Improving the Boeing 787 Final Assembly Corrective Action Process

by

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Submitted to the MIT Sloan School of Management and the Engineering Systems Department in Partial Fulfillment of the Requirements for the Degrees of

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and
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Abstract

This thesis evaluates and then recommends improvements to the process used to correct errors found in the Boeing 787 final assembly operations, known as the corrective action process. The goal is to reduce the time and resources required to perform the process, and also ensure the process is effective at eliminating errors on future airplane builds. These improvements will decrease the resources spent on rework and defect resolution in the future.

A detailed characterization of the defect resolution processes was built by examining established process documentation, shadowing and interviewing key stakeholders, and analyzing process and defect related data. Total rework reduction goals were not being met, signaling a shortcoming in the effectiveness of the corrective action process. The characterization revealed a number of opportunities for improvement.

Actionable recommendations were developed and are presented in this thesis. Recommendations include: providing data visibility from defect resolution processes to identify when corrective action is required; removing unnecessary complexity and ambiguous work instructions from the process; and a system to add accountability to supplier related corrective actions to increase and encourage supplier engagement in defect resolution. Finally, the thesis provides a management framework encouraging inter-functional goals, a holistic viewpoint of improvement programs, and succession planning to help implement the developed recommendations.

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Improving the Boeing 787 Final Assembly Corrective Action Process

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## Glossary

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<th>Term</th>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrective Action</td>
<td>CA</td>
<td>The discipline of eliminating the cause of non-conformities or undesirable situations.</td>
</tr>
<tr>
<td>Non-conformance</td>
<td>NC</td>
<td>An error in the build process, most notably a defect found or caused during assembly.</td>
</tr>
<tr>
<td>Non-conformance (process)</td>
<td>NC Process</td>
<td>A process in which a non-conformance is resolved during final assembly.</td>
</tr>
<tr>
<td>Pick-up (process)</td>
<td>PU Process</td>
<td>An alternative process in which a non-conformance is resolved during final assembly. The pick-up process does not require material deposition.</td>
</tr>
<tr>
<td>Emergent Process Document</td>
<td>EPD</td>
<td>The electronic document that contains information about a non-conformance and the steps taken to resolve it in the non-conformance process, pick-up process, or corrective action process.</td>
</tr>
<tr>
<td>Integrated Supplier Information System</td>
<td>ISIS</td>
<td>The IT platform in which information about non-conformances and corrective action are communicated with tier-1 suppliers.</td>
</tr>
<tr>
<td>Velocity</td>
<td></td>
<td>The internal (Boeing only) IT platform that tracks EPDs for the PU, NC, and CA Processes.</td>
</tr>
<tr>
<td>Root Cause Corrective Action</td>
<td>RCCA</td>
<td>A method problem solving to find the root cause of problems; also the highest level of magnitude given to supplier-related corrective action requests.</td>
</tr>
<tr>
<td>Direct Cause Corrective Action</td>
<td>DCCA</td>
<td>A method of corrective action where the first cause of an error is eliminated; also, the second level of magnitude given to supplier-related corrective action requests.</td>
</tr>
<tr>
<td>Effectively</td>
<td></td>
<td>The third level of magnitude given to supplier-related corrective action requests.</td>
</tr>
<tr>
<td>Notice of Non-conformance</td>
<td>NN</td>
<td>The fourth level of magnitude given to supplier-related corrective action requests.</td>
</tr>
</tbody>
</table>
1 Introduction

1.1 Purpose of Project

This thesis investigates, evaluates, and recommends improvements to the corrective action (CA) process used in Boeing’s 787 final assembly operations. The corrective action process is implemented to identify the source of errors or defects during final assembly and correct these errors on future airplane builds. A successful corrective action process reduces the total resources required to manufacture airplanes by eliminating system errors and rework.

This thesis is based on an internship project completed between July 2013 and January 2014 at Boeing’s 787 final assembly line located within their Everett Factory.

1.2 Problem Statement

As production rates of the 787 increase, a central focus of operations is to eliminate the amount of resources dedicated to rework. The 787 Program has reiterated its position that the overall quality of the delivered airplanes must improve. For these reasons, the corrective action process was selected as an important area for improvement to meet the goals of both rework reduction and quality improvement.

Target goals for the corrective action process, however, are not being accomplished. Many corrective requests take months or years in order to implement a fix, negatively impacting both production rates and cost. Finding and implementing solutions to issues in an effective and timely manner proved to be more difficult on the 787 Program due to new and added complexities in the areas of engineering, supply chain management, and organizational communication.
Making improvements to the corrective action process has proved to be challenging due to the number of stakeholders, work groups, and functions encompassed in the end-to-end process. These issues are highlighted by difficulties in coordinating activities and communication between separate organizations within Boeing, such as manufacturing, engineering, and outside suppliers which are often responsible for defects and resolving errors.

1.3 Project Goals

The overall objective of the project is to make recommendations that increase the speed in which corrective action is completed and improve the outcome of the process, thus ensuring fixes are satisfactory and sustained. In order to fully understand and evaluate the process, three key aspects are studied: (1) Analyzing if corrective action is initiated when required, (2) following the flow of information and corrective action requests, and (3) investigating the outcome of those requests. Further, the research focuses on granulizing the process by examining each process step in an in-depth manner, including the tools, methods, process maps, and associated data.

1.4 Thesis Overview

The thesis will begin with a description of the context in which the issues facing 787 assembly and corrective action lie. Chapter 2 gives an overview of The Boeing Company and its current positioning in the commercial jetliner marketplace, a brief history of the 787 program, its unique supply chain, and the current state of the assembly operations. Chapter 3 examines how defects are resolved in final assembly including the non-conformance (NC) and pick-up (PU) processes, and how they relate to corrective action. Chapter 4 maps the current state of the corrective action, including a description of the workflow, methods, and associated metrics. Synthesizing the previous two chapters, Chapter 5 analyzes the disconnect between the pick-up
and the corrective action process. Chapter 6 characterizes the complexity of the CA process and its impacts on effectiveness. Chapter 7 investigates rework within the process. Chapter 8 focuses on the relationship with suppliers and their role in CA, building on important elements discussed in Chapter 2. The thesis concludes by summarizing actionable recommendations and a discussion of management practices that will help enable effective implementation and continuous improvement.

2 Background and Context

2.1 The Boeing Company

Boeing is the leading aerospace and defense company in the world, with greater than 160,000 employees in over 65 countries. In 2013, revenues were $86.6B, representing steady growth from $81.6B in 2012 and $68.7B in 2011. The company is the top producer of commercial airliners and defense aircrafts combined. Additionally, Boeing designs and manufactures rotorcraft, electronic and defense systems, missiles, satellites, launch vehicles, advanced information and communication systems, and is a major service provider to NASA (Boeing, 2013).

