 Project Plan (DATA)
 - ASSC.7.2 Project Management Plan (DATA)
 - ASSC.7.3 Work Breakdown Structure (DATA)
 - ASSC.7.4 Statement of Work (DATA)
 - ASSC.7.5 Organizational Breakdown Structure (DATA)
 - ASSC.7.6 Team Charters (DATA)
 - ASSC.7.7 Work Package Agreements (DATA)
 - ASSC.7.8 Risk Management Plan (DATA)
 - ASSC.7.9 Quality Plan (DATA)
 - ASSC.7.10 Cost Estimates/Budget (DATA)
 - ASSC.7.11 Schedules (DATA)
 - ASSC.7.12 Network Diagrams (DATA)
 - ASSC.7.13 Configuration Management (DATA)
 - ASSC.7.14 Records Management (DATA)
 - ASSC.7.15 Status Reports (DATA)
- ASSC.8 Quality
 - ASSC.8.1 Quality Assurance
 - ASSC.8.1.1 Vendor Qualification (DATA)
 - ASSC.8.1.2 Functional Configuration Audits (DATA)

- ASSC.8.1.3 Physical Configuration Audits (DATA)
- ASSC.8.1.4 Certified Ready to Produce (DATA)
- ASSC.8.1.5 Certified Ready to Integrate (DATA)
- ASSC.8.1.6 Process Audits (DATA)
- ASSC.8.1.7 Production Audits (DATA)
- ASSC.8.1.8 Critical Design Audits (DATA)
- ASSC.8.2 Quality Engineering
 - ASSC.8.2.1 Process Development (DATA)

The WBS is organized in a chart to represent the elements in a more visual perspective in Figure 4. The chart captures the outline that was presented previously [13, 20].

