A Systems Approach to Procurement of Automated Technology

By

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Submitted to the MIT Sloan School of Management and the Engineering Systems Division in partial fulfillment of the requirements for the degrees of

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and
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ABSTRACT

Company A's Product Group B (PGB) is developing an automated system to complete final assembly of the Component, a structural member of the product that includes technology supporting two features of the product's competitive advantage. PGB contracted with an industry partner to supply the automated assembly system, which will be built and tested in 2015. Amid the wide spread perception that automation projects purchased from suppliers include schedule delays and performance deficiencies, PGB must specify the activities to verify automated assembly system performance prior to purchasing it from the Supplier.

Interviews with project teams were completed to gather data about the procurement of existing automated systems at Company A. A range of success in completing project buyoff on time with no deficiencies was found with variation in buyoff results mainly associated with the presence or lack of fully-defined requirements and detailed procedures to verify and validate the system according to the requirements. The findings led to the hypothesis that automation system buyoff can be improved by applying an approach that includes development of good requirements, planning detailed procedures to verify and validate the system according to the requirements, and tracking progress towards meeting requirements to a schedule.

To test the hypothesis, an approach to buyoff plan development and execution incorporating these factors was defined and then evaluated using a model. Buyoff of the automated assembly system will occur in 2015 according to the approach defined in this research. Results should be evaluated to validate the hypothesis and provide evidence for further buyoff plan improvement.

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Chapter 1

Introduction

This Chapter is an overview of this research including the research motivations, problem, question, methods, results and conclusion. Section 1.6 includes a map of the thesis content to the structure of this document.

1.1 Motivation

Since 2007, demand for the Product makes up 75% of gross Company A[1] orders, outselling a similar well-known Product by over ten times. Due to increasing demand and competition, Company A plans to increase the production rate to an unprecedented level with the introduction of the Product.

The Component is a critical part of the Product's competitive advantage, since it significantly impacts two key performance characteristics of the Product. Given its importance to the competitive edge of the Product, Company A decided to design and assemble the Component for the Product internally, departing from recent programs that awarded the Component work to partners.

Company A's own Product Group B (PGB) is responsible for the design and assembly of the Component. PGB is therefore faced with the compounding challenge of designing the Component, designing a new production system, and operating that system, to meet unprecedented production rates. To help meet the goals of delivery speed, product quality, and workplace safety, PGB has planned for automated assembly of the Component.

The automated assembly system includes part transfer and mating as well as drilling, sealing and fastening operations. The Component team contracted with an automated systems integration partner to develop this automated assembly system. Phase 1 of the system has completed preliminary and critical design reviews and will be built and tested in 2015. Phase 2 will add capacity to the Phase 1 system prior to 2018 production rate increases.

[1] All company names have been disguised to avoid disclosing proprietary information

Since automated assembly is a new process for Company A, and it is being introduced to support a new product which is to be a source of competitive advantage, it is critical that the PGB team is confident that the system meets customer and operational requirements when it is bought-off from the Supplier. With system build and integration scheduled for 2015, PGB has significant motivation to develop a detailed buyoff plan to prescribe the activities required to verify and validate performance of the system.

1.2 Problem Statements

Past automation projects at Company A have had a range of success and failure in buyoff completion timing and system performance in terms of quality, functionality and usability requirements. The primary cause of this variation is a lack of a detailed buyoff plan according to well-developed system requirements. The PGB team is faced with developing a detailed buyoff plan in approximately four months.

At a meeting related to automated assembly system development status, leaders from throughout Company A reported stories of other automation projects being bought off from suppliers with performance deficiencies or behind schedule. They told of projects that had been bought off with less performance capability than planned, projects that had overrun development and testing schedules by months, projects that resulted in a contentious and unproductive relationship with the supplier, and projects that perform under the anticipated rate capability, resulting further investment in duplicating the technology. There is a wide spread perception that automation projects are bought off with delay and performance deficiencies.

The stories didn't make clear exactly why these faults were occurring or whether they'd been reconciled. Leaders admitted to the possibility of a negative perception of automation projects resulting from false expectations and political or cultural factors. Interviews with Company A teammates involved in other automation projects showed that there are in fact projects bought from a supplier with schedule delays and performance deficiencies. Teams involved in automation buyoff didn't use a consistent approach to buyoff plan development and execution and achieved variable buyoff results, including schedule delays and performance deficiencies. For example, some teams based procurement on a purchase specification document and others created a separate verification plan. Teams used varying levels of planning and documentation of acceptance testing.

At the start of the automated assembly system project, PGB team included an outlined vision of how acceptance testing and equipment buyoff would go in the supplier's purchase specification. The contract directs testing to be completed in two acceptance testing periods prior to buyoff of the system from the Supplier and one acceptance testing period throughout production start-up. There were few details of what testing would be done, what parts or materials would be needed, or what staff would be involved in the activities leading to equipment buyoff. In several instances, the specification included a note saying that specific requirements would be clarified when developing the acceptance testing plan.

Given the open-ended character of the contract, it was often unclear to Supplier and Company A team members what performance standards the supplier must meet to succeed in system development. Equally important, the Company A team couldn't articulate how they would know the automated assembly system meets customer and operational requirements prior to purchasing the system from the supplier. The automation manager for the Component team expressed the situation succinctly at a project meeting occurring approximately four months prior to beginning of build and integration of the system and the completion of this research, "We don't have a buyoff plan for this system."

Since the team planned to use the equipment purchase specification as the basis of requirements for project quality, functionality and usability, the PGB team may be susceptible to the same variable buyoff results as were past project teams.

1.3 Project Questions

Given the problem outlined above, the objective of this research is to answer the following related questions. The problems and questions are shown below in the order they are analyzed in this study.

1. Why is there a perception that projects are bought off with schedule delays and performance deficiencies?
2. What can be done to ensure the PGB automated assembly project is purchased on-time with zero performance deficiencies?
3. Can the PGB team develop a buyoff plan according to the methodology in four months?

1.4 Project Methods

This thesis is the culmination of work completed between the months of June 2014 and December 2014 at Company A's Product Group B (PGB) in the United States. The project was in partnership with the Massachusetts Institute of Technology Leaders for Global Operations (LGO) program.

Over fifty hours of interviews with Company A employees involved in automation system procurement and observation of automation system acceptance testing form the basis of the research. Interview data was used to assess the causes of success and failure in automation system buyoff. Two hypotheses were formed based linking causes to performance.

Based on the hypotheses, systems theory and lessons learned captured from interview data were used to develop an approach to buyoff plan development and execution. Throughout, the term "systems theory" will be used. It is short hand for conveying the following points: consideration of customer and operational requirements, stakeholders and requirements verification throughout the system design and implementation lifecycle. The approach was applied at PGB by assembling a team of buyoff plan stakeholders and driving collaborative buyoff plan development. Buyoff plan development includes defining the activities necessary to verify the production system meets customer and operational requirements and a schedule for verification.

Although buyoff plan development was nearly completed in the time frame of this research, buyoff plan execution, following the defined verification activities and schedule, will occur over the course of the next year. Therefore, the hypotheses were tested by applying the buyoff plan approach to a model of acceptance testing behavior and comparing the resulting outcomes to outcomes observed at acceptance testing of a similar project.

1.5 Project Results & Conclusions

The results did not refute the hypotheses because significant differences in outcomes impacting acceptance testing schedule and system performance were shown between the constructed buyoff plan and the baseline acceptance testing period. The results lead to a hypothesis about what contributes to or detracts from successful buyoff and show that Company A has potential to improve complex system of automated technologies. Completion of the Component automated assembly system buyoff according to the constructed buyoff plan will occur over the course of

2015, so it is a chance to test those hypotheses, validate these conclusions, and provide evidence for further buyoff plan improvement.

Three key themes emerged in every component of this research: interviewing, literature review, creating an approach to buyoff plan development, testing that approach and developing the buyoff plan with stakeholders. First was time management challenges stemming from a view of requirements management and verification planning as not necessary, but an add-on to procurement. Second is that late-start of requirements-based thinking and verification planning has a negative impact on later phases of project development, including system integration and verification. Finally, the lack of verification planning in early project decision-making had a major impact on the balance between testing cost and realism, which strongly impacts the confidence of the team in system functionality.

1.6 Thesis Organization

This thesis is organized in seven chapters as outlined in Table 1-1, including relevant objective questions.

Table 1-1 Thesis Organization by Chapter

Chapter	Title	Description
1	Introduction	Describes the major motivation and goals of the thesis, including a problem statement and hypothesis in three parts.
2	Background	Illuminates the business environment in which the research was conducted and key academic frameworks considered.
3	Automation Project Buyoff	Why is there a perception that projects are bought off with schedule delays and performance deficiencies?
4	An Approach to Buyoff Development and Execution	What can be done to ensure the PGB automated assembly project is purchased on-time with zero performance deficiencies?
5	PGB Buyoff Plan Development	Can the PGB team develop a buyoff plan according to the methodology in four months?
6	Results	Recap of results and discussion of overall emergent themes of the research.
7	Conclusions	Overall conclusions of the research and motivation for further studies.

Chapter 2

Background

This project was completed at Company A's Product Group B (PGB) with the Component team. The focus was automation procurement, including system verification and buyoff from a supplier. Background information on these important project components is included in this Chapter.

2.1 Company A

Company A is a leading manufacturer in its sector. Company A designs, manufactures, services and supports these the primary Products as well as several related products.

2.2 Product Group B

Company A provides the Product and related services to customers. For past programs, Company A purchased many components from suppliers, including the Component and related systems. More recently, the Component and other product parts were viewed as a potential source of competitive advantage, so expertise in design and manufacturing should be brought back in-house. The first of these parts to be assembled by Company A is the Component, making it the first practical test of this new strategy of insourcing versus subcontracting design and production. Product Group B (PGB) was founded specifically to support this initiative and similar for other Product families.

Due to continuing increase in statement of work and approaching opening of the Component factory, PGB is a rapidly growing and changing organization. Over the course of this research, PGB grew from approximately 50 people to over 100 people and successfully met major design and development milestones for the Component. For example, PGB delivered the first complete Component unit to the product testing facility. During this time, PGB also moved into a new factory built for Component production, accelerating the transition from a design organization to a design and manufacturing organization.

2.3 PGB Component Manufacturing Automation

This research was completed with the support of the Component integrated product team which is currently the largest team within PGB and is leading the development of the new factory. Assembly of the Component at PGB will have an unprecedented level of automation in an assembly process for Company A. It was decided to automate assembly of the Component in order to achieve maximum consistency in product quality at high production rates and to reduce the ergonomic challenges of manual drilling and fastening the cylindrical structure.

The Component team has contracted with the Supplier, to design and integrate the automated assembly process. The automated assembly system includes part transfer and mating as well as drilling, sealing and fastening operations.

Based on the enterprise Product delivery schedule, the automated system is scheduled to make production units at a low rate for approximately one year, prior to a steep rate increase over the course of three years. The manual assembly system used to build Component units used for Product development program testing will be used for production prior to automation system start-up. The manual system will be capable of running in parallel with the automated system in the future.

2.4 Automation Procurement & Buyoff at Company A

Critical to the role of the Component team is procurement of the automated assembly system from the supplier. This section outlines the early phases of procurement to provide background for the development of a buyoff plan, the final phase of equipment procurement.

More than a year prior to this research, equipment procurement began with a Request for Information (RFI) from several automation design and integrators. A Request for Proposal (RFP) was issued to three of the RFI respondents along with funding for initial concept development work. The RFP included a purchase-specification defining equipment and performance requirements and a schedule. Following a selection process including many voting stakeholders, a weighted ranking system, and two in-depth interviews for each firm, the Supplier was selected for the work based on evidence that they had successfully completed similar work and could provide an advantage through experience.

Once agreements were in place between PGB and the Supplier, automated assembly system design development proceeded based on the purchase specification and a design development process common to Company A including an initial design review, comprehensive design review, and final design review. Concurrent with this process, engineering design of the Component was completed.

Purchase of the automated assembly system from the Supplier occurs following full design, physical integration of the system and verification that the system meets customer and operational requirements. A Buyoff Plan directs the activities to be completed to verify system performance. According to the PGB-Supplier contract, performance verification includes two main testing periods: Factory Acceptance Testing (FAT) at the Supplier site, and Site Acceptance Testing (SAT) at PGB. Following successful completion of the buyoff plan activities prior to and during the acceptance testing periods, the system will be purchased and put into production. One further acceptance testing period will occur during the production phase, Rate and Quality Acceptance Testing.

2.5 Systems Engineering Approach to Buyoff

The term "systems engineering approach" is used throughout the thesis. As systems engineering is a very broad topic, the use of the term with respect to buyoff is defined further for the purpose of this thesis.

At a high level, the International Council on Systems Engineering (INCOSE) defines systems engineer as, "an interdisciplinary approach and means to enable the realization of successful systems" (1). The main concern with buyoff is to understand whether the system is successful. INCOSE further specifies that the focus of the approach is "on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem" (1). Similarly, Company A teammates that claimed to apply a systems engineering approach described is as using a structured approach to panning, execution and documentation of system verification. This approach included formulating system requirements and maintaining traceability from verification activities to the driving requirements.

In the context of PGB and automation procurement, the approach includes using the tools in **Table 2-1** for the purpose also listed in the table.

Table 2-1 Systems Engineering Tools and the Research

Systems Engineering Tool	**Purpose in this Research**
System development life cycle	Ground the research and buyoff in the context of the larger production system development effort. Guide the development of the buyoff plan according to "customer needs and required functionality" (1)
"V" Diagram	View the system life cycle with an emphasis on requirements, verification and validation to demonstrate the role of requirements and a buyoff plan
Verification Plan	A component of the buyoff plan that defines the activities required for system verification in a uniform format with traceability to requirements

2.5.1 System Life Cycle

System life cycle is "commonly used to refer to the stepwise evolution of a new system from concept through development and on to production, operation, and ultimate disposal" (2). The purpose of each life cycle phase is summarized in **Table 2-2** shows the life cycle phases graphically. Arrows indicate the start and stop of this research and the completion of buyoff with respect to the PGB automated assembly system life cycle.

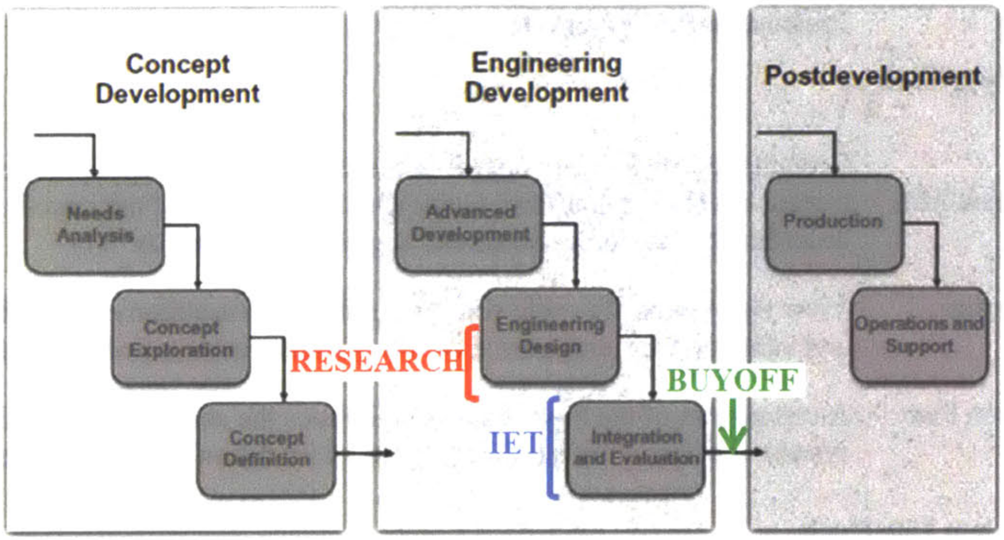
Table 2-2 Life Cycle Phases with Purpose

Life Cycle Phase	**Purpose** (2)
Concept Development	Establish that there is a valid need for a new system, explore potential concepts, formulate a set of performance requirements and develop new technology.
Engineering Development	Design and build a system to meet operational, cost and schedule requirements.
Post development phase	Deployment, operation, and support of the system meeting customer requirements.

Figure 2-1 shows the engineering development phase broken into three major stages, including the integration, evaluation and test stage (IET). In this phase, the system design is built into a physical system. It is then verified that the system meets the requirements developed in the

system concept and refined throughout the design. The PGB automated assembly project is beginning this phase shortly after the conclusion of this research.

Figure 2-1 Major Life Cycle Phases and Research Period



2.5.2 "V" Diagram

As shown in **Table 2-2**, requirements drive every phase of the system life cycle. A common framework, the "V" diagram, highlights the importance of requirements. The "V" diagram is a "view of life cycle development with explicit relationships shown between requirements and systems definition and the developed and validated product" (2). Refer to **Figure 2-2**. Reading the "V" from top to bottom, the system is defined by increasing level of detail, from the system-level view to the component-level detailed design view. Reading the diagram from left to right, time and system maturity are increasing (3). The time period of this research, IET and buyoff are indicated on the figure.