Boeing is split into five primary business units: Boeing Commercial Airplanes (BCA), Boeing Defense, Space & Security (BDS), Boeing Capital, Engineering, Operations & Technology (EOT), and Boeing Shared Services Group. BCA and BDS represent the majority of Boeing’s revenue generation, accounting for 59% and 39% of total revenue respectively in 2012 (Boeing, 2013). Table 1 summarizes Boeing’s structure and key markets.
Table 1: Boeing's structure and markets

<table>
<thead>
<tr>
<th>Business</th>
<th>Market Segment</th>
<th>Key Statistics</th>
<th>Key Products / Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCA</td>
<td>Large commercial aircrafts</td>
<td>$49.1B revenue</td>
<td>737 Twin-engine; single aisle; 85-215 person capacity</td>
</tr>
<tr>
<td></td>
<td>Support services</td>
<td>80,000 employees</td>
<td>747 Four-engine; twin aisle; 467-605 person capacity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13,000 jetliners in service</td>
<td>767 Twin-engine; twin aisle; 180-375 person capacity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>777 Twin-engine; twin aisle; 301-550 person capacity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>787 Twin-engine; twin aisle; 210-330 person capacity</td>
</tr>
<tr>
<td>BDS</td>
<td>Military Aircraft</td>
<td>$33B revenue</td>
<td>Global Strike Aircraft</td>
</tr>
<tr>
<td></td>
<td>Networks &amp; Space Systems</td>
<td>58,000 employees</td>
<td>Mobility, Surveillance &amp; Engagement Aircraft</td>
</tr>
<tr>
<td></td>
<td>Global Services</td>
<td></td>
<td>Vertical Lift Aircraft</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Logistics &amp; Training</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Electronics &amp; IS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Missile and Defense Systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Space Exploration Systems</td>
</tr>
</tbody>
</table>

In the commercial jetliner industry, Boeing’s main competition is from the Airbus Company. Airbus was formed in 1970, and has experienced tremendous growth throughout its history. Since the early 2000’s, Airbus and Boeing have delivered similar number of airliners, with Airbus achieving more deliveries since 2004. Figure 1 compares Boeing (Boeing, 2014) and Airbus (Airbus, 2014) commercial airliner deliveries from 1989-2013.

![Yearly Total Deliveries, by Company](image)

Figure 1: Boeing and Airbus deliveries, 1989-2013
Airbus produces jetliners in direct competition with Boeing. The Airbus A320 airliner is a short to medium range narrow-body model that competes directly with Boeing’s 737 models. In 2005, Airbus finished development of the A380, the world’s largest passenger airliner. The A380 is considered competition to the Boeing 747-400 series, which previously was the largest commercial passenger jet.

The pressure from competition posed by Airbus added to the importance of the announcement of the 787 Dreamliner at the end of 2012. Boeing estimated the Dreamliner would address a market need for about 3,000 comparably-sized Boeing 767s, 757s and Airbus A330s due for replacement by 2010 (Lunsford, 2003).

2.2 The 787 Dreamliner Program

Announced in 2002, the Boeing 787 Dreamliner was billed as a super-efficient airliner seating between 200-250 passengers and a range of 8,000 nautical miles. The size and range of the plane was designed to not only replace aging models, but also address the growing market of point-to-point travel.

The key technological breakthrough that separates the 787 from competition is the construction from carbon composites versus aluminum which is traditionally used for airplane frames and structures. Light weight carbon structures and new system technologies enabled the plane to be lighter than competition, providing a higher fuel-efficiency than competitors. Originally, the 787 was marketed as being 20% cheaper to fly and 33% cheaper to maintain than industry standards (Murray, 2007).

In addition to carbon composites, the 787 featured a suite of new technologies that added value to both the operating efficiency and user experience. The plane has a modular design to allow for two types of high efficiency engines (GE and Rolls-Royce), building flexibility into the
supply chain to accommodate for demand and supplier preference changes. Also of note are the large, smart windows which are dimmable by the end-user, reducing the need for interior lighting.

2.3 787 Supply Chain and Outsourcing Decisions

2.3.1 787 Supply Chain Structure

In addition to the new technologies and materials on the 787, the program features a redesigned supply chain. The original supply chain was designed with the goal of reducing development cost from an estimated $10B to $6B, decreasing development time, and reducing financial risk (Gates, 2011). A key feature of the supply chain is a web of strategic partners and lowered tier suppliers spanning the globe. More than 50 strategic partners (referred to as tier-1 suppliers) are charged with designing and assembling structures and subsystems. These subsystems and structure partners are supplied by tier-2 and 3 suppliers, with independently formed supply contracts (Kotha & Srikanth, 2013).

This new supply chain represents a stark contrast from the legacy Boeing airplane programs. The 737, Boeing’s twinjet narrow-body airline and the best-selling airliner in history, is manufactured using a more traditional supply chain. The 737 parts are produced by thousands of suppliers. Larger sections, assemblies, and subsystems are manufactured and assembled by Boeing at their Renton facility. This excludes certain assemblies which Boeing does not retain manufacturing capabilities such as engines, which are supplied by CFM. Figure 2 depicts a general visualization of the 787 supply chain compared to the 737 supply chain.
2.3.2 Outsourcing Decisions

One of the most important decisions when constructing the 787 program was the increased outsourcing of major assemblies. At the beginning of production, nearly 80% of the plane was outsourced. The suppliers also absorbed more responsibility for the design, engineering, manufacturing, and assembly of the airplane. Entire sections were assembled and shipped to Everett for final assembly, including the aft fuselage from Vought, middle fuselage from Alenia Aeronautica, the nose section from Onex, and entire wing assembly sections from Fuji, Kawasaki, and Mitsubishi. Figure 3 shows Boeing’s move towards increased outsourcing (Ebel, 2013).
Another key aspect of the outsourcing decision was the global nature of the supply chain. Suppliers responsible for the major sections were located all across the globe, involving more than eight countries. Further, these tier-1 suppliers outsourced and sub-contracted globally as well, adding to the overall complexity of the supply chain. Figure 4 is a visualization of the global nature of the 787 supply chain (Boeing, 2013).
Boeing considered outsourcing a key strategy for the future of airplane production. The company saw its core competency as an integrator and assembler of complex systems. The goal of outsourcing was to allow Boeing to reduce the number of employees, capital and plants, and the number of suppliers to manage.

The international focus of the outsourcing effort was to align their supply chain with the international nature of the market for the 787. Over 70% of BCA sales are international, and 90% of the 787 backlog is to international airlines. Boeing saw the advantage of selecting partners where their customer base was located. In 2008, Boeing’s CFO James Bell noted, “Some of our ability to have won a lot of the backlog in the international marketplace is driven by the fact that we have expressed a willingness to share some of the economic benefit with the countries that are buying airplanes.” (Hinton, 2008). This strategy initially paid-off, with Japanese airline ANA
acting as the launch partner by ordering the first 787s. Additionally, Boeing saw an opportunity to reduce development time by tapping the international talent pool to develop in parallel.

2.4 Supply Chain and Outsourcing Results

The course of the 787 program has been well documented and reported in the media. Most notably is the legacy of delays in the delivery date and subsequent quality issues of the in-service fleet. After the unveiling of the plane in 2007, first deliveries were slated for May, 2008. As the program matured, it was clear that coordinating the global supply chain posed unforeseen challenges. After a series of issues and announced delays, the first 787 delivery occurred in September of 2011, nearly four years later than anticipated. Table 2 summarizes the program delays from 2007 until 2011 (Reuters, 2013)

<table>
<thead>
<tr>
<th>Announcement Date</th>
<th>Delay</th>
<th>Given Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>September, 2007</td>
<td>First flight delayed until October 2007</td>
<td>Part shortages</td>
</tr>
<tr>
<td></td>
<td>Deliveries would be delayed until first quarter 2009</td>
<td>Supply chain problems</td>
</tr>
<tr>
<td>April, 2008</td>
<td>Deliveries would take place later in 2009</td>
<td>Work traveled from suppliers to Boeing</td>
</tr>
<tr>
<td>September, 2008</td>
<td>Unspecified delay</td>
<td>57 day worker strike, citing job security</td>
</tr>
<tr>
<td>December, 2008</td>
<td>First delivery delayed until first quarter 2010</td>
<td>Implications of strike</td>
</tr>
<tr>
<td>June, 2009</td>
<td>First delivery delayed until later in 2010</td>
<td>Structural issues preventing the test flight</td>
</tr>
<tr>
<td>November, 2010</td>
<td>First delivery delayed until third quarter 2011</td>
<td>Fires during test flights</td>
</tr>
</tbody>
</table>

Many of the issues that caused the delays and subsequent cost overrun can be traced to the supply chain and outsourcing decisions and management. These issues can be analyzed through the lens of Boeing’s actions to mitigate the supply chain deficiencies.
2.5 Mitigation and Future Considerations

Boeing took a reactive stance to many of the problems that they faced during development and ramp (Tang & Zimmerman, 2009). Actions to secure and improve their supply chain and labor force include:

- In order to improve conditions at a supplier of the aft fuselage and increase production capacity, they purchased the Vought’s 787 operations and took control of their facility.
- Boeing sent over one hundred engineers to suppliers across the world to solve issues at underperforming suppliers.
- The unrest and strike from the labor force was quelled when Boeing conceded to the labor union with increased pay and increased insourcing.
- Penalties were paid to customers for missing promised delivery dates.