Advanced Satellite System Cables/Interconnects Work Breakdown Structure Chart

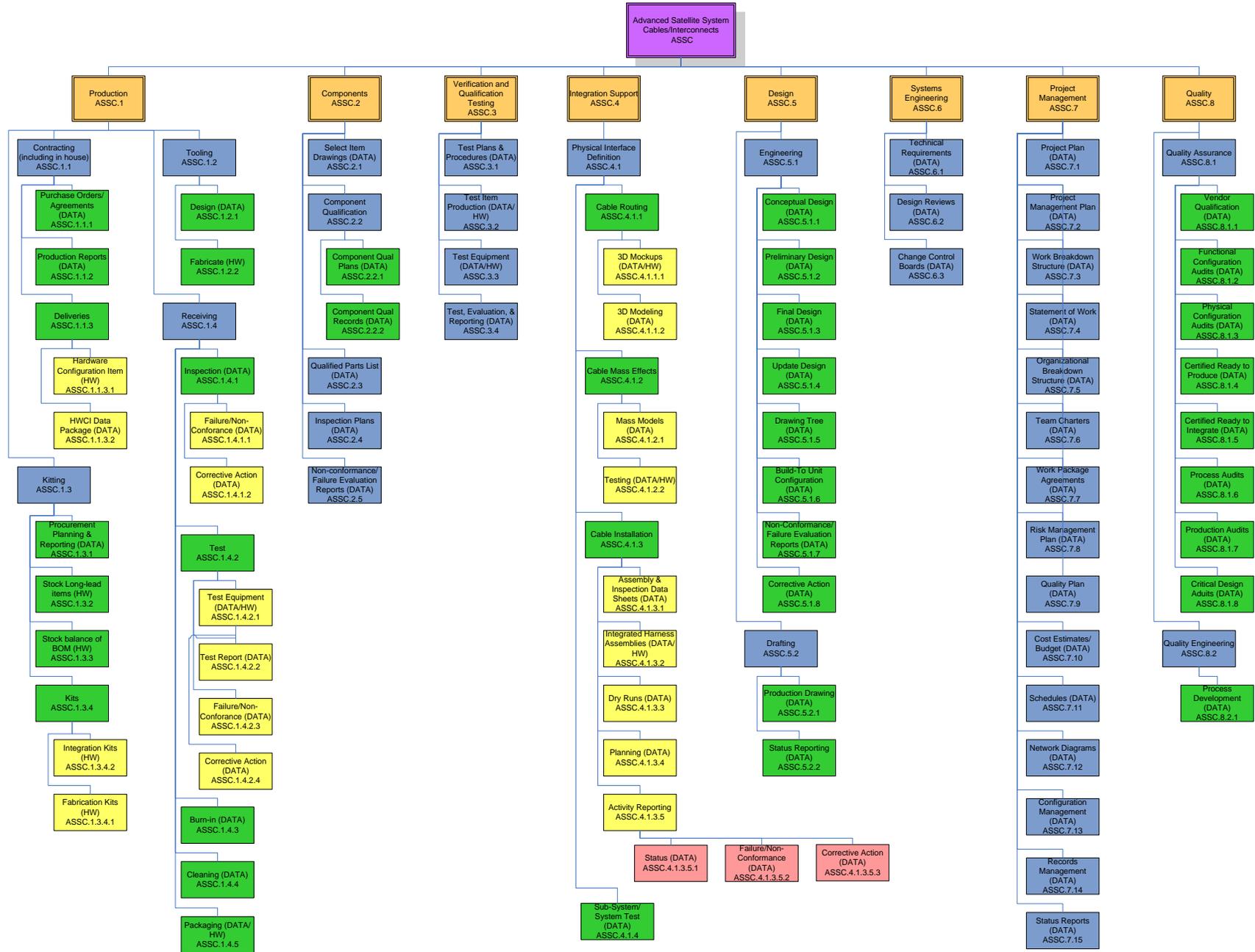


Figure 8. Work Breakdown Structure Chart.

5.5. Developed Process

Theoretically, it is ideal for processes to be built upon the method of concurrent process or something similar. The idea of a concurrent flowing process is to keep the flow of communication open between all phases and team members within the phases. Communication helps reduce chaos, reduce error, share ideas for problem solving, increase team-building relationships, and increase efficiency [1, 2, 3, 12]. After considering the theory of concurrent process and the R&D business nature of SNL, the process method is very difficult to implement within the Cables/Interconnects Business Workflow Process. Once a program kicks off and initiates development, the phases and team members working are not defined. Outside manufacturers or suppliers are not identified, most of the time the outsource facilities need to be certified and their capabilities verified in order to support the program. It is difficult to consider keeping the communication lines open between all phases and team members because these networks of communication do not exist or have not been established. In addition, to build upon a one-way flowing process can be a challenge because a phase is either in progress or has already been completed. Contracts are specifically written, stating that only a certain number of team members are allowed to interface with outside sources or become points of contact (POCs) for SNL. In order to establish open lines of communication between all team members and other associates, the business nature and legal contracts for SNL would have to be modified as well. Due to that fact, it may be difficult to modify the business nature and contract statements. The resulting Cables/Interconnects Business Workflow Process in Figure 9 is developed as a one-way flowing process with appropriate feedback loops. The developed process is built upon what has been defined and considered previously in the research of current SNL business conduct.

Figure 9 illustrates the modified business process flow for the cables/interconnects group in detail. The business workflow process identifies all phases that a cable must undergo, from the top level Figure 7, to produce a functional end product to integrate into the final flight system hardware. The business flow process serves three purposes. First, the process replaces the multiple processes that have been created just to satisfy the operations of only one particular phase (Design, Production, and Integration). Second, it helps the team members and customers realize the amount of work that has to happen to produce a single functioning cable/interconnect. This process helps everyone acknowledge the tasks that are undertaken, assigns the responsible personnel to specific tasks, and guides the team in helping to make each other's jobs easier or less stressful. Finally, the process gives the team a sense of recognition of the work for which they are responsible [1, 2, 3, 12]. On a daily basis, many team members work without acknowledgement or appreciation of the amount of work they supply to the team. The Cable/Interconnect Business Workflow diagram is built considering the standards from ISO 9000 and process improvement models from the CMMI-DEV process.