2.5.3 Integration, evaluation and test phase

The integration, evaluation and test phase (IET) is shown on the right side of the "V" in **Figure 2-2**. The IET has the "objectives of assembling and integrating the engineered components of the new system into an effectively operating whole, and demonstrating that the system meets all of its operational requirements" (3). This phase is the transition to the production and deployment phase. *Systems Engineering Principles and Practices* describes the major activities within the scope of IET as shown in

Figure 2-2 Systems Engineering Life Cycle "V" Diagram (2)

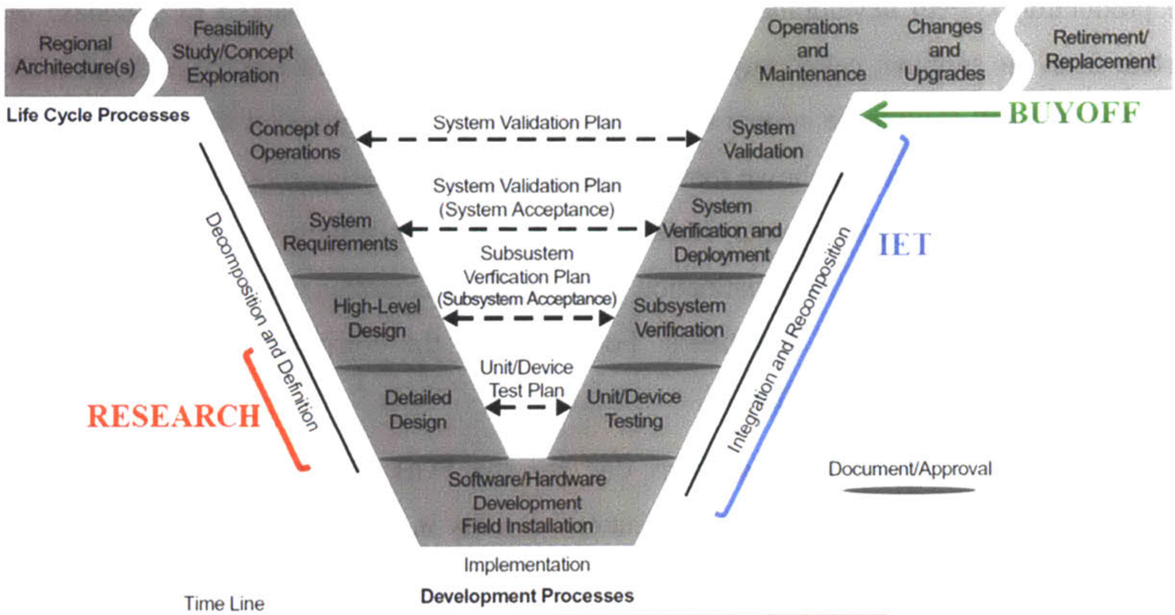


Table 2-3 Integration, test and evaluation phase activities (2)

Test Planning and Preparation. Typical activities include

- reviewing system requirements and defining detailed plans for integration and system testing, and
- defining the test requirements and functional architecture.

System Integration. Typical activities include

- integrating the tested components into subsystems and the subsystems into a total operational system by the sequential aggregation and testing of the constituent elements, and
- designing and building integration test equipment and facilities needed to support the system integration process and demonstrating end - to - end operation.

Developmental System Testing. Typical activities include

- performing system - level tests over the entire operating regime and comparing system performance with expectations,
- developing test scenarios exercising all system operating modes, and
- eliminating all performance deficiencies.

Operational Test and Evaluation. Typical activities include

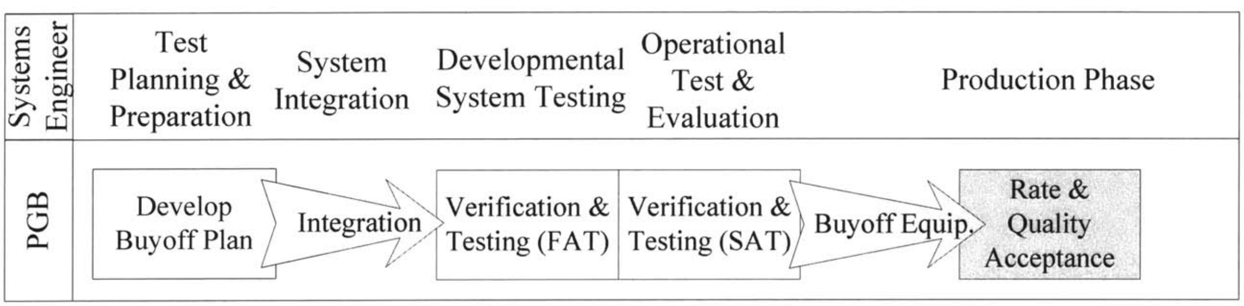
- performing tests of system performance in a fully realistic operational environment under the cognizance of an independent test agent and
- measuring degree of compliance with all operational requirements and evaluating the readiness of the system for full production and operational deployment.

2.5.4 Buyoff Plan

In the case of the PGB automated assembly system, Company A has contracted with a supplier for production system development and completion of the IET is marked by purchase of the system from the supplier, called buyoff at PGB. A buyoff plan in this context is the plan for the activities that will qualify the system to transition from the developmental life cycle phase to the production phase. It must be shown that the system meets the design requirements (verification) and that the design requirements were adequate for the system to operate successfully (validation). Although there is a distinction between these activities, they are jointly referred to as "verification" throughout this thesis. For example, the Verification Plan includes both verification and validation activities.

Development of a buyoff plan, such as one for the PGB automated assembly system, is analogous to the "Test planning and Preparation" activity in **Table 2-3**. **Figure 2-3** shows the PGB buyoff plan activities, including the FAT and SAT specified in the PGB-Supplier contract, as they relate to the typical IET activities described in

Figure 2-3 Company A Integration, test and evaluation phase activities



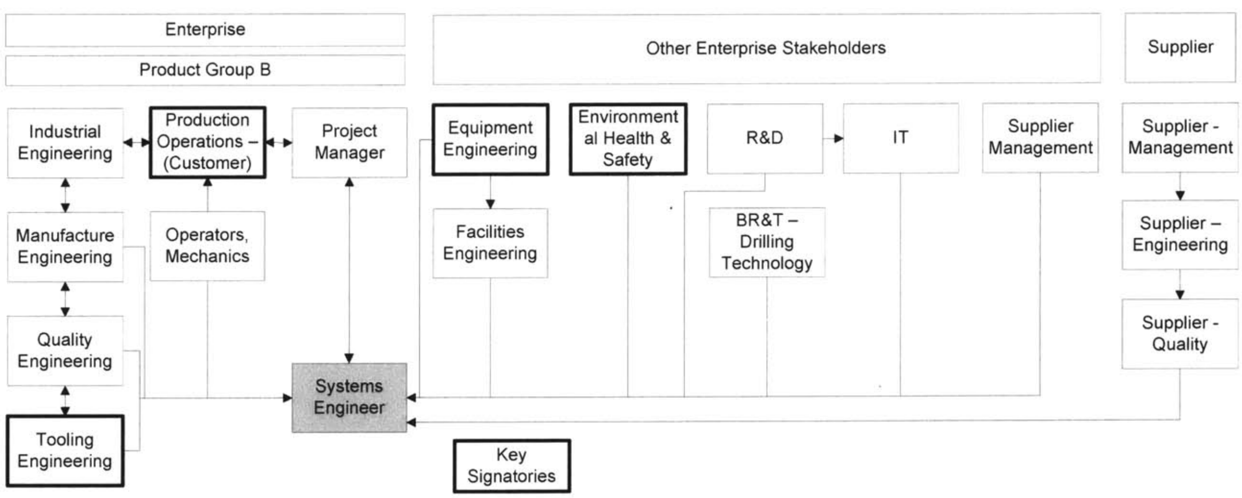
2.6 Key Buyoff Stakeholders

Many stakeholders are involved to some extent in the design and procurement of the manufacturing system. For this research, Stakeholder is defined as an individual who's documented approval is required prior to purchasing the manufacturing system as a production-ready system. Based on the existing Company A process for signing-off on equipment prior to use in production as well as the direction of PGB leaders, fourteen Company A stakeholders were identified.

Figure 2-4 shows a map of the stakeholders arranged vertically to reflect the management reporting structure. Arrows indicate common communication pathways among the stakeholders, which generally include the Systems Engineer as a communication "hub." The "Key Signatories" outlined in bold are the final three signatures and each requires the prior approval of other stakeholders.

System buyoff is primarily the responsibility of equipment engineers who were also integral to the automation supplier selection process. The equipment engineers are a part of the Site Services Group, which provides building, facilities and business services across all Company A organizations. Other stakeholders are involved because they have subject matter expertise, provide an interface to the product or building design or are the customer.

Figure 2-4 Stakeholder Map



Chapter 3

Automation Project Buyoff

In response to stories shared by Company A teammates about other automation projects that face major challenges throughout integration, evaluation and testing, this chapter includes an analysis of several key automation projects at Company A. Interviews showed that while one project was delivered on time with no deficiencies, other projects have been delivered late and with performance deficiencies. The range of results was associated with a range of approaches to planning and execution of automation buyoff, including differing requirements development, documentation and stakeholder involvement. Application of a systems engineering approach and inclusion of lessons learned from previous projects were cited as key success factors by participants from successful buyoff teams. In contrast, projects bought off with delays and performance deficiencies suffered from poor quality requirements and related communication disconnects. According to the data, a systems engineering approach includes: beginning with developing good requirements, planning detailed procedures to verify and validate the system according to the requirements, and tracking progress to a schedule.

3.1 Question: Why is there a perception that projects are bought off with schedule delays and performance deficiencies?

In this chapter, the question of why is there a perception that projects are bought off with schedule delays and performance deficiencies is answered in two parts. First, are projects bought off with schedule delays and performance deficiencies? Second, what factors influence the success and failure of automation project buyoff?

3.2 Methodology

To utilize the rich knowledge base at Company A, staff from several automation projects throughout Company A were interviewed over the course of the project. Each interview covered several issues:

- how the project technology was developed
- the role of suppliers

- acceptance-testing period
- buyoff results
- lessons learned from automated equipment buyoff

Interview participants had a range of involvement with project buyoff. Participants were equipment engineers responsible for procurement, research and technology engineers involved in technology development, manufacturing and industrial engineers, project managers and executive sponsors. Due to the diverse nature of automation application cases and differing timing, teammates of varying roles were interviewed for each project as available and project contributor overlap was rare. Key data from the projects evaluated was compared to determine whether there were wide-spread schedule delays and performance deficiencies at project buyoff.

3.3 Data: Cross-section of interviews

Five similar projects were included in over twenty interviews. These projects all included significant developmental technology or process, similar to the PGB automated assembly system. Each of them represents a new application of automation and robotics for Company A, including some industry-wide advances. **Error! Reference source not found.** shows project similarities for four key project development attributes.

Table 3-1 Automation Project Summary: Attributes

Project	**New application of automation**	**Supplier Partnership**	**Technology development – Company A or Supplier led**	**Verification Planning – Company A or Supplier led**
1.	X	X	Company A	Company A
2.		X	Supplier	Company A
3.	X	X	Supplier	Supplier
4.	X	X	Supplier	Company A
5.	X	X	Supplier	Company A
PGB Component	X	X	Supplier	Company A

Table 3-1 summarizes the key results of buyoff for each project, including the extent to which schedule and performance requirements were met.

There is significant evidence of schedule overruns and performance deficiencies at buyoff in this data. However, there are also two projects that had very minimal schedule delays and no unmet performance requirements.

3.4 Analysis: Success and Failure

This section explores the major drivers that the two successful projects credit for their positive outcomes as well as some of the common challenges cited among the projects.

3.4.1 Success Factors

The two projects that stood out as relatively successful in terms of acceptance testing schedule and performance credited two things to their success, the application of a "systems engineering approach" to acceptance test planning and documentation and being a fifth generation project of a single technology.

According to participants, Project-4, a small fixed infrastructure drill and fill technology, used a "systems engineering approach" to planning and executing acceptance testing. Interviews revealed that this meant the project team used a detailed and structured form of documentation to plan and record testing requirements, activities and results. This included application of a master schedule, progress tracking and a team wide understanding of challenges and risks to the project throughout the integration, evaluation and test phase. The team focused on starting to develop a buyoff plan by developing good requirements and utilizing requirements to drive activities throughout.

According to the project manager, the basis of the approach was to follow the Company A enterprise gated process normally used for product development in order to generate good requirements for the automated system. The team, guided by an experienced systems engineer, started with requirements according to the gated process and then developed a verification plan including all system verification procedures traced to the applicable system requirements in a uniform format. There was a master-list of tests, many with a corresponding tab to include detailed procedure notes as well as testing results data. By following this plan through acceptance testing, the team was confident that all performance requirements had been met prior to completing buyoff. Following the first round of acceptance testing, which occurred during this research, the team confirmed that there were no major performance deficiencies with the equipment. **Figure 3-1** highlights how the Project-4 team's methodology helped them complete buyoff with confidence on the "V" diagram.

Table 3-1 Automation Project Summary: Results

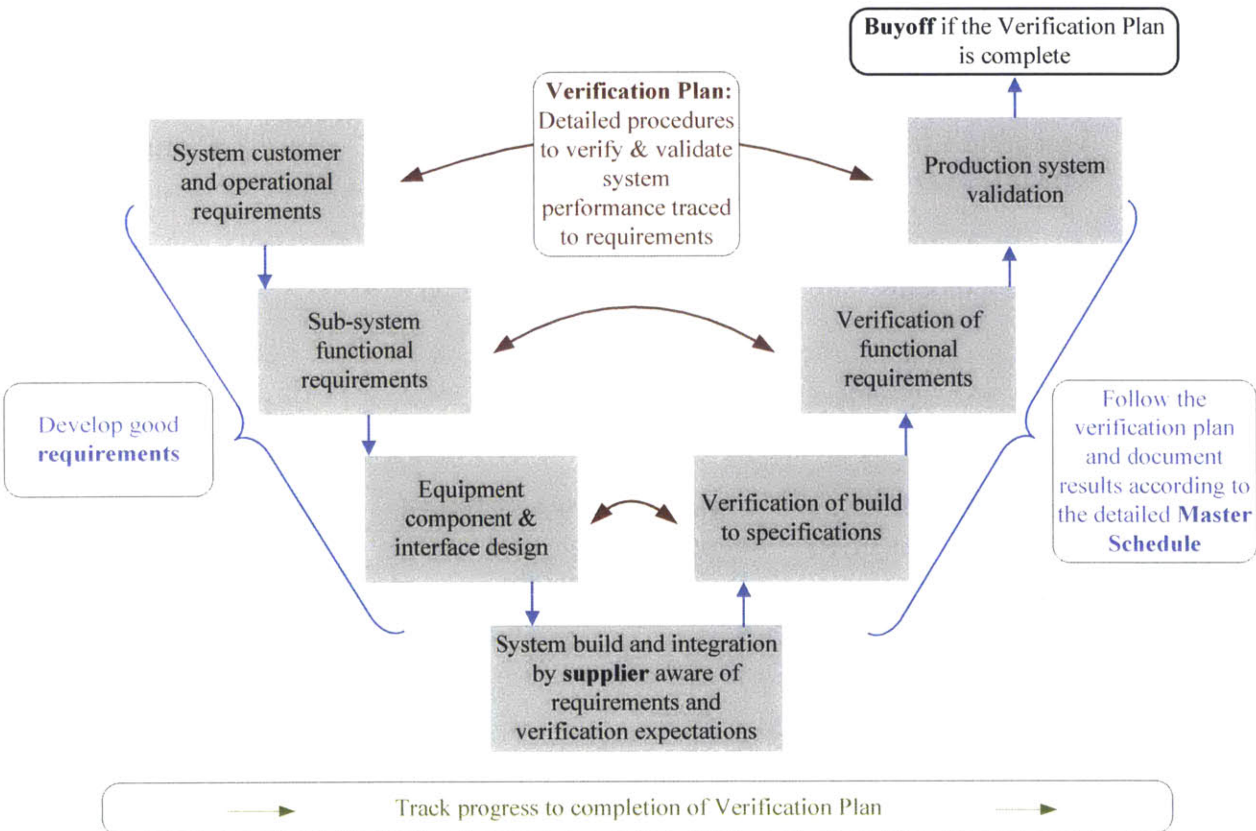
Project	Acceptance testing schedule over-run	Unmet performance requirements?	Comment
1.	Planned: 1 month Actual: 8 months	Rate performance, contouring capability is unused	Not in production
2.	Planned: 1 week Actual: 1 week with overtime	No	5th similar machine procured, systems engineering approach
3.	Planned: 2 weeks Actual: 2 weeks of 16 hour days	Rate performance, fastening performance, data transfer capability	In production, additional equipment procured
4.	Planned: 1 week Actual: 2 weeks	No	Systems engineering approach
5.	Not available	System is capable of fastening, but the process was never qualified completely	System drilling in production

The Project-4 team also based a master-schedule for the testing period off of the contents of the verification plan. The schedule included buffer time and a daily meeting to review progress and check that the team was ready to complete the tests for the next day. The team over-ran their planned schedule of one week by one week.

Another project that achieved successful schedule and performance outcomes from acceptance testing was project number two, a composite fiber placement machine. The team responsible for buyoff of this equipment used an approach to planning and executing testing, similar to described above. This project was also bought off with zero performance deficiencies.

This project also completed acceptance testing within the planned schedule. Reflecting on the process, a key team member noted that the scheduling success could be attributed to the fact that this was the fifth purchase of the same technology. Earlier equipment purchases had not gone as smoothly, but lessons learned were applied to each procurement moving forward.

Figure 3-1 Components of a Successful Approach



One of the key lessons learned was to dedicate sufficient resources to develop a realistic test-part that could serve as the vehicle for testing as opposed to testing requirements by simulation of real-part operations. The interviewee noted that the team had learned to dedicate approximately 10% of the cost of the project to design and manufacture the realistic test-part in order to test requirements in a true production setting. Since the project is an additive manufacturing process, the same test part could be used repeatedly throughout testing without diminishing realism.