While these technical, supply, labor, and customer issues hindered the program, there can be many lessons learned for future programs and the continued improvement of the 787 assembly operations. Additionally, Boeing has strengthened its ability to coordinate a global supply chain and has increased its sales globally. Some key conclusions from the 787 program include:

- Coordinating a global supply chain requires on-site technical and quality management.
- Outsourcing major technical innovations comes at a greater risk than outsourcing known products.
- Tiered outsourcing requires even greater management of suppliers as executed by the Toyota model (Sake, 2004).
• Outsourcing and supply chain decisions need to include labor force inclusive and labor relation risk analyzed (Tang & Zimmerman, 2009).

2.6 Current Operations and Rework Reduction

After mitigating the supply chain and development hurdles, the 787 Dreamliner final assembly operation is facing the challenge of increasing production rates to meet the record backlog and reducing the total cost of production. Many of the challenges of development persist, however, including the task managing an international supply chain. While production has been ongoing for years, the nature of the product requires constant management of the global supply chain due to changing product specifications from value engineering and quality engineering activities, unique aspects of every plane due to customer requirements, and increasing volumes due to production ramp-up.

Reducing rework in final assembly is a key enabler to increasing production rates and lower costs. The cost of poor quality (COPQ) has been studied widely. COPQ is commonly defined as all costs incurred because the underlying quality was not perfect (Campanella, 1999). High costs of quality are common in airplane manufacturing (Dostaler, 2010). Unfortunately, research has shown that it is difficult to characterize the exact cost of rework due to the numerous indirect costs (Love, 2002). Herein, the assumption that positive activities that reduce the overall amount of resources – time, money, man-hours, materials, etc. – will both reduce the cost of production and grow the resource pool for first-pass assembly activities.
3 Defect Resolution in 787 Final Assembly

3.1 The NC EPD Process

During final assembly, a large team of personnel coordinate to resolve a variety of issues that occur during the build process. Discrepancies outside the planned build process are called non-conformances (NCs). These NCs take on many forms during the build process, ranging from damaged parts, missing parts, holes that do not meet tolerance, or even erroneous work instructions or reference drawings.

In order to track and resolve issues, an Emergent Process Document (EPD) is created. The dominate EPD for non-conforming issues is an NC EPD that is electronically updated to contain pertinent information. Figure 5 is an example of an NC EPD showing the associated discrepancy text and the EPD process stage.

Figure 5: Example non-conformance electronic process document
The process to resolve the non-conformance is a multi-step resolution process involving teams from manufacturing, quality, engineering, and material management organizations. Figure 6 depicts the basic process steps of the NC EPD Process.

- **1. Initiation stage** is performed by the Quality function after a NC is detected. Data logging occurs.
- **2. Validation stage** is performed by the Quality function to ensure the EPD is processed correctly and all required data is present.
- **3. Engineering Disposition** is performed by Liaison Engineering if engineering support is required, or similarly the Material Resource Disposition Designee.
- **4. Approval** is performed by Quality.
- **5. The Plan/Check function** is performed by Manufacturing Engineering and at minimum is reviewed and planned by two separate team members.

**Figure 6: NC EPD Process with stage descriptions**

In total, the NC EPD is passed through five queues and touches three different engineering team members. The team responsible for deciding this disposition of discrepant material is known as the Material Review Board Designees (MRBD). While no numerical data was retrieved to illuminate the amount of touch time and queuing for each individual NC EPD step, interviews with manufacturing managers and quality assurance team members illuminated three key facts about the dynamics of the NC EPD Process:

- The engineering disposition stage is the longest and most complex stage before a fix can be planned by manufacturing engineering in the Plan/Check stage.
Initiation and Validation occur in a timely manner (<1 day) given an appropriate number of Quality members are present, i.e. the backlog is not too large.

The length and complication of the NC EPD Process becomes an important factor when considered in the context of 787 manufacturing. During the course of the project, the rate of production was of paramount importance given the high number of airplanes on backlog. A faster, more manufacturing friendly defect resolution process known as the Pick-Up (PU) EPD Process is often utilized.

### 3.2 The PU EPD Process

Similar to an NC EPD, a Pick-up Emergent Process Document (PU EPD) is used to record conditions that exist on material, parts, assemblies, installations, data sheets, equipment, or test operations which are not satisfactory and do not conform with engineering drawings or specification requirements in final assembly. The key difference is that PU EPD can only be created when the non-conforming issue can be reworked to specification without requiring Quality or Engineering Disposition. Figure 7 depicts the PU EPD Process.

1. 
   - Initiation includes identifying the non-conforming condition and documenting information such as part number, location, quantity, etc. This information is entered into the Velocity IT system.
2. 
   - A resolution order is created that includes rework instructions.
3. 
   - The PU EPD and instructions generate a work order in the production system.
4. 
   - The work is performed by the manufacturing team.

Figure 7: PU EPD process with stage descriptions
A key feature of the PU EPD process is its relative simplicity. As noted, the process can be conducted by the mechanic, with virtually no hand-offs of information. Chapter 6 explores this issue in more depth, with Figure 19 showing the responsible roles for each process step and the relative simplicity compared to other business processes analyzed in this project.

3.3 Issues and Discussion

From an analysis of the two processes, it becomes clear that the Pick-up EPD Process path is simpler and friendlier to the manufacturing function. The most prevalent metric for every position and team is Jobs Behind Schedule (JBS). A job is defined as an individual work task during production. This metric is calculated by taking the difference between the number jobs at a given time as scheduled by the production team and the number of jobs actually completed.

\[
\text{JBS} = (\text{Jobs supposed to be completed at the present time}) - (\text{jobs actually completed})
\]

A discussion of the merit of this metric is left for production focused studies, but acknowledging its importance to managers and mechanic teams reveals that the PU EPD Process is preferred in almost every situation it can be applied.

Another important issue to discuss is the change in total rework in final assembly. Throughout the project, the relative importance of rework on total man-hours became clear. Trends for total rework, which is primarily composed of man-hours related to the NC EPD and PU EPD Process, is presented in Figure 8.
While the magnitude and line numbers have been obscured due to information security purposes, it's clear that total rework hours are not decreasing. Rather, the overall trend covering a portion of 2013 is slightly positive. Given these facts, the importance of improving the corrective action and rework reduction becomes evident.

4 The Corrective Action Process and Rework Reduction

4.1 Boeing’s Corrective Action Process versus CAPA Management Techniques

The 787 program has a strict, well-defined process for addressing and eradicating non-conformances that are found during the build process called the corrective action process. A note here should be made to differentiate Boeing’s specific process versus the general idea of corrective action and preventive action (CAPA) as described by general management best-practices (Motschman & Moore, 1999) and ISO-9000 standards (Yahya & W., 2001). Generally,
these include the identification of the root cause of the problem and defining an effective action plan to eliminate the issue. While Boeing’s official corrective action process is an integral part of traditional CAPA, other functions and processes within Boeing play an important role as well. Boeing implements a wide-sweeping production philosophy known as the Boeing Production System which encompasses CAPA and other fundamental tools including process control and statistical inspection tactics.

For the scope of this project, the focus of discussion and analysis is Boeing’s corrective action process as it relates to the 787 final assembly. Further, particular scrutiny is given to the introduction of errors into the corrective action process and the processing of supplier caused errors given the supply chain and outsourcing decisions unique to the 787 Program.