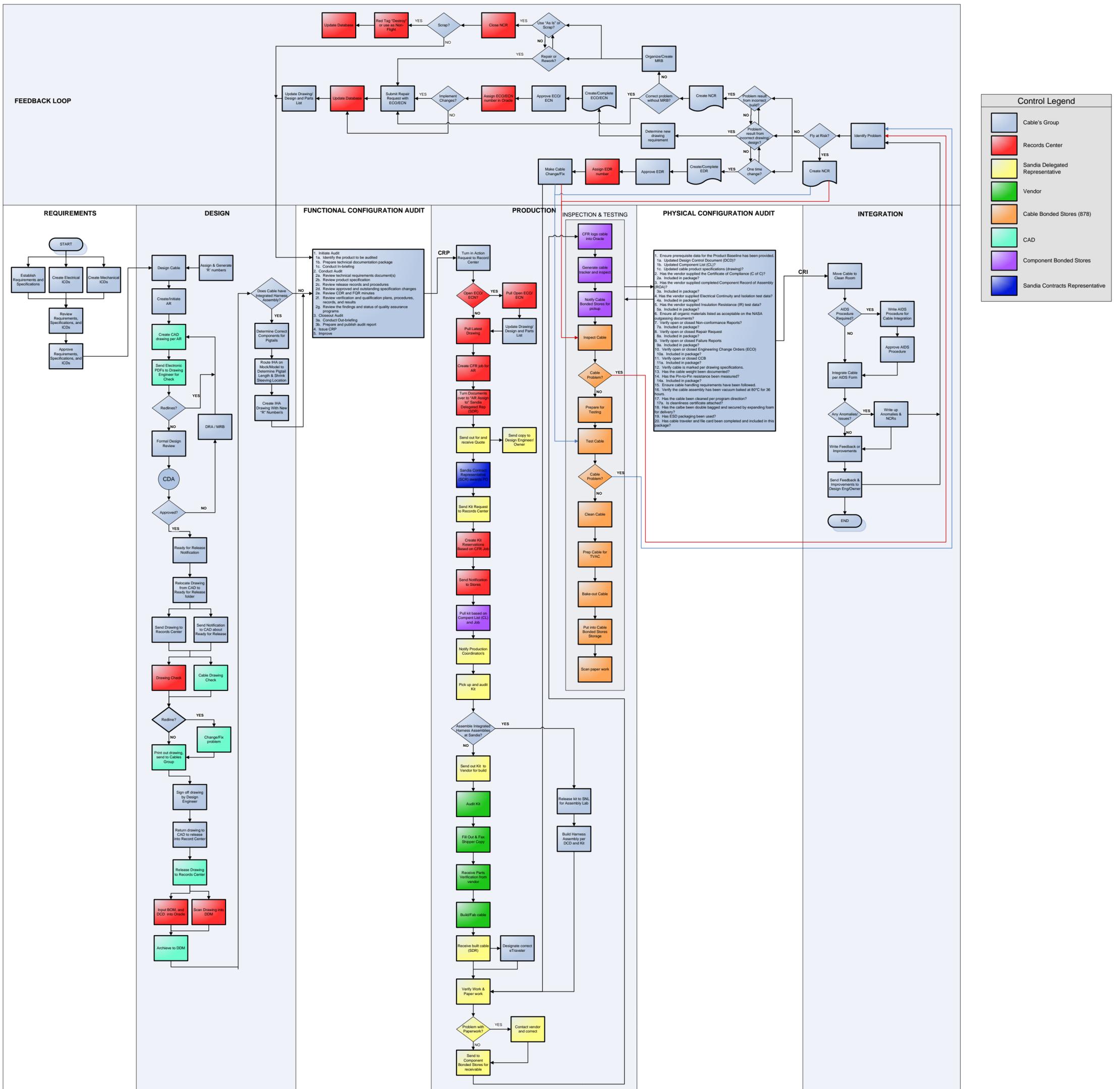


Figure 9. Cable/Interconnect Business Work Flow.

The effort to develop a formalized process was directed to help address problems seen within the program and to derive solutions to increase the quality of the production for system cables/interconnects. In this study, the production phase was not the only area analyzed. Instead, all the different areas that relate in any way to the production of the actual product was considered and analyzed. The results from all the efforts have been seen to be positive and heading in the direction the team had hoped for.