3.4.2 Challenges

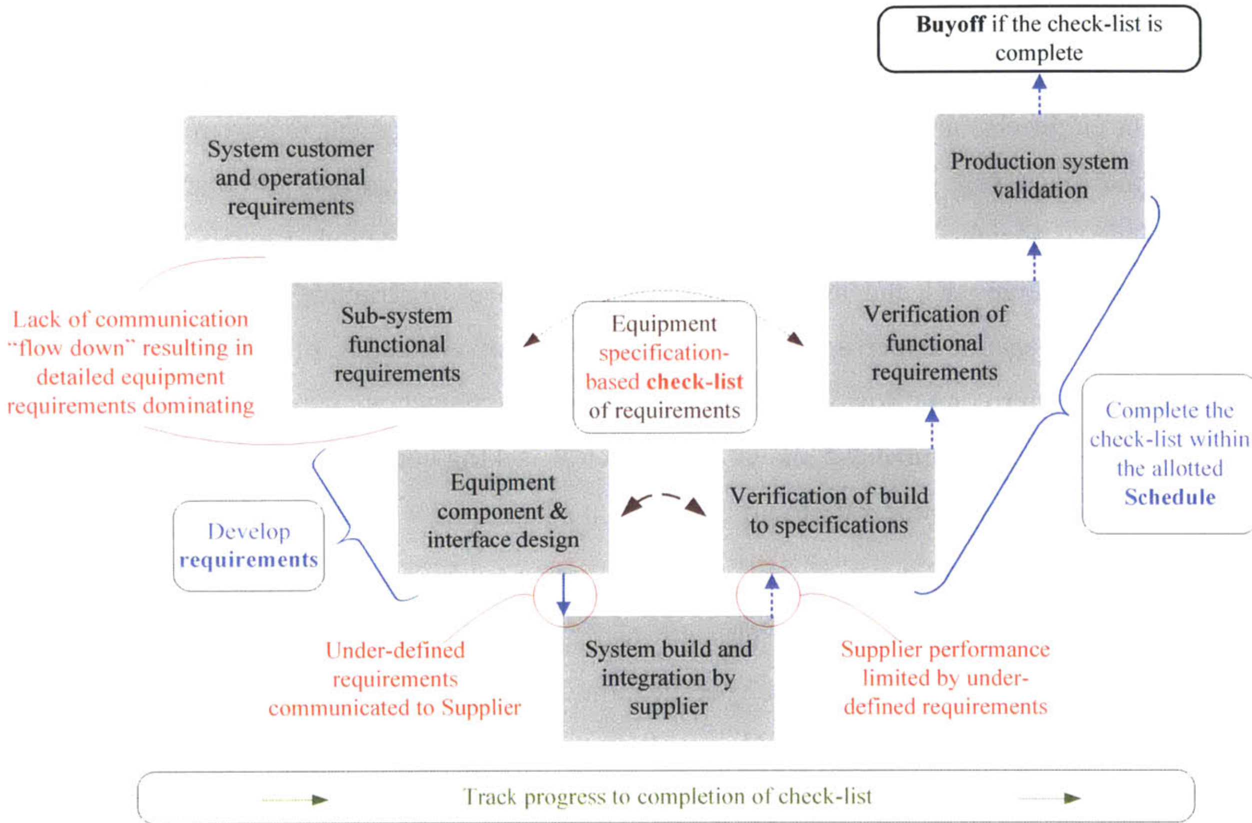
The projects that were bought off with significant schedule delays and performance deficiencies also showed some similarities. Interviewees were asked what the key challenges were and what lessons learned resulted from the projects. The responses were mostly related to challenges with quality requirements and multi-stakeholder communications.

In Project-1, lacking communication between internal stakeholders and poor quality requirements were highly related. The team described a lack of communication between research and development engineers, design engineers and equipment engineers. In the end, the equipment engineers ran procurement based heavily on the equipment requirements (verifying that the machines were built to specification). The team recognized that acceptance testing did not include sufficient verification of system performance to higher-level customer and operational requirements and attributed this problem to a "disconnect" among Company A engineers with separate expertise during requirements and verification plan development. They recommended improving "flow down" of requirements from each engineer involved throughout the project life cycle. **Figure 3-2** shows the impact of lacking communication and requirements "flow down" on the supplier and buyoff.

In the case of Project 3, there was also a relationship between the system requirements and a stakeholder disconnect; however, it was downstream in the process compared to the above example. The team used the purchase specification as a check-list, expecting to check off each line as the two suppliers demonstrated compliance. One of the main lessons learned from the interviewees was that, "based on the purchase spec, the requirements were not interpreted by the customer as we thought they would be." The recommendation from the team was to "define requirements with expectations and acceptable limits." They recognized that frustration related to under-defined requirements contributed to "non-collaborative" interfaces between Company A and suppliers, which hampered data sharing and problem resolution. **Figure 3-2** shows how a specification check-list type communication of system verification expectations (lacking detailed procedures and acceptance limits) only translates part of the information the team needs to complete a successful buyoff to the supplier.

These cases show that poor requirements (inappropriate, lacking or under-defined) can both result from and lead to deteriorated interfaces among stakeholders. It is clear to see that a disconnected internal requirements development process with little requirements "flow down" leading to inappropriate, lacking or under-defined requirements will impact Supplier performance and make complete verification and validation of the system impossible.

Figure 3-2 Requirements and Stakeholder Communication Challenges



3.5 Results & Conclusion

Although it was shown that there are schedule delays and performance deficiencies at automated production technology buyoff at Company A, there were also projects that had favorable buyoff results. The teams that had the best results at buyoff attributed their success to two main factors: (1) application of a systems engineering approach to acceptance test planning and buyoff, and (2) application of lessons learned from previous generations of technology buyoff. In this case, a systems engineering approach includes: beginning with developing good requirements, planning detailed procedures to verify and validate the system according to the requirements, and tracking progress to a schedule.

Conversely, the projects that had schedule delays and performance deficiencies demonstrated that poor communication during requirements development can cause poor requirements (inappropriate, lacking or under-defined) communicated to suppliers. With poor requirements and lack of a detailed verification plan, supplier actions and system performance differed from

Company A expectations. Overall, schedule delays and performance deficiencies at buyoff are attributed to (1) inappropriate, lacking or under-defined requirements, and (2) lack of detailed procedures to verify and validate system performance traced to requirements. **Table 3-2** compares the factors leading to success vs. failure.

These observations lead to a hypothesis that automation system buyoff can be improved by applying lessons learned from past projects as well as an approach that includes development of good requirements, planning detailed procedures to verify and validate the system according to the requirements, and tracking progress to a schedule. The following section presents a deductive test of the theory.

Table 3-2 Summary of Factors driving Success and Failure of Automation Procurement On-time with Zero Performance Deficiencies

Factors Leading to Success	**Factors Leading to Failure**
(1) Presence of a "systems engineering approach," meaning: - Develop good requirements - Plan detailed procedures to verify and validate the system according to the requirements, - Track progress to a schedule.	(1) Presence of inappropriate, lacking or under-defined requirements (2) Lacking procedures to verify and validate system performance traced to requirements
(2) Presence of lessons learned from past procurements	

Chapter 4

An Approach to Buyoff Plan Development and Execution

In Chapter 3, it was asked why is there a perception that projects are bought off with schedule delays and performance deficiencies? It was found that there was a range of success in completing project buyoff with one project delivered on time with no deficiencies and several projects delivered late with deficiencies. This range of results was mainly associated with the presence or lack of appropriate fully-defined requirements and detailed procedures to verify and validate the system according to the requirements.

In this chapter, a related question is answered to address the problem that the PGB automated assembly project may be subject to the same variation in buyoff results that other projects showed. An approach to buyoff plan development and execution is formulated based on the hypothesis developed in Chapter 3 and then tested through application to a model of an acceptance testing period. The evaluation shows that applying lessons learned from past projects as well as an approach that includes development of good requirements, planning detailed procedures to verify and validate the system according to the requirements, and tracking progress to a schedule.

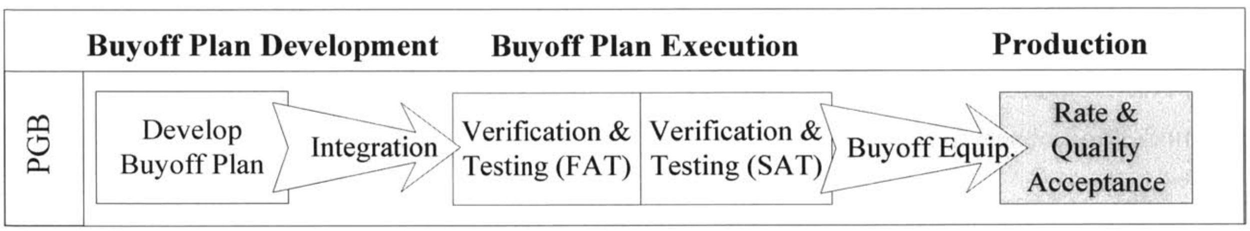
4.1 Question: What can be done to ensure projects are bought off on-time with zero performance deficiencies?

The objective of this analysis is to answer the question: What can be done to ensure projects are bought off on-time with zero performance deficiencies? To answer this question, the hypothesis developed in Chapter 3 is tested. The hypothesis is that automation system buyoff can be improved by (1) following an approach that includes development of good requirements, planning detailed procedures to verify and validate the system according to the requirements, and tracking progress to a schedule, and (2) applying lessons learned from past projects.

4.2 Methodology

An approach for developing and executing a buyoff plan was defined according to the hypothesis in order to determine whether it is valid. Recall that development and execution of a buyoff plan are tasks the PGB must do to complete the integration, evaluation and test phase and transition the automated assembly system to production. **Figure 4-1** clarifies the difference between development and execution. In this section, an approach for development and execution is defined, enabling expansion of **Figure 4-1** to show what developing and executing a buyoff plan entails and how it will all be accomplished.

Figure 4-1 Buyoff Plan Development vs. Execution



In Part 1 of this chapter, an approach to buyoff plan development and execution, is defined by first fully understanding the requirements for buyoff plan development and execution. Requirements are developed with a systems engineering methodology. As noted in Chapter 2, systems engineering provides a framework for guiding a project through its life cycle, which is both useful to understanding the role of the buyoff plan as well as guiding the definition of an approach to developing and executing the buyoff plan. Systems engineering was considered to inform the approach to buyoff plan development and execution due to the reference of other Company A teammates to its usefulness. It was selected because the systems engineering methodologies reviewed in Chapter 2 also account for the factors that were shown to drive the success or failure of project buyoff. As noted in **Table 2-3 Integration, test and evaluation phase activities** the test planning phase includes, "reviewing system requirements and defining detailed plans for integration and system testing" as well as, "defining the test requirements and functional architecture" (2). These correspond closely with the hypothesis which requires development of good requirements, planning detailed procedures to verify and validate the system according to the requirements, and tracking progress to a schedule.

In the Part 2 of this chapter, the approach is improved by applying lessons learned that capture organizational factors that have impacted similar projects. Lessons learned were collected throughout interviews with automation project teams at Company A and categorized to show ten common themes.

In Part 3 of this Chapter, the newly formulated approach is tested in a model. Since the integration, evaluation and test phase culminating in buyoff will not be complete for the PGB automated assembly system until early 2016, the effectiveness of the new buyoff plan approach cannot be directly evaluated within the scope of this project. Therefore, an Actions-Conditions-Outcome model is developed to evaluate potential effectiveness. The model is based on a case study with several instances of actions and conditions leading to unfavorable outcomes (base case) that impact schedule and confidence in system performance. Analysis of a test case is completed by applying the buyoff plan approach developed in Parts 1 and 2 to the conditions in the model and observing the change in outcomes.

4.3 Data Part 1: Developing An Approach to Buyoff

In this section, the approach to buyoff plan development and execution is defined according to the following process: determining the purpose of the buyoff plan, defining buyoff plan requirements, developing a buyoff plan design concept, refining the requirements, and designing the buyoff plan approach. This process is based on the use of a "top-down progression to develop and refine requirements" in order to achieve a fully-developed set of requirements for the buyoff plan approach (4).

4.3.1 Buyoff Plan Purpose

According to the definition developed for the buyoff plan in Chapter 2, the buyoff plan must include planning for test and evaluation activities throughout integration, the FAT and the SAT. The buyoff plan must result in buyoff of a production-ready system. PGB leaders helped to develop some additional requirements for the buyoff plan process and results:

- Result in Company A confidence in the functionality of the system in the Company A environment
- Avoid a schedule set-back or cost impact due to non-value added work during testing period or production
- Increase cross-functional consideration of requirements among the Company A team

- Leverage Company A expertise in engineering requirements, lessons learned from past buy-off process, and Supplier expertise in automation system & component testing methodologies

The definition of the buyoff plan and PGB objectives overlap, resulting in four main requirements the buyoff plan must meet.

1. Plan for test and evaluation and avoid non-value added work during the testing period
2. Result in a production-ready system and Company A confidence in its functionality
3. Increase cross-functional consideration of requirements
4. Leverage Company A and Supplier expertise

4.3.2 Requirements Definition

The requirements definition for the buyoff plan was initiated by determining the highest-level components necessary to meet the buyoff plan requirements. The requirements and these sub-requirements are listed in the form of a requirements tree, below. **Figure 4-2** is a representation of the high-level design components based on the "V" life cycle diagram reviewed in Section 3.

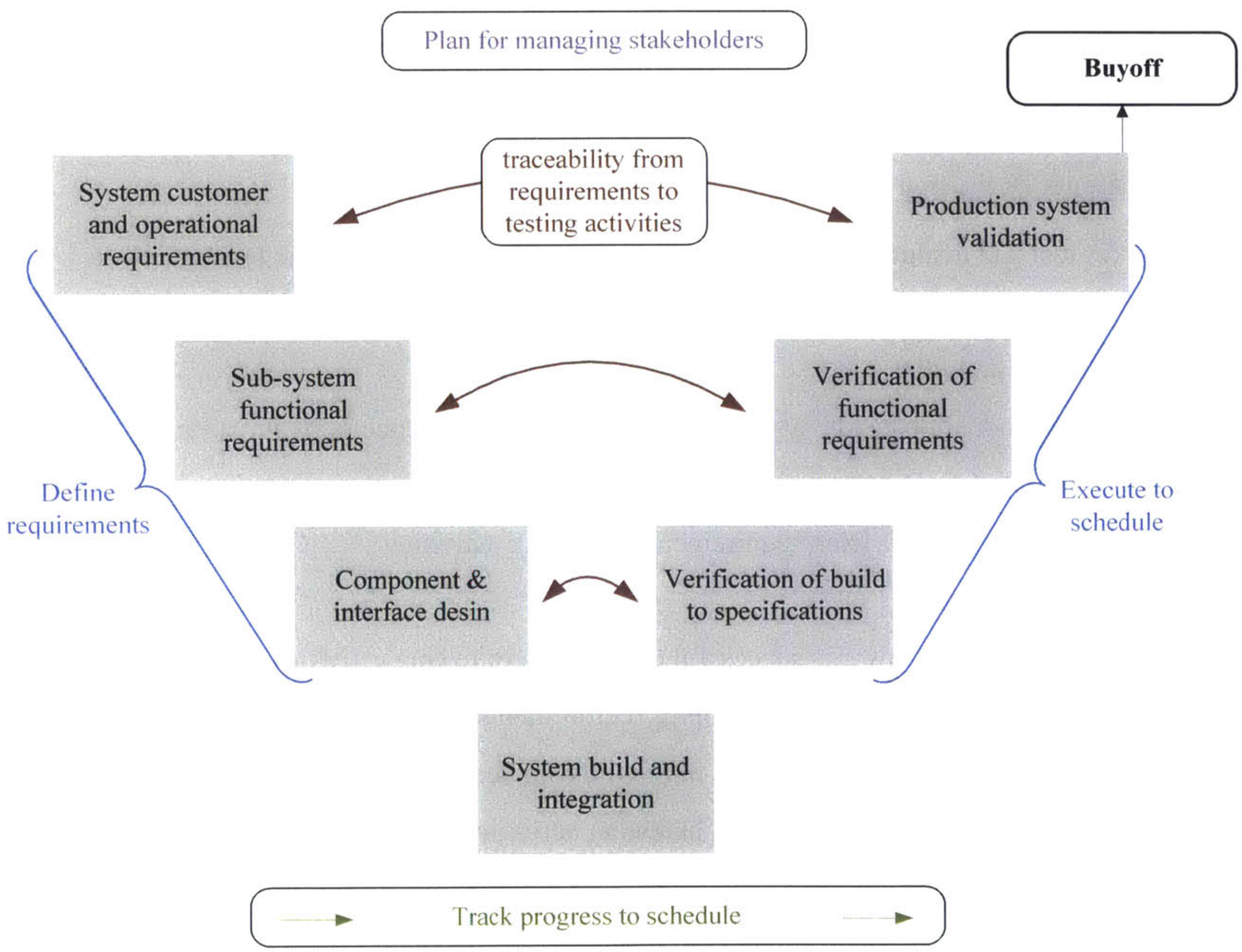
Requirements Definition

1. Plan for test and evaluation and avoid non-value added work during the testing period
   1.1. Define activities
   1.2. Schedule activities
2. Result in a production-ready system and Company A confidence in its functionality
   2.1. Define requirements
   2.2. Define Traceability from requirements to testing activities
   2.3. Execute testing
   2.4. Record progress towards successful completion of testing activities continuously
3. Increase cross-functional consideration of requirements
   3.1. Engage appropriate stakeholders in buyoff plan development
   3.2. Engage appropriate stakeholders in testing activities
   3.3. Create interaction among stakeholders
4. Leverage Company A and Supplier expertise
   4.1. Develop the buyoff plan in collaboration
   4.2. Create agreement between both parties on buyoff plan content

4.3.3 Concept Consideration

In order to develop the buyoff plan design, we consider the possible design concepts for a system that would meet these requirements. So far, the buyoff plan includes four major components: a requirements definition, traceability from requirements to testing, a schedule with tracking, and a plan for managing stakeholders. These make up the design concept for buyoff plan development and execution. **Figure 4-2** is a view of these components shown relative to the systems engineering "V" introduced in Chapter 2 and used to show the factors leading to project buyoff success and failure in Chapter 3. It is clear that the approach to buyoff plan development and execution is not fully developed, since **Figure 4-2** lacks the detail of **Figure 3-1 Components of a Successful Approach**.

Figure 4-2 High-level Approach to Buyoff Development & Execution



4.3.4 Refine Requirements

Although the preliminary buyoff plan concept meets the initial buyoff plan requirements, further development of the design concept is required to better understand the functionality and connectivity between the four components it defines. This section outlines more detailed requirements that are necessary to successfully meet the high-level requirements. The more detailed requirements were generated by asking what is required in order to make the higher level requirements happen.