4.2 Corrective Action Process Description

The corrective action process describes the steps taken to eliminate or mitigate the cause(s) of detected non-conformances including the coordination of CA activities among 787 tier-1 suppliers when at fault. Like the Pick-up and non-conformance process, the process follows an electronic Emergent Process Document (EPD) that contains the pertinent information about the issue that updates as the document flows through the process. The process includes six distinct steps as defined by the IT system and information handoffs, although it should be noted each step often includes multiple activities and coordination of multiple parties. Figure 9 shows the stages of the corrective action process.

Figure 9: Simplified CA process diagram
The true complexity of the process cannot be adequately represented with a process diagram. Due to its importance in this project, Chapter 6 provides a discussion of the process complexity including the number of responsible parties, stakeholders, and decisions, and analyzes the impact of this complexity. The following is a description of the process in relation to supplier caused build issues.

4.2.1 Initiate a CA EPD

The CA process for an incident is started by the creation of CA EPD. The vast majority of CA EPDs are created from recurring NC EPDs, although independent CA EPD can be created. Generally, the conditions that lead to the initiation of a supplier related CA EPD include:

- A non-conformance that affects multiple units (planes), batches of parts, or lots. These are known as chronic or repetitive non-conformances
- Defects immediately known to be caused by a supplier that require CA to prevent recurrence.

The CA EPD requires many data fields to be completed, such as part number, location, etc. Additionally, available documentation about the affected part(s) including defect data, photographs, and applicable research is included.

4.2.2 Validate and Investigate CA

Once the EPD has been created, the information is sent to the next workstation to review documentation, validate that CA is indeed required, and investigate the cause or source of the non-conformance. Ideally, this work will determine whether the defect was supplier caused or related to an issue during manufacturing, engineering, or the build process. In this stage there are numerous reasons the CA can be routed back to a previous stage or cancelled. Major issues include:
- Incomplete or inaccurate documentation, such as a lack of product definition data. This will lead to a routeback to the Initiation Stage.

- The underlying NC EPD has been cancelled or determined to be resolved. This will lead to the CA EPD being cancelled.

- A CA EPD already exists pertaining to the same condition. This will lead to the CA EPD being cancelled.

The investigation of the CA EPD will lead to the source, validate the need for CA, and determine the level of CA. A further discussion of the tools used for this investigation for supplier related corrective action is found in Chapter 8. The four levels of CA are:

- Notification of nonconformance (NN): Notifies the supplier of a NC and requests them to conduct CA. No response is required.

- Effectivity only: Confirms an immediate correction of the problem statement and identifies the corrected unit, lot number, batch number, or date where the correction will occur. A response from the assigned party is required in 5-manufacturing days (M-days).

- Direct cause correction action (DCCA): Identifies an action to eliminate or mitigate the direct cause of the nonconforming condition, and also identifies the incorporation point. This level of CA requires a response due in 10 days after assignment.

- RCCA: Identifies an action to eliminate the root cause of the nonconforming condition. This level of CA requires a response in 20 days.

4.2.3 Assign

Once the CA EPD has been fully documented, a responsible party identified, and an appropriate CA level determined, the supplier will be assigned a CA Task and notified that action is required. For this stage, two key distinctions should be highlighted:
1) The CA Task is the action required by the responsible party. The CA EPD will remain within Boeing at the appropriate work center. The CA Task will go to a supplier work station to be processed, with all the pertinent information about the underlying issue and investigation included.

2) Communication with the supplier is performed through a separate IT tool called Integrated Supplier Information System (ISIS).

4.2.4 Plan & Monitor

For supplier related CA, the CA Plans are created and performed by external tier-1 suppliers as a part of contracted statement of work. Boeing’s role in the process is to provide constant feedback and support when requested (Monitor), as well as ensure responses are communicated in a timely manner according to business process guidelines. Again, issues arise in this stage that require CA EPD to be routed back to a previous stage or cancelled. Major issues include:

- The supplier does not believe they are responsible for the build, assembly, or engineering of the part. This will lead to a denial of responsibility request that will require Boeing to identify the true responsible party.

- Evidence or documentation of discrepancy is missing.

Given no issues with the CA EPD or CA Task, the supplier will give an Effectivity, DCCA, or RCCA response that outlines the action plan and scheduled completion date. If more time to develop a CA Plan is required, an extension request may be granted.

4.2.5 Verify

The verify stage is when it’s determined if the CA Task and CA Plan are successful at eliminating the non-conforming issue. This stage can be completed with an inspection during
final assembly, known as a Check Order, or at a supplier site, known as a Capture and Control procedure.

4.2.6 Results

The Results of the inspection schedule above is added to the CA EPD. If the results are positive, the CA EPD is completed. If the results are negative and the non-conforming condition endures, the CA EPD is routed back to the Plan and Monitor stage and new CA Tasks and Plans are generated.

4.3 Current State Characterization

Given the process flow and description, an attempt to categorize the current state of the CA process was performed. This analysis sets out to determine whether the high-level metrics of achieving efficient and swift corrective action are met. An overarching goal for the length of time it takes to achieve corrective action is 80 days on average. This goal was set prior to the project, and communicated throughout the Quality organization. The 80 average day goal applied to all CA EPDs, despite different levels of CA – NN, Effectivity, DCCA, and RCCA – all which require different root cause analysis and supplier response times. Figure 10 charts the total amount of unresolved CA EPDs over time, and compares the total number over 80 days old to management goals.
Comparing the overall goals of speed for the CA process to the actual collected values in 2013 shows there is a substantial gap to overcome. Three conclusions can be drawn from Figure 10:

1) CA is not performing at the goal of 80 days set by management.

2) The number of CA EPDs that take longer than 80 days is and has been increasing since February of 2013.

3) The total number of CA EPDs is increasing.

Further, to gain more insight on the current state of the supplier related corrective action timeframe, data was gathered on the age and time spent in queues of uncompleted CA EPDs which is shown in Figure 11 and 12.
When analyzing the average age and queuing time of supplier related CA presented in Figure 12, it’s clear that CA needs to be performed quickly to meet the program’s goals. Additionally, the amount of time spent in queues is a significant portion of the CA EPD lifecycle time – nearly 47%.
An analysis of where the process can fail can be deduced from the process description presented above. Of note, the steps and methods in which the CA EPD can be routed back to a previous step or cancelled represent wasted processing time and queue itemed. This is represented symbolically in Figure 13, where the red lines represent routebacks, the triangles represent queues, and the cancel signs represent where the CA EPD can be removed from the process. An in-depth discussion of routeback and cancellations is presented in Chapter 7.

![CA EPD process flow with failure modes](image)

Identifying points where routebacks and cancellations occur can help guide the decision of where to focus process improvement efforts. Characterization of the routebacks and queues can help to understand the dynamics of the system and understand the impact of process improvements.

5 Achieving Corrective Action on Pick-Ups

5.1 The PU and CA EPD Process Disconnect

The two goals of corrective action are identifying when to seek the root cause of defect and effectively eradicating the issue on all future builds. The corrective action process described in Chapter 4 mainly covers the latter of the two goals. To get a holistic view of rework reduction, it is important to also consider where the defect resolution processes and the corrective action
processes meet. This concept relates to one of the major goals of the project — analyzing if CA is getting initiated when necessary.

In the duration of the internship, various work groups were shadowed and interviewed to learn more about the decision making process and tools used during each step. To investigate this research question, the Initiation stage of the corrective action process was analyzed. Through discussions with team members whose responsibilities included determining what criteria are used to initiate a CA EPD and analyzing business process documentation, three important facts became clear:

- Data from the NC EPD process is used to determine whether or not a non-conformance is recurring, and therefore requires corrective action.
- PU EPD data is not as robust as NC EPD data regarding defects and build issues.
- PU EPD data is not visible to suppliers through the supplier communication IT system, ISIS.