The process shown in Figure 7 has been implemented. It shows progress of creating requirements and specifications for the system and subsystems. The design development of cables/interconnects have their guidelines and structure. The FCA and PCA audits hold absolute authority. The requirement to have the CRP and the CRI created is mandatory prior to proceed further into the production phase and the integration phase, respectively. The feedback loop within the top level business flow process has shown to reduce the number of recreated problems. The feedback loop has increased the amount of communication occurring among the team and has enabled them to work together to find the best working solutions to problems as a team.

The process in Figure 9 is the next level down from Figure 7. Figure 9 represents the working business flow for the production of cables/interconnects in greater detail. Various tests of the process have been conducted to verify the functionality of the process flow. These tests also find weak links that need more work to make it solid. In essence, the process is still evolving. A number of different cables/interconnects, which require more or less attention in different areas, have been tracked through the process from start to finish to verify that the end product is functional and that it ultimately gets properly integrated onto the flight hardware. If the product failed in a certain area, the cable/interconnect was tracked throughout the rest of the process in order to find a solution. Then the failed cable/interconnect was successfully modified with realized solution that was followed by documentation of the change onto the design drawings, the revision by which future production of copies for that particular cable/interconnect can happen.

The developed process has also increased the amount of communication and acknowledgement of responsibility throughout the team. Prior to the formalization of the process, the ownership or responsibility of a specific task or action was unknown throughout the team. The Cables/Interconnects Business Workflow Process in Figure 9 has helped to define the responsibilities assigned within a specific group or department as well as to define where the various responsibilities fall within the rest of the process. Improvements to increase required support of program issues have been made successfully. The complex process of developing a single cable/interconnect has now been recognized throughout the program and has been considered into the team's efforts. This recognition has caused major improvements for the cables/interconnects group as it is also acknowledged as a subsystem, which has given the team authority over critical decisions. Now, the team can work toward the same goal with the implemented formal process in place.

6. CONCLUSION

Considering the difference between the production facilities in the private sector and the R&D facilities in the government sector, production processes will obviously differ from one another. Although there are differences in the production environments, the theories and principle methods still remain the same for processes and their development. The developed Cables/Interconnect Business Workflow Process is customized primarily for an R&D facility, specifically for SNL. The tools and methods used for this study are directly implemented into SNL's advanced space satellite systems program. The cables/interconnects team does not only support one project, but two, with the possibility of additional projects in the near future.

Based on the development of the Cables/Interconnects Business Workflow, the cables/interconnects team can now use the formalized process to conduct their business to help reduce problems, chaos, confusion, additional costs, and schedule slips that have occurred in the past. The projects and programs can raise up a more efficient team with an increased channel of communication, gain a more effective track record, and deliver a higher quality of design methods and deliverable products. As the project/program matures over time and changes take place, this production process will eventually advance. In order to utilize the effectiveness of the Cables/Interconnect Business Workflow, improvements will be necessary to evolve with the project and program to continue to deliver high quality products that meet growing customer demands.

7. REFERENCES

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8. APPENDIX A - DEFINITIONS

Change Control Board – is a committee that makes decisions regarding whether or not proposed changes to a product should be implemented. The change control board consists of the project stakeholder(s) and/or their representatives.

Connector/Interconnect – a device, either a plug or receptacle, used to terminate or connect the conductors or optical fibers of a harness or cable and provide a means to continue the conductors or optical fibers through a mating connector/interconnect.

Contaminant – An impurity or foreign substance present in a material that affects one or more properties of the material. A contaminant may be either ionic or nonionic. An ionic, or polar compound, forms free ions when dissolved in water, making the water a more conductive path. A nonionic substance does not form free ions, nor increase the water's conductivity. Ionic contaminants are usually processing residue such as flux activators, fingerprints, and etching or plating salts.

Certified Ready to Integrate – A letter issued by Quality certifying that a product has been successfully produced in accordance with the product specifications and is ready for integration.