Refined Requirements Definition

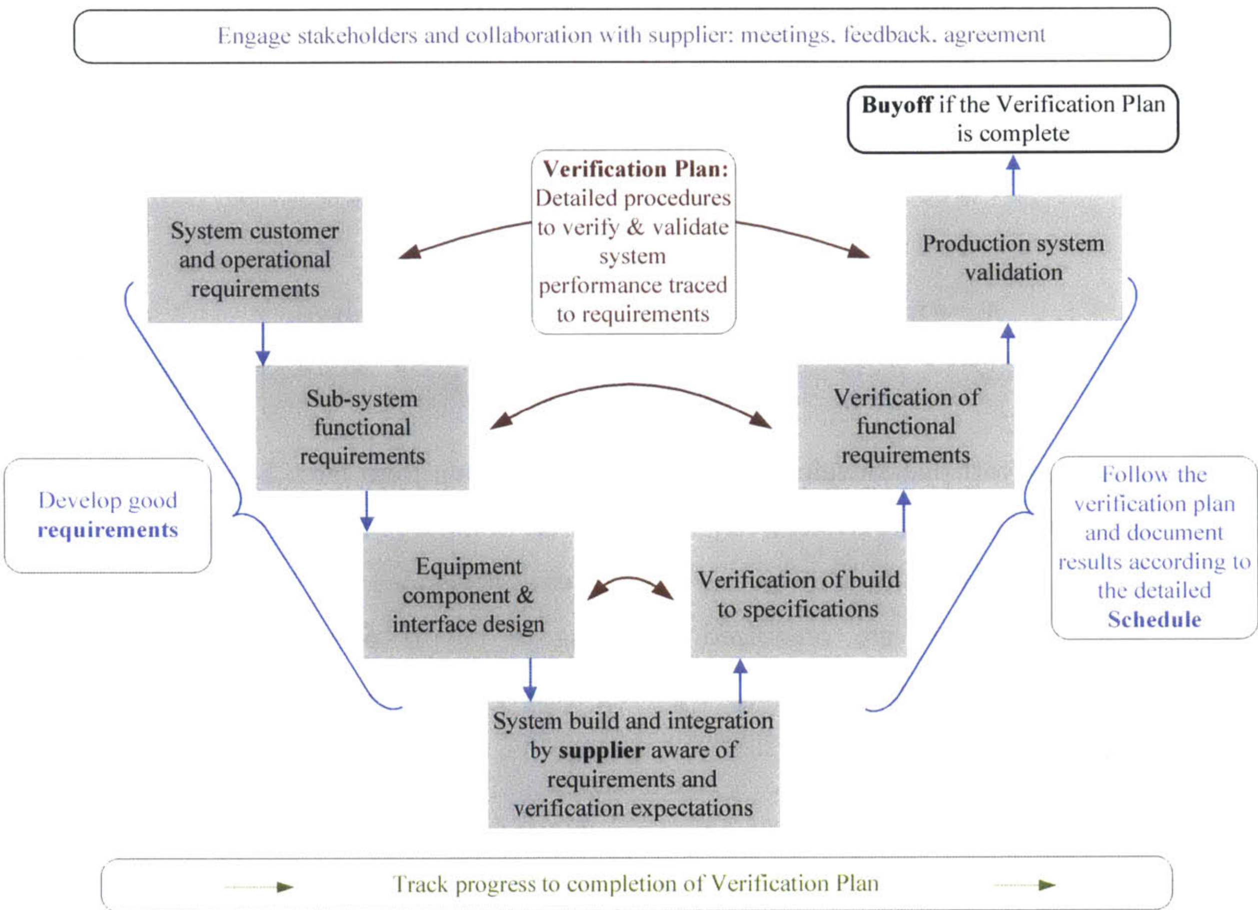
1. Plan for test and evaluation and avoid non-value added work during the testing period
   - 1.1. Define activities
     - 1.1.1. Create a verification plan format
     - 1.1.2. Stakeholders generate the verification plan according to the format
   - 1.2. Schedule activities
     - 1.2.1. Determine the time needed for testing activities
     - 1.2.2. Determine what phase of integration, evaluation and test activities should be completed in
     - 1.2.3. Create a test-by-test schedule of activities
2. Result in a production-ready system and Company A confidence in its functionality
   - 2.1. Define requirements
     - 2.1.1. Create a requirements list based on specifications
     - 2.1.2. Stakeholders determine requirements applicable to acceptance testing
   - 2.2. Define Traceability from requirements to testing activities
     - 2.2.1. Include reference to applicable requirements in the verification plan
   - 2.3. Execute the Verification Plan and Schedule
     - 2.3.1. Designated stakeholders witness and approve testing according to the verification plan
   - 2.4. Record progress towards successful completion of testing activities continuously
     - 2.4.1. Verification plan progress tracked and displayed
   - 2.5. Approve buyoff once the system has successfully completed the activities in the verification plan

3. Increase cross-functional consideration of requirements
    3.1. Engage appropriate stakeholders in buyoff plan development
        3.1.1. Define and identify stakeholders
        3.1.2. Assign responsibility for buyoff plan development
    3.2. Engage appropriate stakeholders in testing activities
        3.2.1. Assign responsibility to stakeholders to witness and approve tests
        3.2.2. Require stakeholder agreement on the plan
    3.3. Create interaction among stakeholders
        3.3.1. Hold meetings throughout development
        3.3.2. Assign multiple stakeholders responsibility for planning and completing activities where multiple disciplines have an interest
4. Leverage Company A and Supplier expertise
    4.1. Develop the buyoff plan in collaboration
        4.1.1. Share all activities to develop the plan between Company A & Supplier
        4.1.2. Share all Supplier feedback on the plan with Company A
    4.2. Create agreement between both parties on buyoff plan content
        4.2.1. Complete a comply/non-comply activity to create agreement on requirements list
        4.2.2. Complete a comply/non-comply activity to create agreement on the verification plan

The buyoff plan approach concept is revisited with this revised requirements definition. Refer to **Figure 4-3**, now very similar to **Figure 3-1 Components of a Successful Approach**. The requirement definition refined the design concept and four buyoff plan components to include three major documentation pieces which closely reflect the documentation used by the successful projects in Chapter 3: the requirements list, verification plan, and schedule. The difference is that the requirements definition also includes more detail about the role that these documents plan and what purpose they serve.

The buyoff plan also now includes more detail around stakeholder engagement, which is the main interconnection between the documentation and addresses the lacking communication among team members noted as a root cause for poor requirements in the one project that had an unsuccessful buyoff. **Figure 4-3** shows complete "flow down" of requirements and transfer of information to and from the supplier. These have been defined as parts of the "V" diagram, **Figure 4-3**.

Figure 4-3 Approach to Buyoff and Documentation



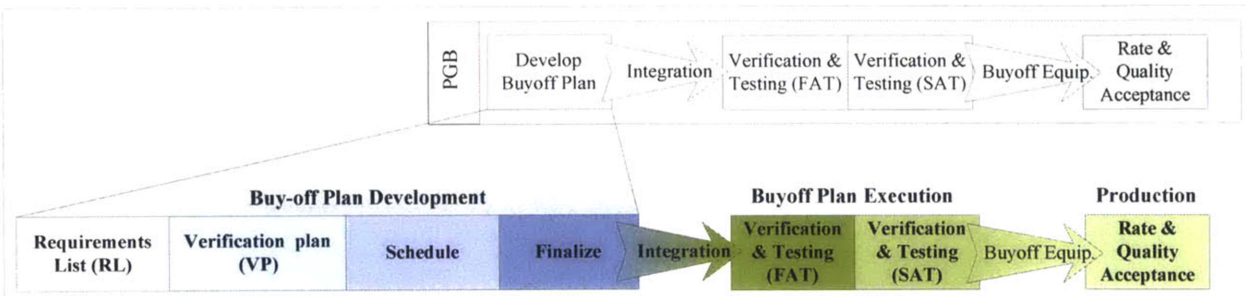
4.3.5 Defining the approach as a set of actions over time

To complete defining the approach to buyoff plan development and execution, the concept and requirements definition are used to inform the set of actions over time that will need to be taken in order to develop and execute a buyoff plan. Furthermore, actions are assigned to appropriate stakeholder groups.

Working through the final concept diagram, **Figure 4-3**, from left to right, top to bottom shows that the highest-level actions to take are to first develop the requirements list, then populate the verification plan and finally create a schedule. Observe that stakeholders are involved from the start to the finish. In the buyoff plan development phase, the team is establishing the content of the Requirements List, Verification Plan and Schedule. In the execution phase, the team is using those documents according to the buyoff plan design to complete testing.

At this point, **Figure 4-1**, the most basic Company A buyoff plan process, can be expanded to further define the first stage of the process, "Develop Buyoff Plan." Refer to **Figure 4-4**.

Figure 4-4 Buyoff Plan Development and Execution



Completion of buyoff plan development requires contribution from three main groups: buyoff plan management including systems engineering, the Company A buyoff plan team and the Supplier team. **Figure 4-5**, shows the requirements developed and listed in the Refined Requirements Definition are organized according to buyoff plan development step and contributor. The figure indicates each stakeholder's task with a reference to the Refined Requirements Definition in parenthesis (#).

4.3.6 Part 1 Conclusion

The approach to buyoff plan development and execution was defined above in order to test the hypothesis that automation system buyoff can be improved by (1) following an approach that includes development of good requirements, planning detailed procedures to verify and validate the system according to the requirements, and tracking progress to a schedule, and (2) applying lessons learned from past projects as well as. The approach developed does include the factors that were found to influence project success; however, lessons learned from past projects still need to be applied.

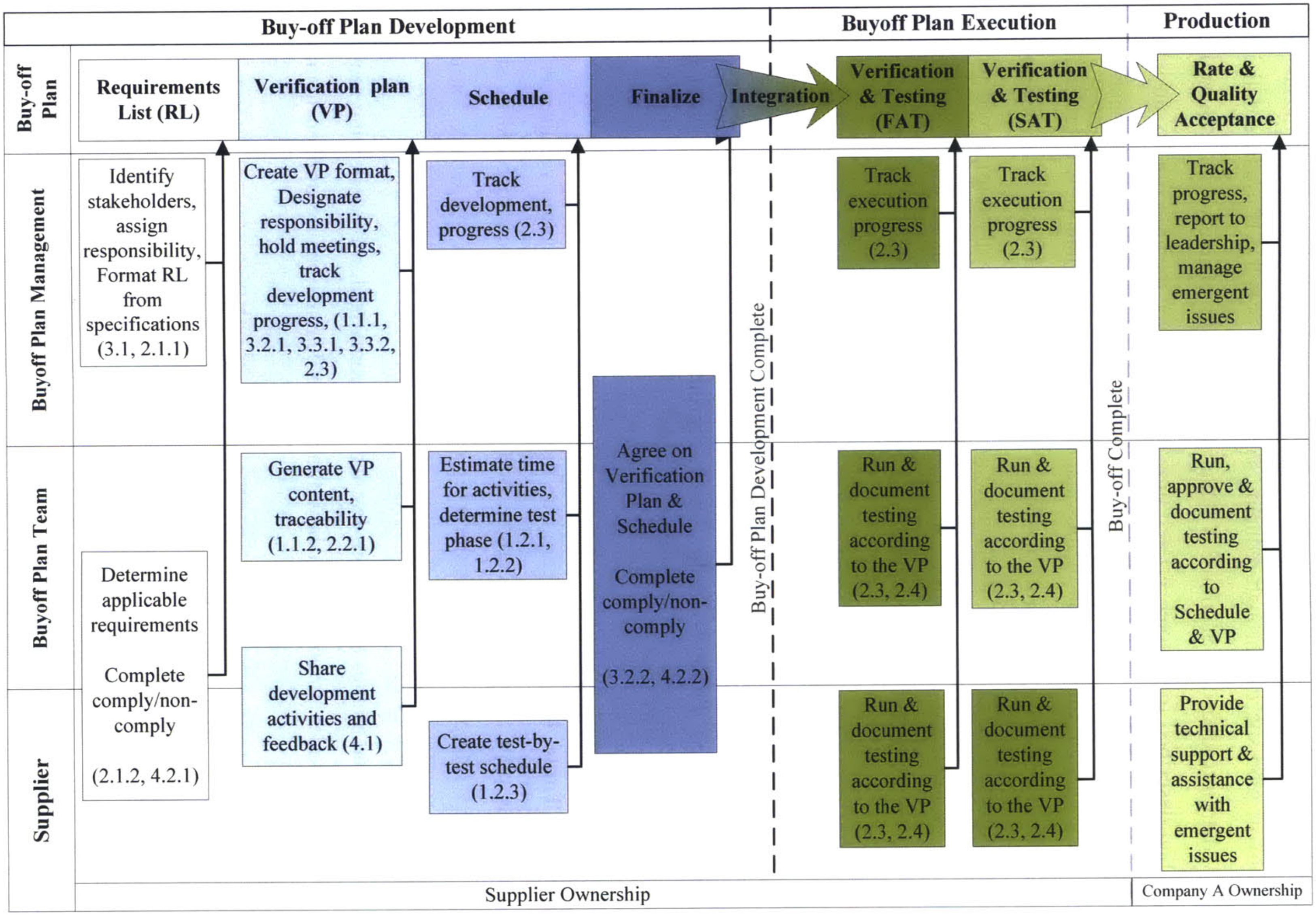


Figure 4-5 A Detailed Approach to Buyoff Plan Development and Execution

4.4 Data Part 2: Lessons Learned & Buyoff Plan

In order to determine whether the application of lessons learned from previous projects can also impact buyoff plan success through reducing schedule delays and performance deficiencies, the interview data introduced in Section 3.3 Data: Cross-section of interviews was analyzed more closely than described in Chapter 3. Each time an interviewee mentioned a lesson learned from their experience with automation system buyoff, it was noted and later categorized. In this section of the chapter, the common themes that emerged from the interview data are detailed and supported by specific quotes from interviews. The approach to buyoff plan development and execution summarized in **Error! Reference source not found.**will be improved to reflect the experience of interview participants. The improved approach will be tested in Part 3 of this Chapter to assess whether it may be effective for future projects to use the approach.

4.4.1 Study 1 Overview – Cross-section of interviews

Approximately 110 lessons learned were collected from the interviewees related to the eight projects profiled in Chapter 3. The lessons learned were analyzed for commonalities, resulting in nine common themes. **Table 4-1**, below shows each theme and the percent of best practices or lessons learned that were related to that theme.

The themes arose from grouping the lessons learned according to similarity. For example, the comments in **Table 4-2** are what compose the "Validate specification requirements prior to inclusion in the plan" theme. The comments listed in this table were reported by six different interviewees in reference to five different projects. Refer to the Appendix for a complete collection of interview data.

Each of the common themes and lessons learned are summarized in the following sections. Each summary also includes an analysis of how the lessons learned can be applied to improve the buyoff plan design.

Table 4-1 Common themes from multi-project interviews

Theme	Related Comments (% of total)
Engage Stakeholders in unified team approach	24
Verification plan should include true-life conditions and expectations	23
Plan sufficient resources for verification planning & testing	11
Front-load resources and buyoff plan development	10
Base the buyoff plan on well-founded requirements	7
Collaborate with the supplier	7
Define responsibility & authority for requirement verification	6
Manage emergent issues	6
Senior leader visibility and support is required for success	6

Table 4-2 Detailed comments supporting a common theme (Validate specification requirements before including them in the plan)

Validate specification requirements prior to inclusion in the plan

Center the acceptance testing around engineering requirements

Challenge managers, leaders, planners… How do you know you captured all the requirements in your process? How can you validate your assumptions?

Check that each requirement is necessary

Check validity and relevance of all requirements

Evaluate necessity and purpose of requirements in spec

Every time you make a factory activation decision… what requirement are you meeting?

Get rid of out of date engineering requirements

Relax requirements with tight tolerances that don't need to be that tight

4.4.1.1 Engage Stakeholders in a Uniform Approach

The common theme of lessons learned noted by interviewees was to utilize a uniform approach to developing and executing a buyoff plan throughout the project. Interviewees focused on three main aspects of this: including all stakeholders from the beginning, having a clear process for stakeholders to follow to buyoff completion, and creating cross-silo visibility among stakeholders to address multi-stakeholder issues. One interviewee that captured all of these commented, "A good buyoff plan will force everybody to be on the same plan, see everything, and buy-in." Other comments were more specific. For example, more than one participant described past frustration and delay due to the IT stakeholders becoming involved too late or lacking adequate access to project information. Late involvement caused changes in system requirements that caused rework and schedule impacts. A lack of information sharing among internal Company A organizations and the supplier was also seen as problematic.

Buyoff Plan Consideration

By requiring stakeholders to generate the content of the requirements list, verification plan and schedule in the pre-determined format and then execute buyoff based on these documents, the buyoff plan includes a clear process for stakeholders to follow. The plan for sharing information among stakeholders includes group meetings and assigning multiple-parties to develop particular verification plan content together. The buyoff plan design currently includes stakeholder identification and involvement, but doesn't specify when stakeholders should be engaged, which is a point of significance according to the interviews.

The buyoff plan approach should be updated to specify inclusion of all stakeholders as soon as possible. As defined in Chapter 2, stakeholders for this research are people whose signature is required to buyoff the system. Furthermore, more consideration should be given to increasing information sharing, particular to comments related to the difficulty of information access when different internal organizations are involved.

4.4.1.2 Verification plan should include true-life conditions & expectations

The second most popular theme that interviewees commented on is specific to the quality of verification plan content. Many lessons learned referenced issues with the quality of testing plan content. Comments were centered around two main issues: lacking statement of expectations for testing procedure and tests that didn't adequately show compliance with the system operational requirements.

Several interviewees told stories of mis-interpreted test descriptions, one stating that, "based on the purchase spec [specification], the requirements were not interpreted by the customer as we thought they would be." In this case and others, a high-level testing plan guided testing or the purchase specification was used in lieu of a testing plan. Expectations for how the supplier would show compliance to each requirement were not included in sufficient detail for the supplier to prepare for successful testing periods. For example, the supplier prepared to complete a test using a measurement device that they had on-site. In this case, Company A employees were surprised that supplier didn't use a different measurement device more common to Company A testing. Other examples of differing expectation include how many holes to drill in a sample, materials to be used for testing, test speed, etc.

Other interviewees focused on being sure that the tests written represent reality as closely as possible. One comment was to "make the buyoff plan as lifelike as possible, real parts, real systems, real connections." Another said, "make testing as close as possible to build conditions." In these cases, the system passed acceptance testing, but acceptance testing had not resulted in confidence that the system met performance requirements, since tests were not sufficiently representative of the operating conditions.

Buyoff Plan Consideration

The buyoff plan approach does not include requirements specific to verification plan quality. The buyoff plan approach should be updated to specify a verification plan design that includes test expectations for procedure, tools, materials, and acceptable results. The buyoff plan approach also doesn't include a requirement that tests represent realistic operating conditions.