When these facts are synthesized, it raises the issue of data visibility when utilizing the PU EPD process to resolve defects. Without data visibility, corrective action cannot be initiated when required. This issue can be illuminated by looking at a simplified process flow diagram, Figure 14, combining the defect resolution processes and the Initiation stage of the corrective action process.
1. A non-conformance is identified in final assembly.
2. If the defect requires review by MRBD, it is reviewed and data is collected by the Quality Technician (QT) → if the defect does not require review by MRBD, a PU EPD fix can be processed.
3. The NC EPD process is utilized to resolve the NC EPD.
4. If the NC EPD is chronic or requires CA, then a CA EPD is created and the CA process is initiated.

Figure 14: CA initiation process flow

In the diagram, the dotted lines represent data visibility. The broken dotted lines from the PU box represent how data is not visible to suppliers, Supplier Management teams, or decision makers who initiate the CA EPD Process.

5.2 Characterizing Pick-up Impact and Trends

By establishing that the PU EPD process and the Corrective Action Process are disjointed, it raises the questions:

1) What is the impact of Pick-ups on overall rework?
2) How has the amount of Pick-up work trended over time?

It can be postulated that if corrective action is not getting initiated on Pick-ups, we should not expect PUs to be decreasing over time.
Qualitatively, conversations with manufacturing personnel led to the conclusion that PUs play a major role in defect resolution. A discussion of the advantages in processing time, number of touches, and overall complexity was included in Chapter 4. To further analyze this impact, data was collected on the number of man-hours recorded as Pick-ups relative to total rework hours. A representation of this relationship is depicted in Figure 15.

![Figure 15: Man-hours as a percent of total rework activity](image)

Although this analysis was performed for a single manufacturing position on one line, the data supports the qualitative analysis that PUs make up a major fraction of rework. In this case, nearly 30% of all rework was performed without an NC EPD being created.

To investigate the second question regarding the historical trend of Pick-up use over the course of the 787 assembly operations, data was collected on the total quantity of Pick-ups jobs performed on each individual line (Figure 16).
Figure 16: Total PU jobs over time

The data shows that over time the number of PU jobs has held steady. Although total PU jobs is steady, it is also important to view PU as a percentage of total work. Because each airplane is not the same, the number of jobs can vary greatly. We can expect, therefore, that as the total number of jobs increase, so will the total number of Pick-ups. Figure 17 shows the total number PU jobs as a percentage of total jobs performed.
As a normalized statistic, the number of Pick-ups per airplane is trending upward, indicating an increase in usage of the simpler defect resolution process.

5.3 Discussion and Countermeasures

By performing process analysis and conducting stakeholder interviews, a disconnect was discovered between the data collected from resolving non-conformances through the PU EPD process and the CA process. To investigate the impact and effects of this disconnect, data on PU was analyzed as a percentage of rework, total work, and trends over time. The data analysis showed that PUs are a significant portion of rework – 30% for a particular manufacturing position. Further, the total amount of PUs per plane has not decreased over time. In fact, as a percentage of total work, the regression shows a slight increase in PU activity.

This analysis supports the hypothesis that CA is not initiated on issues relating to PUs. Also, evidence supports that PUs are an important part of the manufacturing process and favored by many manufacturing managers.
The discussion of the issues highlight a number of countermeasures that can bridge the PU EPD and CA EPD gap, and ensure CA is achieved:

- The data that is collected from the PU process must be treated similarly to NC EPDs.
- The fidelity of the data on PUs must improve. In the NC EPD process, the Quality team is brought in to collect data, known as tag writing. This practice should be used for PU EPDs as well.
- A strong influence on overarching metrics, such as total rework, and rework reduction, should be rewarded program-wide, versus siloed metrics such as JBS.

A future state process should include the above features, while retaining the speed and simplicity of PU EPD process. Data visibility will lead to a flagging of a recurring issue or supplier related non-conformance in the tagging phase. This flagging will trigger CA Initiation, and the current state process will involve the engineering support teams (Liaison Engineering, Quality Engineering, and Manufacturing Engineering), and/or supplier facing support teams (Quality Assurance, Supplier-Factory Interface). These support teams can lead the root cause analysis in parallel to the PU defect resolution process.
6 Process Complexity

The corrective action process from end-to-end is a complex business process. The high level of complexity stems from many factors which have been touched on in previous sections. Some of the main features that add to its complexity include:

- The length of time it takes to resolve a CA EPD, which is on the order of 5-6 months.
- The number of work functions and individuals internally that can potentially have touch time on a CA EPD. This complexity is further discussed below.
- The integration of numerous other business processes that feed into the CA process. Already explored are how defect resolution business process such as the PU EPD and NC EPD processes are interrelated.
  - While beyond the scope of this project, it should be noted that other business processes such as part removals, capture and control procedures (when a NC is known to exist outside of final assembly) and escapement policy (when a plan is released from final assembly with a build issue) are related to the CA process.
- The intimate involvement of tier-I strategic suppliers who in many cases own all of the engineering and/or manufacturing of a part or assembly.
- Coordinating with Boeing South Carolina which acts in many ways as a strategic partner but requires an entirely different set of processes and communication guidelines.

In the course of the project, it became apparent that process complexity added challenges to achieving timely and effective corrective action. The adverse effect of complexity on business process management is well studied. It has been shown relationship between complexity and the ability to standardize work methods is inversely related (Shafermeyer & Rosenkranz, 2011).
6.1 Work Function Involvement

There are numerous ways to define and measure process complexity, including decision points and flow measurements (Cardoso, 2006) and graph theory methods (Latva-Koivisto, 2001). A recurring theme throughout the project was complexity that arose from the multiplicity of work functions responsible for similar tasks and the many different routes a CA EPD could travel through the process. In order to capture this feature of the corrective action process, analysis of business process documentation and interviews with key stakeholders was performed. In order to gain further insight on the negative effects of multiple roles accountable for similar tasks and to relate the inquiries to one of the main project thesis questions, additional emphasis was put on the Initiation stage of the CA process.

![Figure 18: Work function involvement in CA process stages](image)
Figure 18 above depicts which work functions are responsible and/or accountable for each stage of CA process. The Verification stage was split into two stages to indicate that a manufacturing engineer is required to create a work order to inspect a part in final assembly. As an illustrative example, the blue line represents one of the many paths that a CA EPD can travel through the business process:

*A Quality Technician (QT) identifies an issue that requires CA, believing it to be a supplier issue. Quality Assurance Investigations (QAI) validates the CA EPD was initiated properly, determines how extreme the issue is, and assigns a supplier the CA EPD to supply a CA plan to eradicate the issue. QAI receives the plan, validates it, and send it to manufacturing to create a shop inspection to check the work when it is completed. Quality receives the inspection report and closes the EPD.*

Figure 19 is presented to compare the CA process to the relative simplicity of the PU EPD defect resolution process discussed previously.
Analyzing the two figures begins to explain the intricacies of the CA EPD process. Notably, the corrective action process distinguishes 17 different work groups responsible for initiating a CA EPD. The CA Planning stage, where root cause analysis and countermeasures are produced, counts 18 responsible parties. While the supplier group is only counted once, in reality it represents the 50+ tier-1 suppliers for the 787 Program.

Another tool to quantify the complexity of the process is to determine the number of paths the CA EPD can take to completion. A rough first pass at this analysis is given by using the number of possible work functions per stage and total number of stages.

\[\text{Permutations} = N_{\text{Stage1}} \times N_{\text{Stage2}} \times \ldots \times N_{\text{Stage Last}}\]

In this equation, \(N\) is the number work stations the EPD can travel for each stage. This simple calculation gives 99,144 different possible paths for the CA EPD process. Compare this to 256 paths for the PU EPD process.