Certified Ready for Production – A letter issued by Quality certifying that a product has successfully completed the product development process and is ready for production.

Crimp – The physical compression (deformation) of a contact barrel around a conductor to make an electrical and mechanical connection to the conductor.

Critical Design Audit – is an audit/assessment performed to present a final design review of the design function, requirements compliance, inspection and test plans, and process to authorize fabrication or continuation of production.

Engineering Change Order – is used for changes in documents such as processes and work instructions. It may also be used for changes in specifications.

Electromagnetic Interference – Any electromagnetic disturbance that interrupts, obstructs, or otherwise degrades or limits the effective performance of electronics or electrical equipment. In terms of wiring design, the concern is with avoiding unintentional interruptions in other pieces of electronic equipment induced as result of spurious emissions, intermodulation products, and the like.

Design Risk Assessment – An exchange forum between knowledgeable designers conducted with the objective of identifying high or very-high technical risks that may exist in the design of a particular product as defined by its specification/requirement.

Functional Configuration Audit - ¹is a formal, independent audit intended to provide a high degree of assurance to a project that the design development of a hardware configuration item has been completed satisfactorily, and that all requirements have been met by the design. ²An

assessment intended to provide independent confirmation that the development of a design, including associated manufacturing processes, has been completed satisfactorily, and that all requirements have been met by the design such that it is ready for production.

Integrated Harness Assembly – A wiring harness that has been integrated with various components (e.g., switches, gauges, sensors) in addition any terminations (e.g., connectors). Basic integrated harness assembly designs use three different cable construction techniques: (1) multi-conductor cable assemblies with pigtails; (2) multi-conductor harness assemblies with pigtails; and (3) connectorized pigtails.

Interface Control Document – is a document that describes the interface to a system or subsystem. The ICD describes the inputs and outputs of a single system and may also describe the interface between two systems or subsystems. The purpose of the ICD is to communicate all the possible inputs to all the potential outputs from each subsystem.

Outgassing – The release of volatile particle(s) from a substance when placed in a vacuum environment.

Physical Configuration Audit – is the formal examination that the “as built” physical configuration conforms to the design and construction process or technical documentation that defines it.

Pigtail – A length of conductor or fiber (generally short) in which one end is attached to a component and the other end is free.

Program – includes multiple number of projects that service or may service different functions and operations, but fall within the same supporting program.

Project – is an individual project within a program, different from other projects in its same category.

Technical Requirements Document – is a document that defines the technical data that explicitly states performance and design specifications or standards to which an outsourced product is manufactured. It includes both allocated and derived requirements, as well as applicable interface control documents (ICD) and verification plans.

Work Breakdown Structure – is a hierarchy designed to organize, define, and display all the work that must be performed in order to accomplish the objectives of a project.

9. APPENDIX B – ABBREVIATIONS/ACRONYMS

AIDS	Assembly and Inspection Data Sheet
AR	Action Request
CAD	Computer Aided Design
CCB	Change Control Board
CDA	Critical Design Audit
CDR	Critical Design Review
CL	Component List
CfC	Certificate of Compliance
CMMI	Capability Maturity Model Integration
CRI	Certified Ready to Integrate
CRP	Certified Ready for Production
DCD	Design Control Document
DDM	Define Definition Manager
DOE	Department of Energy
DR	Design Review
DRA	Design Risk Assessment
ECN	Engineering Change Notice
ECO	Engineering Change Order
EDR	Engineering Deviation Report
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FCA	Functional Configuration Audit
ICD	Interface Control Document
IHA	Integrated Harness Assembly
IR	Insulation Resistance
ISO	International Organization for Standardization
MRB	Material Review Board
NASA	National Aeronautics and Space Administration
NCR	Non-Conformance Report
PCA	Physical Configuration Audit
PDR	Preliminary Design Review
QA	Quality Assurance
RFQ	Request for Quote
ROA	Record of Assembly
SCR	Sandia Contracting Representative
SDR	Sandia Delegated Representative
SNL	Sandia National Laboratories
TRD	Technical Requirements Document
WBS	Work Breakdown Structure

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