4.4.1.3 Plan sufficient resources for verification planning & testing

Interviewees were also significantly concerned with planning adequate time and staffing for acceptance testing. Since nearly every project studied exceeded the planned schedule, there is good reason for the attention. Several comments addressed building buffer time into the schedule and planning acceptance testing days with a realistic amount of testing. However, the deeper issue raised by interviewees was a lack of staffing at appropriate levels. One leader cited not having enough "worker bees to get things done."

Buyoff Plan Consideration

The buyoff plan approach doesn't include requirements for including time for buffer in the schedule or reviewing the capacity of key staff members in the scheduling phase. The buyoff plan design should be improved to include both of these.

4.4.1.4 Front-load resources and buyoff plan development?

The interview responses included many comments related to the timing of buyoff plan development. The common theme was to plan as early as possible. One interviewee commented, "put in the effort up-front to plan and prepare, acceptance testing will go smooth." Others pointed out that the sooner you determine what criteria the system must meet to pass, the sooner the team can work towards those goals. One interviewee emphatically said, "start now!"

Buyoff Plan Consideration

In the case of the PGB Automated Assembly system, the buyoff plan is being developed prior to the start of the integration, evaluation and test phase. Although this may be early compared to other procurements, the effort could have started much earlier. Consideration for verification of requirements should be a continuous process throughout the life cycle, beginning writing requirements in a way that allows them to be verified with success (5). Verification can then also be considered as a part of decisions during the design phase. Not only would integrating this strategy into future buyoff plans address the concern for front-loading resources, it would more importantly align the team to the same goals, as suggested by the stakeholders interviewed.

The buyoff plan approach requirements definition is amended to include the requirement to start the process with the start of a project.

4.4.1.5 Base verification on the right requirements

Some of the interviewees told stories of completing acceptance tests that didn't add value to system buyoff because they didn't show the system could meet a relevant requirement. Others told of missing tests that were included at the last minute because the team realized they hadn't shown compliance with a key requirement. Multiple interviewees from the same project mentioned time wasted testing the system to tolerances significantly tighter than the product required. The stories illustrated instances where the requirements in the purchase specification had been assumed to be relevant to testing despite sometimes years of design, changes, and technology improvements since the specification was written. Testing was completed to show requirements that were out of date and yet testing did not reflect relevant requirements that were missing. These stories all resulted in similar comments to check the relevance of all requirements before including them in the verification plan and consider requirements that may be missing.

Buyoff Plan Consideration

The buyoff plan design from Section 5.3.3 includes creating a requirements list based on the purchase specification with the involvement of the stakeholders. The design specifies that stakeholders should determine which requirements are applicable to acceptance testing because the PGB project was already constrained to a particular requirements set and timing. However, a more effective approach would be to generate system requirements using a structured top-down iterative approach, similar to the approach followed in Section 4.3. Therefore, the approach is updated to reflect this process supporting the requirements list.

4.4.1.6 Collaborate with the supplier

Interviews also included comments related to working with the supplier. They emphasized communication, sharing information and giving the supplier plenty of time to prepare for acceptance testing. One particular comment pointed out the impact of having a good collaborative relationship with the supplier, "Competitive and non-collaborative relationships made resolving issues more difficult."

Buyoff Plan Consideration

The PGB Automated Assembly project generally includes good collaborative relationships with the Supplier. On several occasions throughout the project, PGB and Supplier leaders asked each other for help, gave each other thanks, and complimented the work that each other were doing.

Collaboration was emphasized in the buyoff plan design developed in Section 5.3 in response to a requirement dictated by PGB Leaderships that the buyoff plan leverage both Company A and Supplier expertise.

4.4.1.7 Define responsibility & authority for requirement verification

Defining responsibility and authority was another popular topic in interviews. Interviewees felt strongly that stakeholders, including suppliers, needed to be clear about their responsibilities in order to have a thoroughly developed buyoff plan and smooth acceptance testing period. Interviewees were also concerned with decision-making. One specified that the team should, "have the right decision-making authority on the floor to address issues & change requirements and tests as necessary."

Buyoff Plan Consideration

The Buyoff Plan design includes specification of stakeholder responsibilities throughout buyoff plan development and execution, based on the PGB Leadership goal to increase cross-functional consideration of requirements. Although this assigns responsibility for witnessing particular testing, it doesn't clarify the suppliers' responsibilities or who has decision-making authority throughout planning and acceptance testing.

The buyoff plan design should be improved to designate the Suppliers' responsibility to direct the testing period according to the verification plan and schedule and include designated authority for decision making.

In the PGB case, the supplier's responsibilities are defined at a high-level in its contract with Company A. Since Company A doesn't own the project until buyoff completion, the Supplier will be responsible for running testing in the FAT and SAT. Also, the contract between Company A and the supplier indicates that Company A will develop the verification plan content with the assistance of the Supplier but the Supplier will generate the schedule, with the assistance of Company A.

4.4.1.8 Manage emergent issues

Especially in a developmental system, there are many conditions that are unknown prior to testing that can cause emergent issues. Regarding acceptance testing, one interviewee advised to, "plan for managing emerging issues: meeting the spec, but not meeting expectations; or not meeting the spec." Another interviewee who also recommended structured management of emergent issues warned that the existing organizational change processes developed to manage design evolution could create schedule delays in a time sensitive testing environment, in particular they advised to develop a group understanding of when each stakeholder should be involved in a change based on their expertise.

Buyoff Plan Consideration

Although there is a PGB change management process that the buyoff plan team is involved in, the buyoff plan design developed in Section 5.3 doesn't include requirements that the team follow a structured process for managing emergent issues during buyoff plan execution. The buyoff plan design should be revised to include management of emergent issues. The goal of managing emergent issues is to avoid expansion of requirements and testing procedures as well as fully consider the teams' response to surprises during testing. A good process would involve the correct decision-making authority, consider the costs and benefits of making a change, record decision-making and ensure the whole team is aware of test and schedule changes. During the acceptance testing periods, this process should be separate from the PGB process if possible, to enable faster on-the-floor decision making to minimize schedule setbacks.

4.4.1.9 Senior leader visibility and support is required for success

A few comments from the interviewees were related to the role of senior leaders in a project. Senior leader support for the project was stressed because of the value senior leaders can add through procuring funds and removing organizational barriers to progress. It was also mentioned that the verification plan should help provide senior leaders with the type of information they need to perform that role. One interviewee noted that it is wise to, "Create an interface for leaders to easily look-in and evaluate progress, they'll be confident and stay out of the way." The comments showed that leaders can make or break the success of an initiative, hampering progress with continual micro-managing or enabling progress through clearing organizational roadblocks.

Buyoff Plan Consideration

Although it is specified that information should be shared among the team in the buyoff plan design, there is no requirement to provide information on the plan that is appropriate to bolster leadership confidence in the system and team as well as raise leadership awareness of issues that they can help with. The buyoff plan design should be revised to include a basic requirement to provide leadership with information on buyoff plan progress throughout planning and execution.

4.4.2 Summary of Buyoff Plan Considerations

Based on the above lessons learned data analysis and comparison to the buyoff plan design, there are several improvements to be made to the buyoff plan design. They are summarized and numbered in **Table 4-3** as D.1, etc.

Table 4-3 Additional Buyoff Plan Design Requirements

No.	Additional Buyoff Plan Design Requirements
D.1	Include expectations for test procedure, tools, materials, calculations and acceptable results in verification plan
D.2	Create tests that represent realistic operating conditions by using actual operational procedures and parts
D.3	Begin buyoff plan development early in the project to ensure that requirements needing testing are defined and communicated to the supplier (D.3)
D.4	Include buffer time in the schedule
D.5	Confirm sufficient labor resources exist in the scheduling phase
D.6	Manage emergent issues throughout buyoff plan development and execution
D.7	Create a process to manage emergent issues that is appropriate for time sensitive on-the-floor decision-making
D.8	Create a requirements list based on an iterative top-down consideration of customer and operational needs
D.9	Develop acceptance criteria for each requirement that will be tested during the buyoff exercise
D.10	Supplier directs testing according to the schedule
D.11	Designate authority for decision making
D.12	Provide leadership with information on buyoff plan progress throughout planning and execution

The numbers are used to identify each new requirement within the buyoff plan design in the following section.

4.4.3 Improved Requirements Definition

The buyoff plan design in the form of a requirements tree developed in Section 5.3, revised with the additional design requirements resulting from the lessons learned from other projects is shown below. The additional design requirements are indicated by (No.) corresponding to the numbers in **Table 4-3** (need to update).

<u>Improved Requirements Definition</u>

1. Plan for test and evaluation and avoid non-value added work during the testing period

    1.1. Define activities

    1.1.1. Create a verification plan format

    1.1.2. Stakeholders generate the verification plan according to the format

    1.1.2.1. Include expectations for test procedure, tools, materials, calculations and acceptable results in verification plan (D.1)

    1.1.2.2. Create tests that represent realistic operating conditions by using actual operational procedures and parts (D.2)

    1.1.3. Begin buyoff plan development early in the project to ensure that requirements needing testing are defined and communicated to the supplier (D.3)

    1.2. Schedule activities

    1.2.1. Determine the time needed for testing activities

    1.2.2. Determine what phase of integration, evaluation and test activities should be completed in

    1.2.3. Create a test-by-test schedule of activities

    1.2.3.1. Include buffer time in the schedule (D.4)

    1.2.3.2. Confirm sufficient labor resources exist in the scheduling phase (D.5)

    1.3. Manage emergent issues throughout buyoff plan development and execution (D.6)

    1.3.1. During buyoff plan development, manage scope and schedule changes through the PGB change management process

    1.3.2. During buyoff plan execution, use a process to manage emergent issues that is appropriate for time sensitive on-the-floor decision-making (D.7)

2. Result in a production-ready system and Company A confidence in its functionality

    2.1. Define requirements and acceptance criteria

2.1.1. Create a requirements list based on an iterative top-down consideration of customer and operational needs (D.8).

2.1.2. Develop acceptance criteria for each requirement that will be tested during the buyoff exercise (D.9)

2.2. Define traceability from requirements to testing activities

2.2.1. Include reference to applicable requirements in the verification plan

2.3. Execute the Verification Plan and Schedule

2.3.1. Supplier directs testing according to the schedule (D.10)

2.3.2. Designated stakeholders witness and approve testing

2.4. Record progress towards successful completion of testing activities continuously

2.4.1. Verification plan progress tracked and displayed

3. Increase cross-functional consideration of requirements

3.1. Engage appropriate stakeholders in buyoff plan development

3.1.1. Define and identify stakeholders

3.1.2. Assign responsibility for buyoff plan development

3.2. Engage appropriate stakeholders in testing activities

3.2.1. Assign responsibility to stakeholders to witness and approve tests

3.2.2. Require stakeholder agreement on the plan

3.2.3. Designate authority for decision making (D.11)

3.3. Create interaction among stakeholders

3.3.1. Hold meetings throughout development

3.3.2. Assign multiple stakeholders responsibility for planning and completing activities where multiple disciplines have an interest

4. Leverage Company A and Supplier expertise

4.1. Develop the buyoff plan in collaboration

4.1.1. Share all activities to develop the plan between Company A & Supplier

4.1.2. Share all Supplier feedback on the plan with Company A

4.2. Create agreement between both parties on buyoff plan content

4.2.1. Complete a comply/non-comply activity to create agreement on requirements list

4.2.2. Complete a comply/non-comply activity to create agreement on the verification plan

5. Engage leadership in the project regularly (D.12)
    5.1. Provide leadership with information on buyoff plan progress throughout planning and execution

Expanding upon **Figure 4-5** by adding the additional requirements, D.1 – D.12 (in red), the buyoff plan design is now expanded as shown in **Error! Reference source not found.**.

4.4.4 Part 2 Conclusion

The approach to buyoff plan development and execution was improved in this section in order to test the hypothesis that automation system buyoff can be improved by (1) following an approach that includes development of good requirements, planning detailed procedures to verify and validate the system according to the requirements, and tracking progress to a schedule, and (2) applying lessons learned from past projects as well as. Lessons learned from other projects impacted the design, particularly through highlighting the importance of developing good requirements including acceptance criteria and beginning verification planning as early as possible. The lessons learned also helped to define the role of buyoff plan management with respect to tracking progress and communicating with leaders.

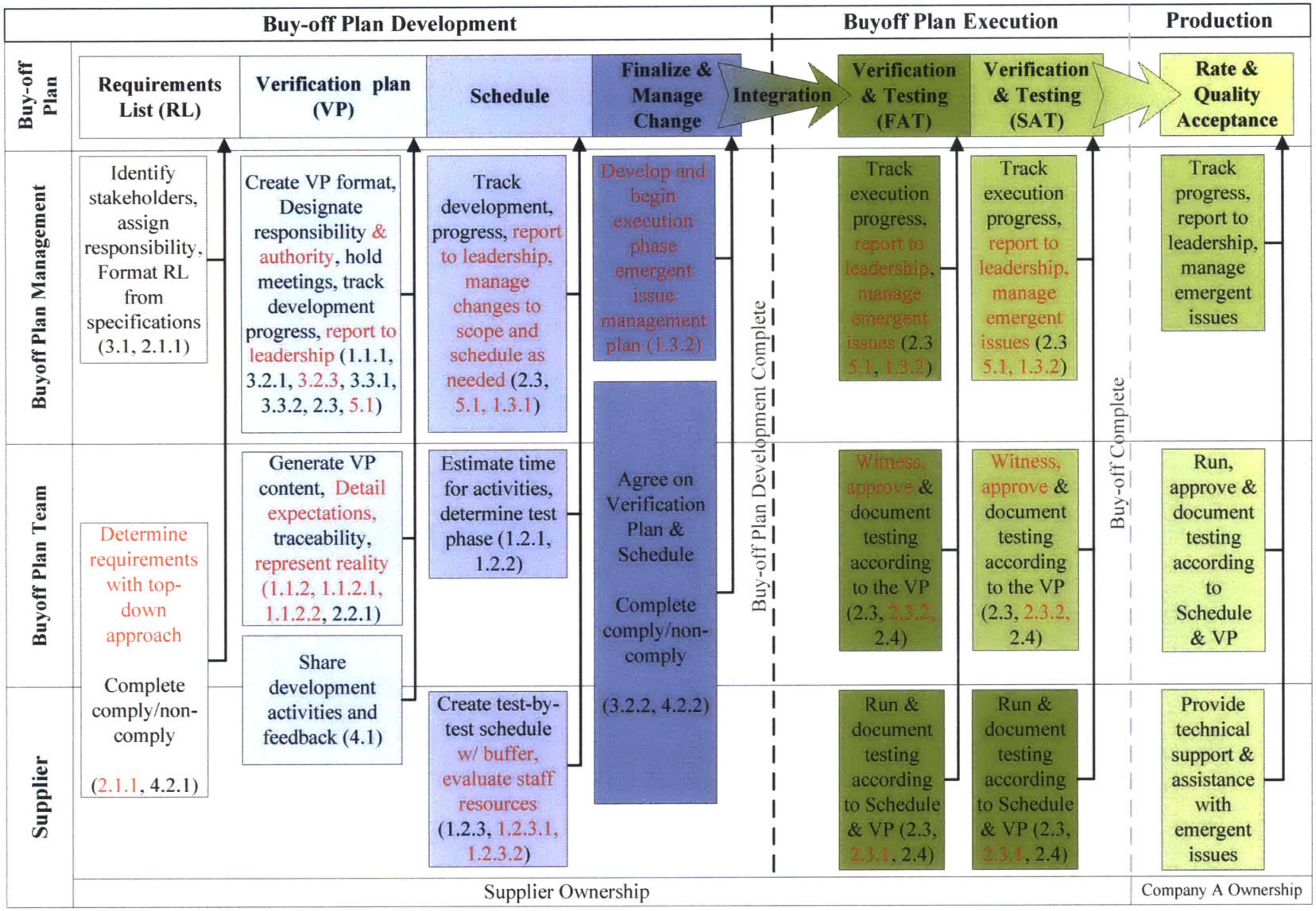


Figure 4-6 Improved Approach to Buyoff Plan Development and Execution

4.5 Analysis: Application of the buyoff plan in a model

A new approach to buyoff plan development and execution was created in order to help solve the problem that automation projects at Company A have been bought off with a range of success at transitioning the system to production on time and with zero performance deficiencies. It was hypothesized that application of a systems engineering approach and lessons learned from similar projects to buyoff plan design will enable delivery of the system on time and with zero performance deficiencies.

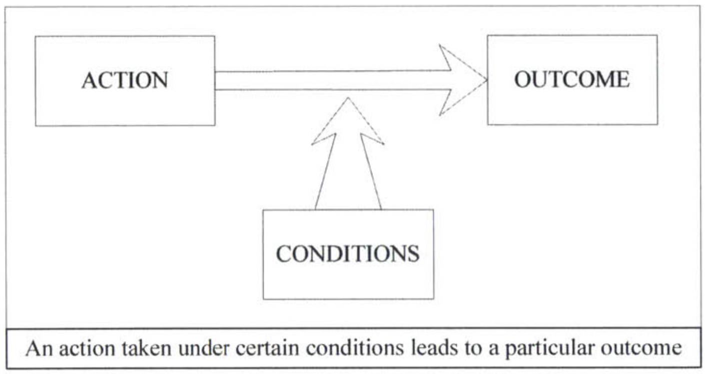
In this section, the newly formulated approach is tested in a model to help postulate whether it would reduce schedule delays and performance deficiencies if applied in reality. Since the integration, evaluation and test phase culminating in buyoff will not be complete for the PGB automated assembly system until early 2016, the effectiveness of the new buyoff plan approach cannot be directly evaluated within the scope of this project. Therefore, an Actions-Conditions-Outcome model is developed to evaluate potential effectiveness. The model is based on a case study with several instances of actions and conditions leading to unfavorable outcomes (base case) that impact schedule and confidence in system performance. Analysis of a test case is completed by applying the buyoff plan approach developed in Parts 1 and 2 to the conditions in the model and observing the change in outcomes. Based on the model outcomes, application of the buyoff plan design would reduce schedule impacts and performance deficiencies at project buyoff. The model's many limitations are discussed following the analysis.