While this analysis is an oversimplification and many paths are unlikely, it gives a basic measure for relative complexity. Further, the analysis does not include routebacks, which would add many more possible paths. A discussion of the impact of routebacks and countermeasures is provided Chapter 7.

### 6.2 Stakeholder Perspectives on Process Complexity

Stakeholder interviews were collected to determine the impact of the diffuse accountability of specific tasks. A brief synopsis of the most informative views is given below.

**QAI Team Member:** *It's my responsibility to work through my queue of validating CAs. I have certain number that I am responsible for each day. People think we're here to track down, identify, and solve every corrective action request, but that’s just not true nor do we have the time.*
QAI Manager: *We’re here to move CAs through process and assign supplier’s responsible. If you look at the Boeing Production System text, it clearly states Pit Bosses and Manufacturing Representatives are responsible for detecting trends and performing root cause analysis.*

Quality Engineer: *There is no way we can initiate CA. We have to go through QAI, and their tools are limited at best. QE shouldn’t even be identifying these issues in the first place; we’re here to support the Quality Managers.*

Manufacturing Manager: *We’re currently 47 Jobs Behind Schedule on this plane. I’ve scheduled my team work the next two weekends, and it looks like we’ll have to work a third to avoid traveling too many. How am I supposed to respond to a CA Task and find out who else is messing up?*

By synthesizing these stakeholder views, we can see that diffuse accountability raises a number of issues:

1) Metrics don’t align with the goals of initiating or performing corrective action. This is clear when distilling the viewpoint of a QAI team member who is more concerned with meeting goals of queue reduction, and the cell manager who is judged by JBS.

2) Diffuse accountability provides an opportunity for finger pointing and deflection of responsibility.
3) Parties that cannot initiate CA but work in order to identify non-conformance trends, such as Quality Engineers, are frustrated that they often perform work they do not believe is in their scope.

6.3 Discussion and Countermeasures

After investigating the multiple flow paths a CA EPD can travel and collecting viewpoints of stakeholders who share responsibility for certain process steps, it is clear a simplification of the process would be beneficial. Special attention should be given to the origins of the CA EPD in the Initiation stage. The input and responsibility of multiple parties is reasonable from perspective of identifying corrective action from many areas of Final Assembly. For example, a tooling engineer will be best qualified to determine if corrective action should be sought for tooling issues.

As a countermeasure, the number of initiating parties should be collected into a smaller group. This group should focus on encouraging experts, such as the tooling engineer and quality engineer, to supply information and issues to initiate CA quickly, without deflecting. In the current scope of the Corrective Action process, the groups should be focused under existing work groups:

- **Quality Assurance Investigations (QAI):** Supplier related CA
- **Manufacturing Engineering (ME):** Manufacturing related CA
- **Liaison Engineering (LE):** Design related CA

Another countermeasure to facilitate the process is developing organizational goals and training material related to corrective action. For example, deflecting responsible by pointing the Boeing Production System (BPS) is counterproductive to every group. By relating to the goals of
the two systems, both in official process documentation and work metrics would help eliminate this behavior.

The diverse set of work groups involved in the process also introduces the complexity of different tools, methods, and data collection practices utilized by each party. Currently, as an EPD is created, developed, and passed along, key information is missing or poorly communicated. Chapter 7 provides a discussion of these issues.

7 Corrective Action Process Rework

Within the corrective action business process there are built in rework cycles, such as reprocessing of information, redoing inspections, and work function reassignment, that inhibit the flow of a CA EPD. In the Boeing work environment, the movement of information backwards in a business process is called a routeback. Identifying routebacks is important for three reasons: 1) It represents a failure in the process, and namely the connection between two work groups, 2) can help prioritize where to focus efforts for improvement, and 3) provides a metric to manage and assess improvement.

Routebacks for the NC EPD process have been tracked for years. The NC EPD process has been the focus of management because it is the main driver for defect resolution. The process also generates the most data regarding defects and build issues. Routebacks in the CA EPD process, however, are not tracked. Tracking routebacks for the CA EPD process presents a valuable new tool for issue identification, but also presents a challenge to collect and organize the vast amount of data collected.
7.1 Quantifying Process Routebacks

Data was collected on all CA EPDs in 2013. In order to identify routebacks, the data was sorted by EPD number and chronological order it passed through system. Data points were flagged for every time the EPD changed stages. Figure 20 shows a sample of the data organized for a single CA EPD.

![Table of CA EPD data]

Figure 20: Sorted CA EPD data

All CA EPDs were cycled through in this manner. The blue arrows in Figure 20 represent routebacks where the process stage has regressed although the timestamp is greater. In this particular CA EPD lifecycle, the EDP was route back four times. Additionally, a counter was tallied for every instance the CA EPD was cancelled, representing an instance when the CA EPD was unwarranted and an unnecessary cost to the organization. Figure 21 summarizes the results of this analysis.
The stages on the Y-axis represent the start stage of the CA EPD, and the X-Axis the end stage. Entries above the diagonal are forward movement through the process, and below the diagonal are routebacks. The column on the far right represents cancelled records. For data sensitivity purposes, the values are represented as a percentage of total records. For example, 95% of all CA EPDs in the Initiation stage progressed to the Validation Stage, while 5% were cancelled. Of these records, 48% moved from Validation to Assign forward in the process, while 14% were routed back to Initiation and the remaining 38% cancelled.

7.2 Discussion and Countermeasures

Analyzing the data shows a tremendous amount of waste in the process as routebacks and cancellations of CA EPDs. From the Validation stage alone, the data shows over 50% of CA EPDs are routed back or cancelled. To identify the main issues that cause routebacks, team members responsible for key steps were interviewed and shadowed. Extra emphasis was put on the Initiation of the CA EPD because of the personnel resources available within the Quality department and the lack of access to supplier information. The following countermeasures involving standardization have been developed:
1) **Face-to-face meetings to discuss the cause of routebacks**

While the NC EPD process and Boeing Production System explicitly calls out for face-to-face meetings when possible to discuss routebacks and how to avoid the issue, no such meeting was witnessed during the course of the project. Because routebacks are not tracked for the CA EPD process, no attempts to mitigate these routebacks with face-to-face meetings were pursued as well.

2) **Record and standardize text for cause of routeback**

In the Velocity system, there exists a text box for giving the reason for a routeback. While this data was not available for the CA EPD process, it could be retrieved for the NC EPD process. For all routebacks, 23% did not have a recorded reason. Additionally, many requests simply stated “By request” or “By request of manager.” Outlining reasons for routebacks with standard text, such as “no photographic evidenced attached” will make tracking down root causes possible.

3) **Use of text generator to collect and organization part and defect data**

The major reason CA EPDs are routed back to the Initiation is that the data included in the tag is incomplete or inadequate. An example is when the location or part number is absent from the report. A root cause of this issue is the data field is free text – that is there is no drop down boxes or guidance to include all necessary information. Experienced tag writers have templates, but for new issues or inexperienced employees these templates do not suffice. A standard text generator was created to solve this problem, yet is not implemented. Figure 22 shows an example interface that includes all necessary information.
This text generator can be compared directly to the open field section called out in the example EPD presented in Figure 5.

4) **Utilize standard tools to identify the source of the part in question and previous CA**

A significant portion of CA is initiated erroneously, or the part in question is attributed to wrong supplier. While this data exists within Boeing, not all work groups who are responsible for identifying and initiating CA have access to this information or tools to perform this analysis. By consolidating and training these teams, standardized and improved tools can be utilized to avoid these issues.
Many of the issues identified stem from a lack of standardization and accountability practices. Often, these matters are exacerbated when performing supplier related corrective action. Because of the unique supply chain and increased importance of supplier management during 787 final assembly, the relationship between corrective action practices and supplier management was investigated further.

