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Agile in Equipment Manufacturing: Concept to Implemention

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Abstract:
This review examines the growing adoption of Agile methodologies in manufacturing not only software development. Agile principles—such as iterative development, modular design, and enhanced collaboration—are increasingly being adapted to address the unique challenges of hardware-focused industries, including high costs, supply chain complexity, and the need for precision. The paper discusses how Agile frameworks and digital tools like Jira and Confluence can be tailored for manufacturing environments, emphasizing the importance of robust workflow management and document versioning. Adapting Agile practices enables organizations to improve responsiveness, product quality, and competitiveness in a rapidly evolving industrial landscape.

Keywords: Jira, Agile, Confluence, Product Management and Operations Management.

I. INTRODUCTION

Traditional Waterfall methodologies have always dominated the mechanical industry. The advantages of Agile continue to grow in visibility which results in higher adoption rates and successful case studies. The development patterns show mechanical product development moving toward more iterative approaches with customer focus and collaborative practices.

The implementation of Agile methodologies increases in popularity throughout mechanical engineering practices.

1) Reduced Time to Market: By breaking down projects into smaller, iterative cycles, mechanical teams can deliver working prototypes and components more frequently, accelerating the overall development timeline.
2) The implementation of Agile creates better collaboration between employees and enhances their participation within the organization.
3) Companies can adapt their operations more effectively through the implementation of Agile systems.
4) Product quality increases when manufacturers use continuous testing and feedback mechanisms along with iterative refinement to develop products that fulfill user requirements.
5) Early identification and resolution of problems through regular testing and feedback reduces the expenses associated with failures during advanced development stages.

B. Key Themes and Examples:

1) John Deere's Agile Transformation (Global IT Group): The IT department of John Deere achieved significant success through their Agile implementation while focusing on IT development, but their experience provides valuable lessons to industrial companies that contain substantial mechanical engineering elements. Their 2021 report (published around 2022) highlighted, the company achieved more than 100% ROI in return on investment.[1]The company increased their output by 165% while decreasing their time to market by 63%.[1]The function/team level showed major improvements because they delivered 10 times more features during each sprint and they deployed 15 times more frequently.[1]

The success of Agile implementation proves that traditional industries can achieve both efficiency and speed improvements.

2) *Bosch's Innovation in the Industrial Sector:* Bosch serves as a worldwide engineering and technology company that applies Agile methods to enhance organizational innovation while optimizing its wide range of products. The company initiated its Agile adoption through experimental projects in small teams before expanding the implementation to other parts of the organization.[2]

3) *LEGO:* They experienced a transformation when they implemented Agile methodologies to manage their product development teams during the early 2000s product portfolio expansion and declining sales period. Faster development times for popular products like LEGO Friends and Ninjago. The market became more responsive to customer feedback because of the changes implemented by the company.

The organization achieved higher operational efficiency while reducing waste through the implementation of streamlined procedures. Agile brought a hardware-based company into alignment with fast-moving market trends.

4) *Mercedes-Benz's Shift from Hardware to Software:* Through the adoption of Scaled Agile Framework (SAFe) Mercedes-Benz has transitioned from hardware-centered operations to integrating more software-based features in their vehicle products. The implementation of Agile supports complex interdisciplinary product development where mechanical and software engineering converges in modern times.

The implementation of Agile has become fundamental for mechanical engineering success stories because companies rely on multiple rounds of prototyping combined with testing and feedback collection. Through the Agile approach mechanical teams get to detect issues at an early stage which enables them to investigate alternative design paths while confirming that their final product fulfills customer needs. Through the implementation of 3D printing and simulation software companies can perform rapid iterations that outperform traditional sequential methods.[3]

Agile promotes organizational collaboration through the elimination of departmental silos that separate design from engineering from manufacturing and marketing from sales and customer teams. This approach ensures product development stays in line with both market requirements and customer expectations throughout the entire process.[4]

The Agile Systems Engineering (ASE) principle-based method gains popularity for designing and building systems under uncertain knowledge conditions and dynamic environments. Complex mechanical projects benefit from this approach since requirements tend to change after the development cycle starts.

II. PAIN AREAS IN MANUFACTURING

Semiconductor equipment manufacturing serves as a digital age enabler through its operation within a specific industry that faces multiple complex interrelated challenges. The combination of precise operations with fast technological progress along with worldwide supply chain complexity generates these industry challenges. Here are the key pain points:

A. Exorbitant Costs and Investment:

The establishment of modern semiconductor fabrication facilities requires investments of tens of billions of dollars for construction and equipment acquisition. The cleanroom facilities require substantial investment but manufacturing equipment stands as the most expensive component.

The cost of EUV (Extreme Ultraviolet) lithography systems reaches between $150-$350 million each because these machines are essential for advanced chip node production. The machines incorporate hundreds of thousands of parts alongside requiring multiple years of research development.

The ongoing requirement for Moore's Law progress and miniaturizing transistors drives equipment manufacturers to spend significant resources on research and development for innovative processes and tools. The process of developing this R&D requires significant financial investments together with long development times without assurance of successful results.