4.5.1 The model and variables

The model has three variables: action, conditions and outcome. To utilize the model, we assume that an action taken under certain conditions leads to a particular outcome (6). There is a causal relationship between the actions and conditions and the outcomes, depicted in Figure 4-7. If the conditions that an action is taken under are changed, it will change the outcome.

In order to show that the schedule and performance outcomes of a project can be improved by applying the buyoff plan, it must be shown that the buyoff plan design changes the conditions in a way that causes outcomes related to schedule and performance to improve. A base model was developed by observing two days of acceptance testing of a similar technology to the PGB automated assembly system. The base model was then changed to reflect the conditions that would result from implementation of the new buyoff plan design. This revised model shows the change in outcomes predicted due to actions taken under the revised conditions. The model is subject to many significant assumptions, including that buyoff participants will follow through on the intention of the buyoff plan.

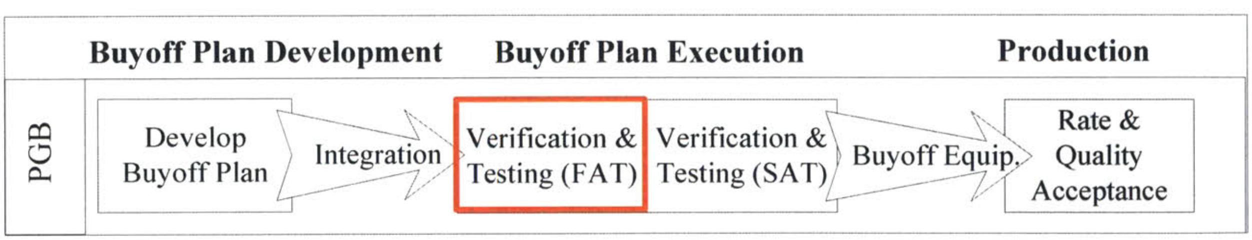
Figure 4-7 Actions-Conditions-Outcome Model Schematic



4.5.2 Developing a Base Model from Acceptance Testing Observation

In this section, the acceptance testing period observations that formulate the base model are detailed in a narrative. The base model, **Table 4-4**, is at the end of this section. Each "(#)" in the narrative text refers to a reference number in the base model. Note that the action-conditions-outcome scenarios in the base model were chosen to reflect particular events that impacted schedule and performance of the system in order to focus the study. Observations were made on two days of acceptance testing for the developmental cell project. The acceptance testing period was analogous to the PGB automated assembly system FAT and was held at the supplier's facility, part of buyoff plan execution phase, indicated in **Figure 4-8**.

Figure 4-8 Buyoff Process and FAT



4.5.2.1 Base Model Project Background

The developmental cell is a project initiated by the product development organization within Company A prior to the Component team's decision to automate Component assembly. Product development contracted with the Supplier to create a robotic cell that would perform part assembly, drilling and fastening. Once the Component team decided to automate production, the success of the developmental cell became critical to the project, which relies on the process and technology being proven by the developmental cell team.

The developmental cell combines the capability of each cell in the automated assembly system into one robotic cell with several tools. Not only will the developmental cell be used to test and qualify process and technology critical to the success of the PGB automated assembly system, there is a long term potential to test and debug production system improvements.

Similar to the PGB automated assembly system, the developmental cell was built and tested at the Supplier's factory (FAT) prior to being built and tested at the Company A factory (SAT). The acceptance testing plan was written by the Supplier based on the project specifications and their previous experience. The Company A team then edited it, making significant changes and expanding its scope.

The FAT, at the Supplier's factory, originally occurred in July. At this time, the system was not fully ready and did not pass several acceptance tests. According to product development staff from Company A, the supplier was not prepared for testing and did not have the equipment sufficiently de-bugged to pass tests without significant stoppage, trouble shooting, and rework. The Supplier cited non-representative testing, re-testing of commodity-type parts, and a surplus of stakeholders as challenges they faced throughout acceptance testing the system.

Since acceptance testing was not completed in July (July FAT), an additional acceptance testing period was planned for September (September FAT), allowing the supplier more time to finish building and de-bugging the system. Observations from the September FAT are recorded in this section.

Based on feedback from the supplier regarding the large number of Company A stakeholders attending the July FAT, Company A personnel included only the two engineers from product development who had primary roles in developing the developmental cell and a technical specialist from PGB who is also responsible for procuring the automated assembly system.

The following sections describe observations from the second FAT, in September. The people involved in the developmental cell testing included the following.

FAT Manager	Supplier	Quality manager, in charge of planning and overseeing FAT
FAT Operator	Supplier	Responsible for writing test programs, running tests, troubleshooting
Technician	Supplier	Responsible providing materials, equipment set-up, assisting the operator
Project Manager	Company A PD	Responsible for developing the developmental cell and using it to complete required testing
Project Engineer	Company A PD	Responsible for working with the Buyoff Leader and approving performance during acceptance testing
Technical Specialist	Company A PGB	Responsible for procurement of the Component automated assembly system, which is dependent on developmental cell success, and specific technical tests
Other	Supplier	Occasional involvement of technical specialists, project manager, executives interested in the project and the Company A relationship

4.5.2.2 Acceptance Testing Process

Testing of the developmental cell followed a testing plan that both Company A and Supplier had a copy of in a three ring binder for note taking and recording test completion. The testing plan was developed by the Supplier, edited by Company A and finalized by the Supplier prior to the testing period. Each page of the binder included several tests, each with a short description next to "yes" and "no" checkboxes.

Throughout testing, the FAT Manager continually verified that a Company A stakeholder was watching the test and verbally confirmed that the test had been performed to their satisfaction. As each test was completed, it was expected that the team check "yes" or "no" in the testing plan binder to indicate whether the test was passed. The Project Engineer also recorded results by writing notes in the binder, taking photos, and taking videos.

At the September FAT, the binder was already populated with check marks and notes from the July FAT. Notes from July vs. September were indistinguishable, since they were all in red pen. Each time the team marked "yes" or "no," they labeled the check mark "sept" to distinguish the updated result. Many tests had a check mark in both "no" (from July) and "yes" (passed on second try in July) and some of the "yes" were marked "sept" (passed in Sept).

The team was working between an office area and the testing area. In the morning, Company A teammates arrived at the facility between 7:00 – 8:00 AM, set up laptops in the office area and checked email or worked while supplier teammates were preparing in the testing area. Eventually, Company A teammates went to the testing area to observe testing. The FAT Manager and Technical Specialist generally spent more time in the office area throughout the day, tending to their non-testing workloads. They visited the testing area to check on progress or if they were summoned to help make decisions.

There was no overall schedule for testing to follow throughout the FAT testing days. According to the FAT Manager, the Supplier team did not prepare one for the September FAT since the July FAT had completely failed to follow the schedule due to the high number of system failures disrupting the plan. At the September FAT, the FAT Manager was running the testing based off of the open issues list from the July FAT and his experience with test durations and was directing the team to complete testing activities verbally throughout the day.

Several times, teammates asked the FAT Manager for information on what was coming up next in the schedule. The FAT Manager and teammates appeared frustrated at the continual need for direction and status. Even with frequent affirmation from the FAT Manager that the testing would be completed on time, there was a lot of discussion centered around guessing how the day was progressing and the possibility of late nights and extra days of work. One teammate frequently expressed concern that the team would have to work very long days, similar to the July FAT.

4.5.2.3 Schedule Delays

The team finished the September FAT in the time allotted, with the help of some over time and a weekend. Due to the lack of clear schedule, it was difficult to record the occurrence and length of schedule delays. Observations from the September FAT that may result in delays include the continual difficulty in running a test without stop, the role of unstructured breaks and other work, and the waiting associated with an unbalanced work load.

Most acceptance tests were not able to be completed without some stopping and restarting. Reasons for stopping a test in the middle of it included making adjustments to lubrication pressure and testing instruments, debugging the program, faulty fasteners, or completing the mandatory re-mastering routine. Although these contributed to schedule setbacks, some are discussed in more detail in the following section on performance deficiencies.

One example of a potential schedule and performance issue was the continual adjustment of the lubrication system. Due to a hose leak, the system ran out of lubricant and needed to be recalibrated. Following recalibration, several tests were paused throughout completion in order to tweak the lubrication system back to its optimal state (M.1).

Recall that the (M.1) or any (M.#) in this section is a reference to the Actions-Conditions-Outcomes Base Model **Table 4-4**, Ref. M.1 or any Ref. M.#.

In another case, a test delay resulted from a difference in test plan interpretation. In this case, the Project Manager strongly recommended that the Supplier use a particular type of coupon to perform the test because they would get better results. However, the test had already been programmed and configured for a different material and thickness, neither was directly specified in the testing plan. Respecting the Project Engineer's well-intentioned request, the FAT Manager decided to re-program the test and coordinate resources to locate and cut the coupon material, which was luckily located elsewhere in the facility. Following the schedule delay, the test passed with the revised material and programming (M.2).

Some delays occurred due to the lack of clear schedule, which made it impossible for stakeholders to plan their necessary breaks during test changeover or teammate break times, maximizing time observing tests. It also wasn't clear when each stakeholder should be in the testing area vs. the office area. The team would arrive over the course of an hour and spend varying amounts of time checking email, etc. in the office area. Lunch length also varied since there were no scheduled start and stop expectations, one lunch lasted over 2 hours because of a mis-communication of the food delivery time (M.3).

Whether in the office area or testing area, stakeholders worked hard throughout the days to be sure that the tasks were completed. One Stakeholder, the FAT Operator, had a particularly demanding role programming, operating and troubleshooting the system. Teammates acknowledged the very long hours the FAT Operator typically worked. The Technician, FAT Manager and various others provided some support for the FAT Operator, but he was uniquely skilled in programming and debugging the cell. Several times throughout testing, the team waited for the FAT Operator to complete programming a test that needed to be adjusted from what he had planned to run (M.4). The team also watched many times as the FAT Operator entered the cell to debug, control with the pendent or investigate some aspect of machine behavior.

4.5.2.4 Performance deficiencies

Overall, tests run were passed, even if after some delay and debugging activities. Therefore, in order for there to be performance deficiencies, observations need to show that the correct tests were not performed, tests performed didn't have procedures accurate to reality or tests were passing in a case where they shouldn't be. There is also a possibility that no performance deficiency exists, but teammates have a perception of performance deficiency due to lacking understanding of testing and system performance status. This section includes observations that support each of those scenarios.

No real parts were used in this phase of testing the system, although there will be one set of parts to be tested in the upcoming SAT. Tests were performed on a coupon stand with a coupon of material similar to the real part attached to the stand. Therefore, all drilling and fastening activities were completed on a flat surface at the same robot and end effector positioning. This was highlighted by the fact that the operator had to program the tests independently from the operational programs the system will run (M.5).

In addition to lacking testing at real parts curvature and position, testing plans did not reflect the best and latest knowledge of the team. For example, the team ran several tests to confirm the accuracy of a quality probe that is used to collect in-process drilling quality data. The test was completed in clean holes; however, in reality the probe will need to operate in holes lined with sealant. Teammates expressed skepticism that the probe would work in reality several times. This test was completed, but did not show that the system could perform to its requirements or build Company A confidence in the functionality of the system (M.6).

Another observation of testing that did not reflect reality is related to fasteners. Weeks before the September FAT, Company A sent the supplier a batch of bad fasteners, which were stored next to the good fasteners on the parts shelf and became mixed in with the good fasteners in the fastener feeder. Each time there was a bad fastener, the robot would fail to torque the fastener sufficiently to break off the shaft upon insertion. Since the bad fasteners were impossible to distinguish visually, several tests were being completed using both fastener types. This resulted in tests that couldn't be performed as intended, with proper parts and without frequent interruption of the process (M.7).

Tools for setup and measurement are also an important part of completing acceptance testing that shows the system can meet performance requirements. Observations showed that tools required for testing were not always readily available. In one case, a Company A stakeholder was advised to measure the thickness of a material with a caliper prior to testing. The caliper was not immediately available when testing was ready to run, so the Project Manager advised the Project Engineer to do the measurement after the test. The test was run without taking the measurement. It is unclear whether the caliper was located to perform the measurement later (M.8). There was no transparent record of the request or open-issue.

Record keeping is a tool to show the progress of testing towards meeting the objective of showing that a test was completed showing that the system can meet performance requirements. Although both teams were recording testing results, observations showed that record keeping didn't always meet this objective. In one instance the notes from the July FAT were not clear in the Company A binder. The team asked the Supplier team what their notes said and discussed their memory of what had happened. It was unclear why the test hadn't passed in the July FAT and whether it had been partially completed, requiring less September FAT testing. The team decided to redo and complete the test as a part of the September FAT after referencing the "open issues list" from the July FAT (M.9).

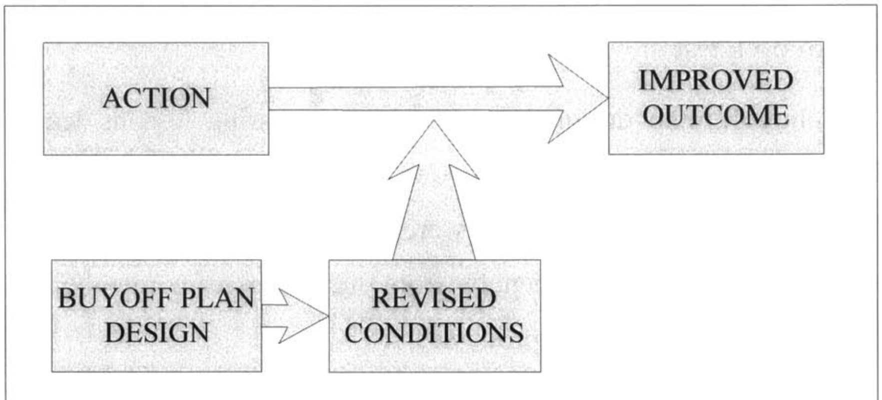
Some tests were completed successfully and recorded but still failed to build confidence in the systems' performance due to stakeholder disengagement with the process and results. For example, teammates in the office area were sometimes unaware of what was happening with testing. In one instance, a teammate in the office questioned "what's going on out there?" The response was, "length testing" to which the teammate immediately replied, "Oh, I wanted to see that" (M.10). Without having witnessed the test they had some interest in, the teammate will not complete acceptance testing with a full understanding of the system's performance capability.

Table 4-4, below shows many of the observations described above presented as a series of outcomes resulting from actions taken under certain conditions.

4.5.3 Developing a Test Model from Buyoff Plan Design

In order to show that implementing the buyoff plan can improve the outcomes in the base model, it must be shown that implementing the buyoff plan can change the conditions that caused the base model outcomes. **Figure 4-9** shows the impact of applying the approach to buyoff plan development and execution developed above on the base model.

Figure 4-9 Test Model with Improved Outcome



An action taken under certain conditions leads to a particular outcome

The results of applying the buyoff plan design to the base model conditions are shown in **Table 4-5**. The table includes the complete base model, with each action reference number corresponding to the base model, **Table 4-4**, and the narrative text in Section 4.5.2.

The table also includes the test model and the requirements from the buyoff plan design that drive the revised conditions, indicated by their reference from the requirements tree developed in Section 4.4.3. By impacting the condition under which actions were taken, outcomes improved.

In the base model, ten action-conditions-outcomes pairs result in outcomes causing schedule delays and performance deficiencies. Nine of the ten outcomes improved significantly as a result of applying the buyoff plan. The Table specifies the "Influencing buyoff plan design requirement" that impacted the base-model conditions.

Note that some of the test plan outcomes (M.5, M.6) represent an ideal state and that the impact of the buyoff plan on the PGB automated assembly project will likely cause an outcome somewhere between the base state and test state. This is due to the balance of testing realism with cost. The improvements made to the base model related to using real parts can be implemented at a reasonable cost for fasteners (M.7), but cost is a decision-driving factor for larger parts of the Component. The Supplier will have a limited number of real parts to debug and demonstrate system performance capability with.

One test model outcome (M.1) is not significantly different from the base plan. The hose leak, an emergent issue, needs to be repaired and the lubricant system needs to be recalibrated regardless of buyoff plan implementation. The test model outcome varies somewhat because instead of allowing the calibration to occur as each major system function was used throughout testing, the issue may have been managed to return to operational state in a way that didn't impact the continuous nature of each test.

The references to buyoff plan design resulting from acquiring lessons learned from similar projects have been included in the buyoff plan design column (D.#). Note that nine of the fifteen applicable buyoff plan design requirements were developed from lessons learned. This could indicate that there would be a large benefit from including team members with automation buyoff experience in subsequent buyoff processes.