8 Supplier Related Corrective Action Practices

In the 787 program, suppliers play a larger role in corrective action than any of Boeing’s legacy programs. In many cases, tier-1 suppliers own every aspect of the design and manufacturing of an assembly. When a defect or other non-conforming issue is found in final assembly, close coordination with these suppliers is required to reach adequate corrective action such that the defect is eradicated on all future builds. In Boeing’s CA Process, the Quality Assurance Investigations (QAI) function is a main link between final assembly operations and assigning corrective action to the responsible supplier. When a CA EPD has been initiated and it is believed to be a supplier related non-conformance or supplier aid is needed in achieving corrective action, the CA EPD is routed to a QAI investigator, where the CA EPD and CA Plan is then coordinated with the supplier.

In order to investigate approaches to improve the supplier related corrective action process, both QAI management and investigators were shadowed and interviewed. Information about tools, work methods, and processes were collected. This portion of the CA process information flow is represented and described in Figure 23.
8.1 Supplier Related Corrective Action Accountability and Visibility

Shadowing QAI revealed that one of the impediments to performing swift and effective corrective action was a lack of supplier accountability. Two main problems regarding supplier accountability were identified:

1) Delinquent responses from suppliers to corrective action requests.
2) Denial of responsibility, even when evidence was thought to be conclusive that the identified supplier was responsible.

When first investigating these issues, however, there was no formal method implemented to track either issue within the QAI group.

8.1.1 Delinquent Supplier Responses

Business process documentation states that responses from suppliers are required in a certain amount of time depending on the level of severity of the underlying non-conformance.

Table 3: Supplier corrective action levels and required response times

<table>
<thead>
<tr>
<th>CA Level</th>
<th>Criteria</th>
<th>Required Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notice of nonconformance (NN)</td>
<td>Low cost or one off</td>
<td>None</td>
</tr>
<tr>
<td>Effectivity</td>
<td>Chronic condition, high-impact or cost</td>
<td>5 days</td>
</tr>
<tr>
<td>Direct Cause Corrective Action (DCCA)</td>
<td>Chronic condition, high-impact or cost</td>
<td>10 days</td>
</tr>
<tr>
<td>Root Cause Corrective Action (RCCA)</td>
<td>Chronic condition, high-impact, high-cost, safety issue</td>
<td>20 days</td>
</tr>
</tbody>
</table>

Using the table above, a chronic condition deemed to require RCCA would require a response from a supplier within 20 days. After 20 days, the response would be delinquent.

Another issue identified was the lack of accountability within the QAI group to track the CA EPDs that were initiated. Within the Velocity IT tool, team members who are working on specific EPDs are assigned responsibility. However, an analysis of uncompleted CA EPD data showed that 81%, of supplier related CA EPDs were not assigned to any QAI team member, as depicted in Figure 24 below.
Discussions with QAI group management exposed that team members were actively encouraged to remove their names from CA EPDs that were troublesome or past due. By removing themselves from the records, team members would be contacted less by other involved parties and could focus on working through new CA EPD records in their queue.

8.1.2 Supplier Denial of Responsibility

For corrective action above the notice of non-conformance (NN) magnitude, a supplier that has been assigned responsibility for corrective action is required to respond with a corrective action plan and a date when a solution is reached. In many, cases, however, the supplier responds by denying responsibility for the defect completely. Observed reasons given by suppliers for denying responsibility include:

- The part in question is not the provided by the supplier.
- The design for the affected part or assembly has already been changed.
- The evidence provided is not conclusive to implicate the assigned supplier. In some cases, no evidence was furnished at all.
Claiming the non-conformance was caused by Boeing. An example would be damage caused by previous stage of final assembly before the non-conformance was discovered.

In order to assess the effect of denial of responsibility on the timeliness of corrective action, one CA EPD record from a prominent tier-1 supplier was followed during the course of the project. The timeline, action taken, and updated status is presented Table 4.

<table>
<thead>
<tr>
<th>Day</th>
<th>Action</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Effectivity CA assigned to supplier</td>
<td>Response due day 5</td>
</tr>
<tr>
<td>25</td>
<td>Supplier responds denying responsibility</td>
<td>Late 20 days</td>
</tr>
<tr>
<td>27</td>
<td>More evidence sent to supplier</td>
<td>Response due day 32</td>
</tr>
<tr>
<td>28</td>
<td>Supplier responds denying responsibility</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>More evidence sent to supplier</td>
<td>Response due day 34</td>
</tr>
<tr>
<td>30</td>
<td>Supplier responds denying responsibility</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Supplier's response implicates supplier</td>
<td>Response due day 36</td>
</tr>
<tr>
<td>42</td>
<td>Supplier responds denying responsibility</td>
<td>Late 8 days</td>
</tr>
<tr>
<td>74</td>
<td>Supplier accepts responsibility and gives fix date</td>
<td>Late 43 days</td>
</tr>
</tbody>
</table>

In the table above, the day count starts after the supplier was notified of the required corrective action, and the red cells show the denial of responsibility. In this particular case, the supplier denied responsibility for the non-conforming issue on four occasions. Further, the response was late on three of the four responses. In total, it took 74 days to for the supplier to accept responsibility and provide a corrective action plan.

8.2 Supplier Corrective Action Prioritization

Prioritization and classification of supplier related corrective action takes two forms: 1) the magnitude levels (NN, Effectivity, DCCA, and RCCA), and 2) a CA EPDs that have been flagged as important by management. Investigators have general guidelines in order to determine
the magnitude level of corrective action requests as outlined in Table 3, however no formal tool
beyond historical non-conformance records exists to aid with the magnitude selection.

Interviews with investigators revealed that pressure to shorten the amount of time each
corrective action request led to fewer applications of the RCCA magnitude CA requests. Further,
workers expressed confusion over the differences between RCCA and DCCA requests beyond
the amount of time suppliers had to respond. In order to quantify this effect, data was collected
on trend of supplier related corrective action magnitude designation, which is presented in Figure
25.

![Supplier Related CA EPD Magnitude Trend](image)

**Figure 25: Trend of supplier related corrective action magnitude designation**

The data supported the qualitative evidence that fewer RCCA magnitude correction
action requests were initiated. In a six month period, RCCAs fell from 20% of all supplier
related corrective action to less than 5%.
8.3 Discussion and Countermeasures

An analysis of issues negatively effecting supplier related corrective action reveals similar issues discussed in previous sections: rework cycles, accountability problems, process ambiguity, and non-standardized tools and work methods. The consequences of these problems are amplified due to the added complexity of communication and coordination with suppliers outside the company, and in many cases across the world. The evidence presented in Table 4 provides a concrete example of this amplification with a 74 day process of reassigning blame and dealing with delinquent responses.

Many of the countermeasures developed to address these in previous sections apply directly to supplier related corrective action. Standardization tools and automated text generation for recording data on non-conformances will help reduce the number of errors in records, which will in turn drive down the denial of responsibility from suppliers due to clerical errors. Moreover, investigators can avoid regenerating data and evidence if data collection is standardized in the Initiation stage of corrective action process. The following countermeasures have been developed specifically for the Quality Assurance Investigation group in order to facilitate improved supplier related corrective action:

1) **Develop standard tools and training to appropriately set corrective action magnitude level and prioritization.**

The four levels of magnitude for supplier related corrective action are set based on the underlying non-conformance’s cost, recurrence, and size of assembly. Business process documentation and training documents do not go deeper into defining these thresholds however. Retrieving this information is difficult, and often done ad-hoc or to satisfy management requirement. QAI team members should have set tools that define these
thresholds by integrating and synthesizing information about each element from various databases and work groups:

- Velocity: recurrence from number of underlying non-conformances
- Cost of rework algorithm: cost of non-conformance per line
- Engineering databases: Number of interdependent parts

2) **Internal accountability to drive response rates**

By keeping QAI members assigned to specific CA EPD records, individuals can be held accountable to work with suppliers and supplier management to ensure cooperation and timely responses. If more information is surfaced about a specific record, all parties will know which team member to contact to update information and facilitate communication.