Table 4-4 Actions-Conditions-Outcomes Model

Ref. #	Actions	Conditions	Outcome
M.1	Lubrication system hose leak is fixed, system is recalibrated	Recalibration continues through running various types of tests	Tests are stopped and started in order to adjust lubrication pressure and gauges
M.2	Supplier prepares for testing activities as planned	Testing activities were not specified and updated to reflect the best knowledge of the team	The test is changed at the last minute to reflect the latest and greatest testing conditions, schedule is impacted as new materials need to be located, the program needs to be edited
M.3	Teammates took email breaks and morning work time as desired	Testing schedule was not clear, start and stop times for testing and breaks were not clear, stakeholder responsibility to observe testing was not clear	Time that could have been used for testing was used in the office area with email or other work
M.4	The FAT Operator operates and debugs the cell	The FAT Operator is uniquely qualified to program tests and debug the cell, Unbalanced workload between managers, the FAT Operator and Technician	Most stakeholders spend a lot of time waiting for the FAT Operator to complete tasks between testing
M.5	Testing is completed using the coupon stand	This differs from production conditions (coupon stand is flat, fixed position, requires different programming)	Stakeholders are not confident that the system can perform in a production environment
M.6	Quality probe testing is completed using clean holes	This differs from the production environment (lack of sealant in holes)	Stakeholders are not confident that the system can perform in a production environment
M.7	Testing includes use of faulty fasteners	Testing must be stopped every time a bad fastener is used to break the fastener off by hand	Stakeholders are not confident that the system performs seamlessly with all good quality fasteners
M.8	Testing is run without completing an independent measurement of thickness	A caliper is not handy, nobody is keeping a transparent record of open issues or to-do items	Stakeholders don't have all the information needed to verify the test was completed properly
M.9	Project Engineer tried to determine whether a test should be run	Notes from July are insufficient to explain the status of a test that could have been partially or fully completed	Company A asks the supplier for information on the status of the test, supplier binder is also unclear, test is repeated
M.10	Tests are run	It is not clear to the Supplier what stakeholders need to be involved in each test, the correct stakeholder was not ready and attentive prior to testing	A stakeholder with a particular interest lost an opportunity to learn more about the system and witness performance to requirements

Table 4-5 Test Model with Revised Conditions and Outcomes

(Ref #) Action	BASE MODEL		Influencing buyoff plan design requirement	TEST MODEL	
	Conditions	Outcome		Revised Conditions	Outcome
(M.1) Testing is started	Lubrication hose leaks, recalibration is required for each function of the system	Leak is repaired, tests are stopped and started in order to recalibrate the lubrication system to various functions	5.2 Manage emergent issues throughout buyoff plan development and execution (D.7)	Lubrication hose leaks, recalibration is required for each function of the system, evaluation is completed to determine the best way to recalibrate	Leak is repaired, recalibration is completed entirely prior to resuming testing
(M.2) Supplier prepares for testing activities based on the test plan	Testing activities were not fully specified, didn't reflect the expectations of the FAT Manager	The test is changed at the last minute to reflect a suggestion to change the test material, schedule is impacted as new materials need to be located, the program needs to be edited	1.1.2.1. Include expectations for test procedure, tools, materials, calculations and acceptable results in verification plan (D.1)	Testing activities were fully specified and reflected the expectations of the FAT Manager	The test is prepared according to Company A expectations and completed without delay
(M.3) Teammates took email breaks and morning work time as desired	Testing schedule was not clear, start and stop times for testing and breaks were not clear, stakeholder responsibility to observe testing was not clear	Testing didn't start as soon as it was ready	1.2.3. Create a test-by-test schedule of activities 1.2.3.1. Include buffer time in the schedule (D.3) 3.2.1. Assign responsibility to stakeholders to witness and approve tests	Testing schedule was clear, start and stop times for testing and breaks were clear, stakeholder responsibility to observe testing was not clear	Stakeholders know the appropriate times to take a break or do non-testing work and the appropriate time to be in the testing area

(Ref #) Action	BASE MODEL		Influencing buyoff plan design requirement	TEST MODEL	
	Conditions	**Outcome**		**Revised Conditions**	**Outcome**
(M.4) The FAT Operator operates and debugs the cell	The FAT Operator is uniquely qualified to program tests and debug the cell, Unbalanced workload between managers, the FAT Operator and Technician	Most stakeholders spend a lot of time waiting for the FAT Operator to complete tasks between testing	1.2.3.2. Confirm sufficient labor resources exist in the scheduling phase (D.4)	Supplier staff are cross-trained to program tests and debug the cell in order to balance workload	Supplier stakeholders are all busy working and overall test changeover and debugging time is reduced
(M.5) Testing is completed using the coupon stand	This differs from production conditions (coupon stand is flat, fixed position, requires different programming)	Stakeholders are not confident that the system can perform in a production environment	1.1.2.2. Create tests that represent realistic operating conditions by using actual operational procedures and parts (D.2)	Testing doesn't significantly differ from production conditions (curved surface drilling, various positions, actual programming).	Stakeholders are confident that the system can perform in a production environment
(M.6) Quality probe testing is completed using clean holes	This differs from the production environment (lack of sealant in holes)	Stakeholders are not confident that the system can perform in a production environment	1.1.2.2. Create tests that represent realistic operating conditions by using actual operational procedures and parts (D.2)	Testing doesn't significantly differ from production conditions (sealant is in holes).	Stakeholders are confident that the system can perform in a production environment
(M.7) Testing includes use of faulty fasteners	Testing must be stopped every time a bad fastener is used to break the fastener off by hand	Stakeholders are not confident that the system performs seamlessly with all good quality fasteners	1.1.2.2. Create tests that represent realistic operating conditions by using actual operational procedures and parts (D.2)	Testing is not interrupted due to faulty parts	Stakeholders are not confident that the system performs seamlessly with good quality fasteners
(M.8) Testing is run without completing an independent measurement of thickness	A caliper is not handy, nobody is keeping a transparent record of open issues or to-do items	Stakeholders don't have all the information needed to verify the test was completed properly	1.1.2.1. Include expectations for test procedure, tools, materials, calculations and acceptable results in verification plan (D.1)	A caliper has been located during test preparation, there is a procedure including pre-measurement of material thickness	Stakeholders completed the measurement and have all the information needed to verify the test was completed properly

(Ref #) Action	BASE MODEL		Influencing buyoff plan design requirement	TEST MODEL	
	Conditions	Outcome		Revised Conditions	Outcome
(M.9) Project Engineer tried to determine whether a test should be run	Notes from July are insufficient to explain the status of a test that could have been partially or fully completed	Company A asks the supplier for information on the status of the test, supplier binder is also unclear, test is repeated	2.3. Continuous record of progress towards successful completion of testing activities 2.3.1. Verification plan progress tracked and displayed	Notes from July explain the status of a test that could have been partially or fully completed	The team has confidence in the performance of the system on this test in the July FAT. The team completes only the parts of the test that hadn't been completed in the July FAT.
(M.10) Tests are run	It is not clear to the Supplier what stakeholders need to be involved in each test, the correct stakeholder was not ready and attentive prior to testing	A stakeholder with a particular interest lost an opportunity to learn more about the system and witness performance to requirements	3.2.1. Assign responsibility to stakeholders to witness and approve tests 3.2.2. Require stakeholder agreement on the plan 3.2.3. Designate authority for decision making (D.5)	It is not clear to the Supplier what stakeholders need to be involved in each test, the correct stakeholder was not ready and attentive prior to testing	A stakeholder with a particular interest learned through experience that the system can perform to requirements

4.5.3.1 Model Limitations

This model has major limitations. The strongest limitation is the small data sample size to build the base model, only two days of acceptance testing observation of a single project. The most significant schedule delay, for example, was the time between the July FAT and September FAT, the causes of which were not observed. While these ten instances show improvement, there are many other cases of actions-conditions-outcomes that were not evaluated. For example, there may be some outcomes that the buyoff plan makes worse. And there are likely many instances that did not occur during developmental cell testing that we cannot know the impact of the buyoff plan on. Overall, the inability to implement any of the buyoff plan at this time in order to validate that the buyoff plan would cause revised conditions compounds the seriousness of the limited and selected data sample. The unique developmental characteristic of the project should also be considered. The developmental cell has several special challenges due to the high level of new technology application and the very diverse functions programmed into the one cell. Since the developmental cell is being used to prove-out new process and capability, the FAT was being used as a step in technology development to the same extent it was being used to show the equipment was ready for the production environment. The PGB automated assembly system will apply this new technology, but the focus of the FAT will primarily be production readiness. This difference highlights a key assumption that the model reflects similar actions and conditions that would occur during PGB automated assembly system testing.

The model also assumes that human behavior will reflect the intentions of the buyoff plan, which may not happen.

4.6 Conclusion: An Approach to Buyoff Plan Development and Execution

In this Chapter, it was found that an approach to buyoff plan development and execution based on systems theory has the potential to improve automation project buyoff with respect to schedule and performance. The approach was also improved to include Company A organizational knowledge by applying lessons learned from similar projects. The impact the design would have on schedule delays and performance deficiencies at buyoff was tested by building a model with a base case using observation data from developmental cell FAT testing and a test case.

The test case, in which the buyoff plan design drove revised conditions and outcomes, showed that application of the buyoff plan would improve buyoff outcomes, both schedule and performance related. The model also showed that the buyoff plan wouldn't change all unfavorable outcomes including those resulting from emergent issues, like a hose leak. The model's significant limitations, including inability to predict human behavior and account for other outcome constraints, such as costs, were also noted in the results. For example, the buyoff plan was shown to have a greater impact on outcomes related to real-parts testing than feasible given that the number of real-parts to be tested was previously determined during capital budgeting.

Chapter 5

Buyoff Plan Development

In Chapter 4, a design for buyoff plan development and execution was generated and tested. According to the analysis, implementation of the approach will have a positive impact on the outcomes of system buyoff. This chapter reflects some of the challenges encountered by the PGB time while attempting to complete the buyoff plan development phase. This research included approximately four months of observation and working with the team with the goal of completing buyoff plan development including the requirements list, the verification plan and the schedule.

5.1 Question: Can the PGB team develop a buyoff plan according to the new approach in four months?

The objective of this analysis is to answer the following question: can PGB complete buyoff plan development according to the new approach in approximately four months? In order to test the hypothesis that PGB can complete buyoff plan development in development according to the new approach in approximately four months, the PGB team was mobilized to act on the approach.

5.2 Methodology

The process of engaging the PGB team in buyoff plan development began with identifying the stakeholders, getting stakeholder buy-in, and assigning responsibilities for buyoff plan development. Actions towards completing buyoff plan development were continually assigned and tracked according to the approach throughout four months. As shown in Figure 5-1 below, buyoff plan development completion is marked by the completion of the requirements list, verification plan, schedule, and plan for managing changes.

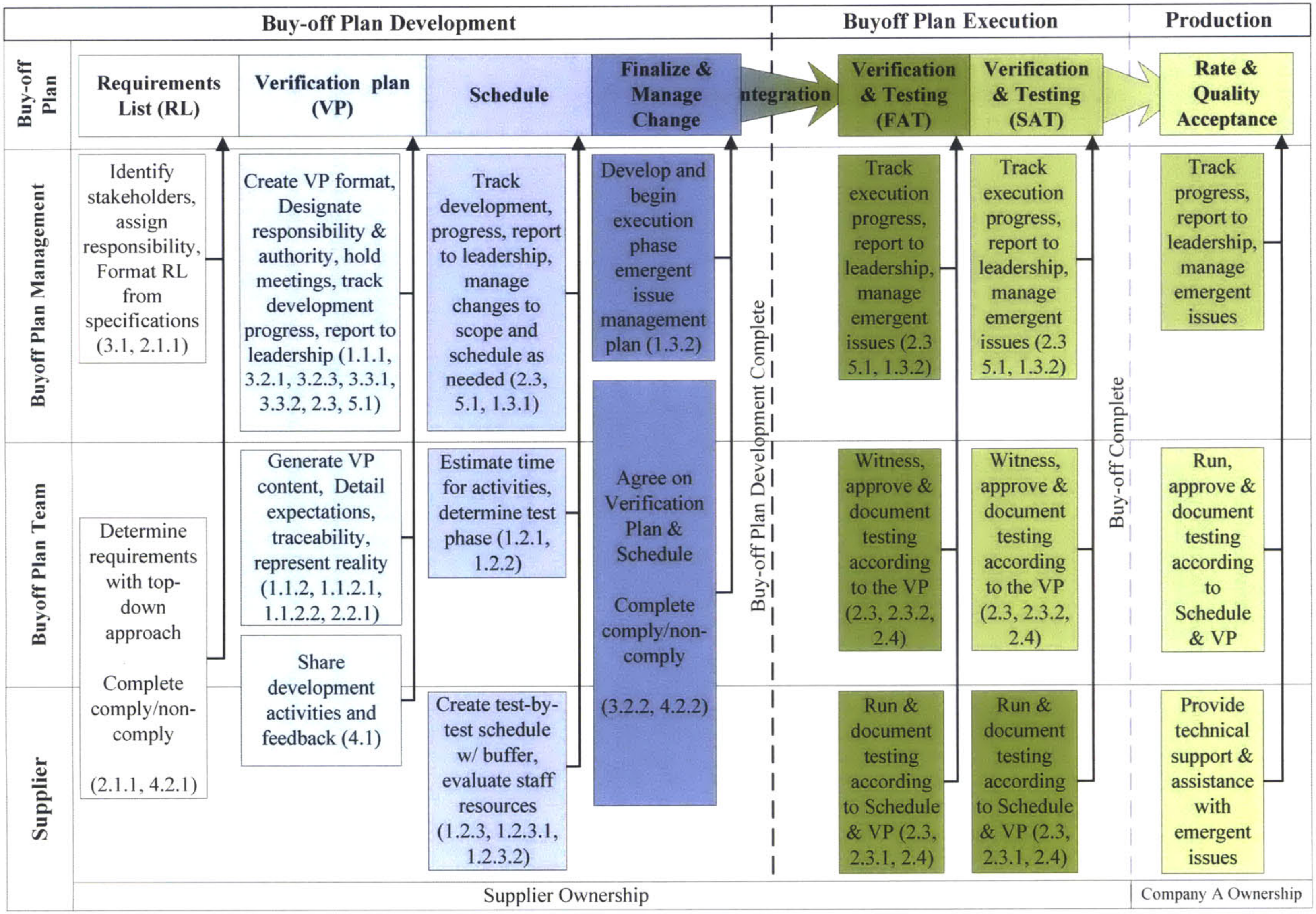


Figure 5-1 Approach to Buyoff Plan Development and Execution

5.3 Data: Buyoff Plan Development Progress

In this section, each step of implementing buyoff plan development is described briefly along with observations of why the team was able or unable to meet schedule targets. The team worked on developing the buyoff plan from September – December 2014 and continued in 2015 following the conclusion of this research.

5.3.1 Identify stakeholders & Get buy-in

The first step of buyoff plan execution was to identify stakeholders. Recall that stakeholder is defined as an individual whose documented approval is required prior to system buyoff. In order to determine the stakeholders, the approval documentation required by the Company A Site Services group was evaluated. The key signatories, Equipment Engineering, buyoff customer PGB Operations, and Environmental Health and Safety were also asked who should be involved in system buyoff for their final approval. The stakeholder group is shown in

Figure 2-4. Note that some stakeholders represented in the figure include more than one person due to differing technical expertise.

In order to get buy-in, individual meetings were held with every stakeholder to describe the buyoff plan design and the schedule for completing the development phase. Buy-in was easy to get and stakeholders were generally happy to have somebody helping with buyoff plan development. Stakeholders were very supportive and helpful and shared their role and their needs openly.

Note that one key signatory, Tooling Engineering, was involved much later in the project than the others because the important role of Tooling was not made clear by project leaders or other stakeholders for 5-6 weeks after the project start. In the first meeting with Tooling, it became clear that Tooling has been progressing behind the other key groups throughout development of the Component. This was later confirmed by managers. It also became apparent that Tooling had an enormous role in buyoff plan development in order to complete required tooling documentation for regulatory approval by the Federal Aviation Administration.

5.3.2 Assign responsibilities for buyoff plan development

Given the huge scope of buyoff plan development, responsibilities were assigned for each stakeholder, with multiple stakeholders being assigned to tasks that might require multiple expertise. The Requirements List (RL), derived from the purchase specification, was used to delineate each stakeholder's responsibilities for (1) both confirming that each requirement was applicable to the current design and needed to be tested and (2) documenting test procedures, required results, tools, materials, traceability to the RL and personnel in the verification plan.

5.3.3 Developing the Buyoff Plan

Stakeholders' progress on completing responsibilities (1) and (2) above was tracked automatically in the RL document. Tracking was reported in weekly meetings to leadership and monthly meetings with senior managers. Once tracking was fully implemented, only about six weeks before the buyoff plan development deadline, the speed of verification plan completion increased significantly.

During development of the buyoff plan, regular "Cross-share" meetings were held for each stakeholder to share what they'd been working on. The intention was to raise awareness for the interfaces between each stakeholder's responsibilities and identify any gaps in testing that needed to be addressed. Key issues were discussed and resolved key at each one of these meetings.

Collaborating with the supplier was also a key part of execution. To unburden the Company A stakeholders, the Systems Engineer kept the Supplier fully aware of the work that was going on at Company A and shared Supplier feedback with the internal team. The stakeholders and Supplier were all interfacing several times a day, but generally focused on automated assembly system design, not buyoff plan development.

With the high density of meetings that stakeholders needed to attend, it was important to highly value their time and make an effort to keep meetings short and useful. Time management was a serious issue throughout the project. Most of the stakeholders were coming to the office on the weekend in order to work on the buyoff plan because there was no time for it among their regular responsibilities. It was also important to make sure that stakeholders weren't completing any work that they didn't see as value-add. Meetings with stakeholders helped to refine the verification plan design so that it was easy to use and contained only the information necessary to satisfy the goals of system buyoff.

Unfortunately, the verification plan was not always easy to use. After struggling to keep the main verification plan document up to date, Company A IT systems experts set up collaborative documents that the team could all edit at once with versioning control. This worked for a short period of time before becoming impractical due to the fact that not all Company A computers had the capability to access the collaborative document with full functionality. The IT systems experts that had set up the system recognized this problem and didn't have a work-around.

Time management was difficult for the entire team, including the Supplier, which was critical to the scheduling process that would complete buyoff plan development. Towards the end of the project, a new schedule completion estimate was solicited from the Supplier about when they could get their schedule-development tasks done considering everything other PGB teams were demanding from them, some demands anticipated and many emergent. The estimate added two months to the expected completion date. This means that at least six months were needed in order to complete buyoff plan development in the context of PGB.

5.3.4 Buyoff Plan Execution

Buyoff Plan execution will occur over the course of the next year, as the team moves through system integration, the FAT and the SAT. After being closely involved in developing the buyoff plan, the stakeholders will hopefully be comfortable with their responsibilities during the FAT and SAT. It will be critical to the success of the FAT and SAT to dedicate sufficient resources to maintaining documentation of testing status and results in the verification plan.

The project should be monitored during the FAT and SAT to collect lessons learned for improving the buyoff plan moving forward. The team may want to track daily progress to schedule and note events that cause overall schedule delays. Also, the team may want to track any capabilities of the system that they believe are at risk for not meeting performance requirements closely. It is recommended that the team record the process of confirming these capabilities are functional as well as any emergent events related to debugging the system carefully in order to maximize learning about the system. Stakeholders should meet after the FAT in order to apply any improvements to the buyoff plan prior to the SAT.

5.4 Analysis

Three challenges observed during buyoff plan development also recurred throughout this research, especially in the interviews and lessons learned. These issues may have been mitigated by development of the buyoff plan, but are likely to continue impacting the project through buyoff plan execution, because they stem from the early phases of the automated assembly system life cycle. Key elements of these challenges are discussed in this section.

5.4.1 Time Management

Many participants in the interviews completed as a part of this project advised to start planning as early as possible. In the case of the PGB team, that moment had already passed, but there was still a significant amount of time to work with, four months prior to integration of the system starts and over eight months before the start of the FAT. The time-crunch challenge, however, was compounded by the work load that stakeholders were already balancing. Stakeholders did most of the buyoff plan work on the weekend.

In *An Analysis of the Requirements Traceability Problem*, Gotel and Finkelstein acknowledge that time management was a common problem of the projects in their study on what causes trouble with implementing requirements traceability. They suggest that creating requirements traceability through a verification plan is, "perceived as an optional extra and considered low priority" (7) resulting in an insufficient allocation of time, staff and resources.

While PGB leadership outwardly recognized the importance of the buyoff plan, there was no plan for how stakeholders would realistically complete buyoff plan development tasks in addition to their other work. Stakeholders' design work and managerial tasks were repeatedly prioritized over the buyoff plan effort.

5.4.2 Buyoff Plan Start

As noted previously, systems engineering principles say that consideration for how a requirement will be verified should occur throughout the writing and refining of the requirement (2). The PGB automated assembly system purchase specification, which served as the basis for the requirements list, was previously developed by a team including many buyoff plan stakeholders and owned by the Supplier Management group. Requirements in the specification were not often traceable to customer or operational needs and generally didn't include sufficient information on verification expectations. The purchase specification included repetitive, out of date and overly-strict requirements.

Gotel and Finkelstein found these types of requirements to be symptomatic of a late-starting requirements management effort. In fact, the most commonly cited problem in their investigations, the inability of a team to access the source of requirements originating prior to specifications, was reported to be a major contributor to many buyoff planning challenges including, "out of date RS [specifications], slow realization of change, unproductive conflict resolution, poor collaboration from changing work structures and responsibilities, difficulty integrating new team members, poor reuse of requirements" (7). Many interviewees from the other Company A projects warned of these exact problems which were also apparent during buyoff plan development with PGB. In their study, Gotel and Finkelstein suggest that the way to achieve significant progress in fixing these problems is to focus on fixing what they refer to as the "pre-traceability problem," which requires attention to requirements management beginning at the start of project development.

Undertaking a thorough requirements development process that includes verification planning as a part of creating the specification and keeping the requirements up to date would have eliminated much of the work the PGB team had to do in order to extract a good requirements list to base testing on from the purchase specification.

5.4.3 Realism vs. Cost

Related to the late consideration for system verification is the lack of real parts that PGB has to use for automated assembly system testing. Due to lead times and cost, the team decided very early in project development to allocate only one set of test parts to the FAT and one to the SAT as well as one set of production parts. As other PGB group needs for parts arose, like testing and certification, these part sets became incomplete and not dedicated to the use of the Supplier during integration and testing. The lack of parts caused a lot of time and stress throughout buyoff plan development. Every day, conversations revolved around how to show functionality on a test stand or material sample and how to debug and calibrate the system without practice.

The lack of parts also highlighted a major cultural difference between the Supplier and Company A which continually caused tension. Company A is accustomed to buying equipment after inspecting every component and function and tweaking the equipment during testing or even production until it is working optimally. With the high cost of parts and initially low production rates, this practice may be the most cost effective choice. The approach reflects the craft manufacturing roots of Company A and the Equipment Engineering procedure for acquiring a piece of equipment. The Supplier, rooted in the highly automated auto industry where there is a low cost of parts and little to no production ramp up time, generally provides an entire system of equipment, highly interconnected and interdependent. The Supplier is accustomed to showing that the system can meet its full requirements by running sometimes hundreds of parts, debugging the system as it encounters inevitable variability and documenting that the system achieves a consistent quality of work.

Defining the scope of the buyoff plan together with these very different approaches was very difficult and is still likely unresolved in undiscovered ways. While, as the test model in Chapter 5 showed, investing in parts to use for system testing and verification would help improve confidence in the outcomes of equipment buyoff, the cost of parts needs to be considered. Kossiakoff confirms that the trade-off between cost and realism is an "inherently systems engineering issue." He notes that added realism increases the "degree of confidence in the validity of the result," (2) which directly reflects PGB Leadership's number one goal for the buyoff plan development, to "Result in Company A confidence in the functionality of the system in the Company A environment." PGB team members included additional testing requirements in the buyoff plan to help build confidence in system functionality in ways that didn't require parts, because of the decision to procure minimal parts in the project's infancy.

Many interviews with other Company A projects resulted in lessons learned related to driving towards increased testing realism. The project with successful buyoff results that had benefitted from the lessons learned of four previous similar procurements invested 10% of the project cost in development of a major product component purely for testing from the start of the project. No other projects had as clear a definition of the balance of cost and realism. A significant research opportunity lies in defining the financial implications of the key factors in the cost vs. realism balance at Company A. Although frequently cited as such, it is unclear whether the high cost of product parts and slow production ramp-up are justified rationale for a low level of realism, lost confidence in the system, resulting increase in unrealistic testing and the lack of ability to prove out a manufacturing process fully before using production parts.

5.5 Results & Conclusion

The team did not finish buyoff plan development in four months, but had a fully established requirements list and a 90% complete verification plan. Time management was the single biggest driver of inability to meet the schedule. Although the stakeholders were expected to complete the buyoff plan and they understood the importance of it, they didn't have the time resources to participate fully or during weekday hours. Time management was also difficult for the Supplier, who was critical to the scheduling process. It is expected that approximately two more months of Company A-Supplier collaboration would be required to complete the requirements list, verification plan and schedule fully.

Although completed outside the scope of this study, observation of buyoff plan development reflect systems engineering texts and the advice of interviewees from Study 2 to begin planning for verification with requirements development and maintain an up-to-date requirements list throughout project development. Observations also highlight the importance of considering the impacts of low investment in testing parts for an automated assembly system. With few test parts, the PGB team is faced with burdensome unrealistic testing and the lack of ability to prove out a manufacturing process fully before using production parts

Chapter 6
Results

6.1 Results

In response to a wide spread perception that automation projects at Company A are procured from suppliers with schedule delays and performance deficiencies and the compounding challenges of procuring the PGB automated assembly systems, three key studies have been undertaken as a part of this research. The studies showed a range of results in Company A automation procurement and drove the PGB initiative to develop a buyoff plan for the Component automated assembly system project. Results from each study are outlined in this section.

1. Why is there a perception that projects are bought off with schedule delays and performance deficiencies?

It was found that there was a range of success in completing project buyoff with one project delivered on time with no deficiencies and several projects delivered late with deficiencies. This range of results was associated with a range of approaches to planning and execution of automation buyoff, including more or less structure to requirements development, documentation and stakeholder involvement. Application of a systems engineering approach and inclusion of lessons learned from previous projects were cited as key success factors by participants in two projects that were able to minimize schedule delays and eliminate performance deficiencies. In contrast, projects bought off with delays and performance deficiencies suffered from poor quality requirements and related communication disconnects.

2. What can be done to ensure the PGB automated assembly project is purchased on-time with zero performance deficiencies?

It was found that an approach to buyoff plan development and execution based on systems theory has the potential to improve automation project buyoff with respect to schedule and performance. The approach was also improved to include Company A organizational knowledge by applying lessons learned from similar projects. The impact the design would have on schedule delays and performance deficiencies at buyoff was tested by building a model with a base case using observation data from developmental cell FAT testing and a test case.

The test case, in which the buyoff plan design drove revised conditions and outcomes, showed that application of the buyoff plan would improve buyoff outcomes, both schedule and performance related. The model also showed that the buyoff plan wouldn't change all unfavorable outcomes including those resulting from emergent issues, like a hose leak. The model's significant limitations, including inability to predict human behavior and account for other outcome constraints, such as costs, were also noted in the results. For example, the buyoff plan was shown to have a greater impact on outcomes related to real-parts testing than feasible given that the number of real-parts to be tested was previously determined during capital budgeting.

3. Can the PGB team develop a buyoff plan according to the methodology in four months?

The team did not finish buyoff plan development in four months, but had a fully established requirements list and a 90% complete verification plan. Time management was the single biggest driver of inability to meet the schedule. Although the stakeholders were expected to complete the buyoff plan and they understood the importance of it, they didn't have the time resources to participate fully or during weekday hours. At the end of four months, the team estimated completion of buyoff plan development after another two months of work.

Chapter 7
Conclusion

Product Group B is facing many challenges as demand for the Product increases and they support Company A's move towards vertically integrated production of the Component. The group has designed the Component and the facility to manufacture the Component including an automated assembly system being designed and built by a supplier. As the automated assembly system approached the integration, evaluation and test (IET) phase of its life cycle, the lack of a comprehensive buyoff plan rose as a new challenge. The buyoff plan should describe the activities of the IET phase that will be completed to show the system can meet customer and operational requirements.

In response to concerns about other automation projects that were subject to schedule delays and performance deficiencies at the time of buyoff from a supplier, this research evaluated three successive questions and drove the team to begin developing a comprehensive buyoff plan. An approach for buyoff plan development and execution developed based on systems engineering concepts and lessons learned from past projects has provided Company A with an approach that can be repeated and refined for future phases of automated assembly system development.

This research not only shows one effective approach to developing a buyoff plan, but brings to Company A leadership's attention several systemic issues common to requirements traceability efforts that have plagued automation projects over and over again. These include time management, developing a thorough requirements list in consideration of verification planning at the start of the project, and balancing cost and realism.

It is recommended that PGB track the successes and failures of the buyoff plan to meet their needs as a guide and tool throughout the execution phase and improve upon the documents and methods moving forward.

This research also suggests topics of further research to increase the decision-making power of PGB and other Company A leaders. Research topics include defining the cost vs. realism curve for the industry. This research should attempt to help determine what level of spending on real-parts acceptance testing is optimal given the high cost of product parts and slow production ramp-up vs. the impacts to a product program of poor buyoff results, lack of confidence in automation and a potentially incapable production system. Defining this field further could lead to new ways of thinking about setting expectations for acceptance testing and production start-up. Company A also has the opportunity to continue developing the process of buyoff plan creation for inclusion in the recently developed enterprise-wide production integration readiness levels (PIRL). Although the PIRL outlines a gated process for production system development including early and thorough requirements management, they do not yet include any guidance for detailed verification planning or execution.

Appendix

Interview Data - Lessons Learned from Automation Procurement Projects by Theme
Engage Stakeholders in unified team approach
A good buyoff plan tool will force everybody to be on the same plan, see everything and buy-in
Bring a maintenance mechanic into the buy-off process early
Chose locations to maximize productivity and support the development environment
Create intentional interaction between stakeholders
Don't assume that each stakeholder can meet requirements, get confirmation that they can
Early review and agreement on verification plan was good but not sufficeint. Need more touch points. Otherwise, everything is vague and people agree to plans with no details
Get appropriate expertise involved in final buyoff
Get groups to review eachother's plans, interact together, agree with eachothers plans
Groups didn't spend the time to learn eachothers requirements, even though it was their "homework." Force groups to know what the others are concerned with through meetings/interaction.
Hold ups are often Company A driven - hammer out issues that are likely to cause a lot of back and forth in the process in advance
Include a daily tag-up during the FAT/SAT to update accomplishments, alterations, start times, etc.
Involve all functions from the beginning
Involve EHS from the start and force in-depth discussion
Involve key team members as soon as possible
Keep the work near personnel resources
Lacking communication between Engineering, Research, Supplier led to not updating requirements appropriately
Limit late-phase requirement additions by involving support functions up-front. For example, Safety
Machine requirements drove procurement, and it should have been engineering and process requirements. Supplier didn't get the full picture of requirements.
Make buyoff plan similar/analogous to the enterprise gated process
Make EHS part of the team, not support group. Build trust, credibility, honesty among team to avoid the "EHS is in the way" perspective later
Make sure the supplier knows what they're doing, why and how
Put the project in a setting that is friendly to start-up and development culture
Start with "What do I need to buy-off the system?" Work from there
Understand change process for all stakeholders
Use the enterprise gated process

Use the standard gated process to get good requirements
Verification plan should include true-life conditions and expectations
Always talk about the function of equipment when discussing with EHS and requirements
Avoid "see OSHA..." safety requirements, get specific, use 3d images when possible
Avoid safety requirements that reference OSHA or compliance docs, interpret the relevant compliance issues according to your system
Balance the cost of parts and the need to test
Based on the purchase spec, the requirements were not interpereted by the customer as we thought they would be
Be specific with requirements and specification
Be sure the controls being purchased include interfaces to the Company A system
Confirm functionality of unique processes and then run the process in a way that's similar to production.
Consider usability
Define expectations from Company A
Define requirements, expectation and acceptable limits
Define tests and methods up-front
Don't allow a grey area in testing, make everything pass/fail
Don't let IT buy-off one robot at a time, which is the tendency. Interconnections matter
Flow-down requirements to acceptance testing documents
Have a mechanic run the machine for testing
Include thorough, well-written testing in the FAT
Learn from EHS experience at other facilities/projects - to help determine what is REALLY a requirement
Make testing as close as possible to build conditions, include challenge areas
Make the buy-off process as life-like as possible - real parts, real systems connections.
Need knowledge - training
Need parts or accesibility to parts
Pay attention to test timing being developed and keep realistic.
Specify the true end product requirements
Use the equipment as intended to buyoff quality
Plan sufficient resources for verification planning & testing
Allow the supplier to push back the acceptance testing date if they're not ready
Build in schedule "fluff" for surprises. Acceptance testing took 2ce as long as expected
Create a rigid schedule, build in buffer daily
Employ a full-time systems engineer
Ensure that the daily agenda is accurate and includes buffer
Have a daily tag-up and review during acceptance testing
Have a full-time support team on site for acceptance testing
Have an analyst responsible for keeping the docs up, tasking action owners, elevating issues

Have Company A teammates on site to confirm whether the supplier is ready for acceptance testing
Keep 1 - 2 months of buffer in the schedule for software debugging
Plan for normal or short days
We hired from the top down and had director-types soley on the project for too long. Need worker-bees to get things done.
Front-load resources and buyoff plan development
Allocate the time and money upfront to avoid a stressed resources problem -
Create quality acceptance criteria with error distribution as soon as possible
Determine which components are likely to fail with a priority matrix and focus component-level testing on these
Develop sampling plans for testing in advance
Every organization has their own internal change process. If a system requirement triggers this change process, it could be months of delay (particularly for IT). Start potential triggers early
Practice/Pilot the FAT - create milestones in the integration phase, determine a sub-set of tests to practice before FAT
Put in the effort up-front to plan and prepare, acceptance testing will go smooth
Rolling acceptance testing throughout integration is a good practice, it pushes earlier integration, mitigating risk
Run reliability testing prior to functional testing
Talk through what is going to happen out on the floor step-by-step
Tie the requirements and testing discussion into design review stages from project start
Base the buyoff plan on well-founded requirements
Center acceptance testing around engineering requirements
Challenge managers, leaders, planners... How do you KNOW you've captured all the requirements in your process? How can you validate your assumptions?
Check that each requirement is necessary
Check validity and relevance of all requirements
Evaluate necessity and purpose of requirements in spec
Every time you make a decision... ask what requirement are you meeting?
Get rid of out of date engineering requirements
Relax requirements with tight tolerances that don't need to be that tight
Collaborate with the supplier
Agree together that programming will be ready
Avoid specifying make/manufacturer, etc. leave to supplier
Competitive and non-collaborative relationships between Company A, Supplier 1 and Supplier 2 made resolving issues more difficult
Don't have correspondence without following up in writing, include supplier management and ask for confirmation of receipt
Get the testing plan to the Supplier for feedback before finalizing it
Give the Supplier enough time w the final test plan to try it out, bring up issues

Pose clear questions and include a follow-up date
Strike a balance between specifying and not over-specifying. Leaving testing methodology to supplier when possible will eliminate them being caught w wrong tools, etc.
Define responsibility & authority for requirement verification
Consider breaking up testing/requirements into subsets based on statement of work to create ownership
Define ownership of testing among supplier/sub-suppliers
Define test ownership up-front
For each group establish a short check-list to determine whether they need to be involved in a decision
Have the right decision-making authority on the floor to address issues & change requirements/tests as necessary
Manage only one contract, leave the rest to the supplier
Manage emergent issues
Except the machine with issues, as long as they don't impact the ability to build the part
Have an internal discussion and a game plan prior to bringing issues to a supplier
Long term service contract is very valuable
Make sure that decisions on test/requirements changes are traced back to the person responsible
New perspectives get added to the team or team members change and requirements/expectations change. Be prepared to manage this
Plan for managing emerging issues: meeting the spec, but not meeting expectations; or not meeting the spec
Senior leader visibility and support is required for success
Create an interface for leaders to easily look-in and evaluate progress, they'll be confident and stay out of the way
Executive sponsorship is critical to success. Need to get money for the project and keep excess visitors out.
Get leadership involved early, particularly with IT, to override manager-level processes
Need the PM to hold teams to the plan and interaction requirements
Show that you're meeting the gates in gated process
The tool will only work if leadership owns it beginning to end
When asking leadership for help, define and find the help that you want first so they can efficiently get it for you

Works Cited

1. **INCOSE.** What is Systems Engineering. *Incose.org.* [Online] 2 17, 2015. http://www.incose.org/practice/whatissystemseng.aspx.

2. **Kossiakoff, Alexander.** *Systems Engineering Principles and Practice.* Hoboke, NJ : Wiley-Interscience, 2003.

3. **INCOSE.** *Systems Engineering Handbook: A Guide for System Lifecycle Processes and Activities.* San Diego, CA, USA : Incose-TP, 2006.

4. **Eisner, Howard.** *Essentials of Project and Systems Engineering Management.* New York, NY, USA : John Wiley & Sons, 2008.

5. **US Department of Transportation.** *Testing Programs for Transportation Managment Systems.* Washington, DC, USA : Federal Highway Administration, 2007.

6. **Spear, Steven J.** *The High-Velocity Edge.* New York : McGraw Hill, 2009. 978-0-07-174140-8.

7. *An Analysis of the Requirements Traceability Problem.* **Gotel, O.C.Z and Finkelstein, A.C.W.** Colorado Springs, CO, USA : IEEE, 1994. Proceedings of the First International Conference on Requirements Engineering, 1994. pp. 94-101.