3) **Delinquent response tracking and visibility tools**

Inevitably, some fraction of suppliers will be late in responding to corrective requests and developing mitigation plans. Internally, tracking these delinquencies will help the team identify which individual requests need action and how long the delay has occurred. A simple tool showing the number of responses that delinquent and how long can show the health of this stage of the supplier related CA EPD process. An example of a visual tool is shown in Figure 26.

![Age of EPD in Supplier Queue](image)

**Figure 26: Example delinquent response tracking tool**
The accountable QAI member will be responsible for initiating standard actions for delinquent EPDs they are responsible. By tracking and displaying this information, CA EPDs that are extremely delayed due to issues with communication or lack of accountability will be escalated in importance. Additionally, this information can be collected and processed to measure supplier responsiveness and ability to perform corrective action.

4) **A standard escalation process to address delinquent responses**

When a response is delinquent, there is currently no standard process in practice or documentation to notify or punish the supplier, or raise awareness internally. A standardized and documented escalation process should be put in place to drive action by suppliers. For example, EPDs in different zones of the Figure 26 initiate escalating events:

- **Yellow:** Notice of delinquency and involvement of supplier management
- **Orange:** Involvement of senior management in quality and supplier management
- **Red:** Delay penalties for the supplier

This levels and the appropriate response will require collaboration from the various stakeholders, including QAI management, supplier management, manufacturing, and supplier representatives.

9 **Conclusions and Management Considerations**

The final chapter in this thesis summarizes key learnings and recommendations put forward in order to improve the Boeing 787 corrective action process. Given the context outlined in Chapter 2, Boeing faces immense pressure to produce Dreamliners at an accelerated rate in order to meet the unprecedented backlog. Additionally, in-service issues and additional scrutiny from customers elevates the imperative for quality. Chapter 3 summarized the current state of
rework and defect reduction, pointing out while the quality of the final product is acceptable, the amount of rework occurring on each new plane is not decreasing. Chapter 4 outlined the current corrective action process as a method to increase first pass quality, increase production rate, and reduce cost by reducing rework in final assembly. Chapters 5 through 8 provided a description, characterization, and analysis of specific features of the as-is corrective action process and provided actionable recommendations to reach an improved future state process.

9.1 Summary of Actionable Recommendations

Analysis of the Pick-up process and its disconnect from corrective action (Chapter 5), process complexity (Chapter 6), rework within the corrective action process (Chapter 7), and supplier related corrective action (Chapter 8) led to number of recommendations:

- The data and information about non-conforming defects resolved through the Pick-up process should be incorporated into deciding whether corrective action is needed. In order for this to be achieved, the quality of the data collected during Pick-ups should be improved, standardized, and made available to parties who analyze non-conformance trends and initiate corrective action including supplier management.

- The complexity and ambiguity of the corrective action process should be reduced. This is especially important for the initiation of corrective action and can be accomplished by reducing the number of responsible parties. It is recommended that three groups should be responsible for initiating correction action: QAI, ME, and LE. Additionally, it should be made clear and consistent in all process documentation as well as Boeing Production System literature which parties are responsible for which stage of corrective action.

- Rework and routebacks within the corrective action process should be tracked and reduced in order to increase the speed in which corrective action is performed.
initiating a routeback, if possible, face-to-face meetings should occur to clarify the cause. This cause should be noted on 100% of CA EPDs within Velocity. Standardized tools such as automated text generators and database look-ups should be used to ensure the data relating to the underlying non-conformance is complete and accurate.

- To increase the speed in which supplier related corrective action is performed, accountability for CA EPD records requiring supplier coordination and communication should be increased. Tools to track assigned QAI member, the delinquent responses from suppliers, and denials of responsibly should be adopted. A standard escalation process involving management and penalties relating to late responses will drive action from suppliers.

9.2 Management Practices and Considerations

Many levels of management across the organization will be required in order to implement improvement programs to the corrective action process. As described in Chapter 6, the end-to-end process is expansive and includes disparate groups ranging from multiple engineering departments, Quality, Manufacturing, and internal and external suppliers. To address these issues, the effects of siloization, the “capability trap”, and management continuity should be considered.

9.2.1 Siloization

A key feature of a high performing organization’s structure is functional integration. Focus should be put on both building deep competency in various functions while still being concerned with the way the individual functions contribute to a process of which they are part (Spear, 2009). Because the corrective action process integrates and involves many functions, this
functional integration and high-level process thinking is paramount towards substantial, long-term improvements.

The negative effects of “silozation”, the optimization of a particular function without regarding interrelated functions, has been touched on in various sections of this thesis. Metrics such as Jobs Behind Schedule may benefit the rate at which defects are resolved in manufacturing, but inhibit initiating corrective action and finding a long term solution to the underlying cause. Quality Investigators are rewarded for churning through CA EPDs in their queue, but in order to do so lose accountability for previous records, accept supplier denial of responsibility without justification, and leave delinquent records in supplier queues without action. These types of silozation issues are harmful towards implementing corrective action improvements. A holistic, process-thinking approach will enable the recommendations put forth in this thesis and future continuous improvements.

9.2.2 The Capability Trap

Another important organizational concept is applying a systems thinking framework to decision-making about corrective action improvements. An example of this approach is taking a longer timeline view of certain projects, and realizing improvements in total cost and productivity will come in the long term. Sterman and Repenning put forward a cautionary tale of companies missing positive projects due to a capability trap (Repenning & Sterman, 2002). In essence, managers cut proactive activity to meet immediate goals, which have long term negative impacts on the organization. A better approach would be to make investments that may have initial costs in the short-term, but have a net positive impact overall.

This concept is applicable to investments in the corrective action process, and can be illustrated using cases discussed in this thesis. Consider total resources spent towards rework as
both the resources spent doing the defect resolution in the PU EPD and NC EPD processes (reactive) and the resources spent collecting data, initiating corrective action, and processing CA EPDs within the QAI group (proactive). In order to improve corrective action, more time will spent performing the proactive work. This will initially increase the total amount of resources spent towards rework. Over time – in the case of corrective action the process varies between days and years depending on the complexity of the solution – the amount of proactive and reactive rework will decrease as fewer non-conformances flow into final assemble. This phenomenon is depicted graphically in Figure 27. It should be noted this graph is presented as a thought exercise and is not based on data collected during the project.

9.2.3 Management Continuity

The size and structure of Boeing lends to a workplace that offers many management positions and opportunities for reassignment. The mobility to manage different groups across the enterprise is an attractive feature for promising managers who wish to learn new skills and
familiarize themselves with a greater portion of the organization. A side effect of this mobility is often short-term management stints or rapid departure from a position without proper preparation or a vetted replacement. For example, during the course of the seven month project, the Quality Assurance Investigation group had three different managers. The group was well trained and business processes are in place to sustain an adequate level of performance.

An obscured negative effect, however, was the lack of transfer of ongoing improvement projects and continued learning from previous audits. While limiting the ability of managers to transfer may not be the solution, a well-formed succession plan where the new manager is selected, trained, and shadows the out-going manager is strongly recommended and was not observed during the project. Given the long term investment required as outlined in the capability trap discussion, managers whose tenure occurs during the initial phases of an improvement project may see declining siloed metrics and be reluctant to sustain those improvement efforts.

9.3 Next Steps and Future Considerations

The scope of the project was sufficiently large and the impacts of improvement may not be bared until many months after improvement efforts. The argument to improve the corrective action process is clear – resources dedicated towards rework must be reduced to meet production rate and cost goals. Each of the outlined recommendations may be the subject of an entire internship in its own right. One of the greatest lessons learned from this project is that a team of cross-functional individuals with sustained support from management will be required for long term improvement.

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