The manufacturing process for wafer printing masks becomes significantly more expensive at advanced node levels because of their advanced complexity. The expensive nature of prototyping becomes more pronounced because of the necessity for "first-time right" designs.
The expenses of operating cleanrooms together with managing ultra-high-purity materials and running sophisticated equipment result in substantial ongoing operational costs.
B. Supply Chain Fragility and Geopolitical Risk:
The semiconductor supply chain operates through a complex web of global interdependence which spans thousands of companies spread across multiple continents. The entire ecosystem remains vulnerable to disruptions because it draws its raw materials and components and specialized services from different nations.
The semiconductor supply chain faces severe disruptions because of trade wars and export controls and sanctions between countries such as the US and China. The flow of essential equipment together with vital raw materials including rare earths, gallium, germanium and design software becomes limited because of geopolitical tensions which creates production bottlenecks.
The majority of advanced chip production facilities together with equipment manufacturing operations are found in East Asia for fabrication plants and Netherlands for EUV machines. The industry operates with high risk because its production facilities are mainly located in limited geographic areas making it vulnerable to regional natural disasters and political instabilities.
The manufacturing process comes to a halt because of raw material shortages or supply disruptions caused by conflicts or trade restrictions. The shortage of neon gas from Ukraine and silicon and tantalum materials creates production halts because of their critical status.
Many Original Equipment Manufacturers (OEMs) face difficulties in understanding their suppliers at levels two and three because it becomes hard to detect and handle risks that exist deep in the supply chain.
The highly sensitive nature of semiconductor equipment and components demands specialized transportation and handling which creates additional logistical challenges and potential delays.
C. Talent Shortage and Skills Gap:
The industry experiences two major challenges because its workforce ages while STEM graduates become scarce in fields necessary for semiconductor production and equipment development. The industry faces a talent shortage because experienced professionals are retiring from their positions.
Multiple technology sectors compete intensely for the limited supply of skilled engineers and scientists and technicians who possess expertise in mechatronics and AI/ML and advanced materials and process optimization and precise optics.
The fast technological development results in skills becoming outdated at a rapid pace. The industry requires ongoing training for its workforce to adapt to new manufacturing techniques and automated systems and emerging materials and automation technologies including AI/ML-based defect prediction and real-time monitoring systems.
The industry faces two challenges: its brand image appears less attractive to young professionals when compared to other leading technology companies and engineers often refuse to move to specific fabrication hubs because of living costs or absence of remote work options.
D. Manufacturing Complexity and Precision:
Ultra-High Precision Requirements: Semiconductor equipment deals with dimensions at the atomic level. An entire chip batch becomes useless when the smallest vibration or defect or impurity occurs in the manufacturing process. The manufacturing procedures require high precision alongside rigorous quality inspection protocols.
The complex semiconductor equipment production process spans over one year which makes it challenging to adapt rapidly to unexpected market demand changes.
The production and operation of semiconductor equipment requires cleanroom environments to maintain product purity while increasing both expense and complexity.
Vibration Control: The increasing requirement for precise manufacturing in dynamic environments presents a growing problem to the industry. Product defects occur when manufacturing experiences small disturbances

so innovative vibration control solutions have become essential especially when equipment needs to be placed in suboptimal locations.

The manufacturing process needs constant optimization to achieve maximum functional chip production from each wafer (yield) because defects severely affect profitability.

E. Rapid Technological Advancement and Obsolescence:

"More than Moore" and Advanced Nodes: Equipment manufacturers need to continuously innovate because the industry demands new materials and manufacturing methods and architectural advancements (e.g. 3D ICs, heterogeneous integration) for advancing beyond traditional scaling barriers.

Fast Product Cycles: The semiconductor industry maintains an unrelenting speed in its innovation process. The short product
life cycle of equipment demands major R&D investments to develop both tool upgrades and new tool generations.

Integration Challenges: The increasing complexity of chips through Systems-on-Chip integration requires equipment to handle diverse engineering domain challenges across different disciplines.

The solution to these challenges requires substantial funding alongside international partnerships together with skilled talent development initiatives and sustained technological advancement and supply chain flexibility efforts.

III. IMPLEMENTATION AND CHALLENGES

In the context of equipment manufacturing, particularly within high-complexity and regulated industries, the direct application of software-based Agile frameworks often proves inadequate. Instead, a tailored approach that adapts core Agile principles—such as modular development, iterative build cycles, and cross-functional collaboration—can yield significant benefits. Table 1 presents a structured overview of these adapted practices, illustrating their implementation, relevance, and associated outcomes in hardware-focused product development environments.

TABLE I. -ADAPTATION FRAMEWORK

Agile Concept	Adapted Practice	Example	Key Benefits
Modular Design & MVS	Build independent subsystems as “Minimum Viable Systems”	Robotic arm, vacuum chamber as standalone modules	- Early flaw detection [5] - Parallel builds - Easy upgrades
Iterative Build Sprints	Use 2–4 wk. time-boxed sprints	Sprint for frame build; next for software install	- Predictable timelines - Early detection -Continuous testing [6]
Cross-Functional Teams	Multi-disciplinary teams per module	Mech, Elec, SW, QC on one subsystem	- Faster fixes - Clearer comms [7] - Shared ownership [8]
Kanban Flow	Visual boards to track WIP	Machining → Assembly → Testing flow	- Visibility - WIP limits - Pull system - Spot bottlenecks [9]
Daily Stand-ups	10–15 min team huddles	Station-level check-ins	- Fast issue resolution - Daily sync - Boost accountability

Customer Feedback Loops	Internal stages act as customers; use field input	Integration flags issue in upstream part	- Quality improves - Quicker response to needs [10]
Lean Integration	Combine Lean tools with Agile	Use VSM or Kaizen in assembly	- Less waste [11] - Faster flow

A. Challenges and Considerations:

Cost of Change in Hardware: Unlike software, making changes to physical hardware is expensive and time-consuming. Agile in this context means "deferring commitment to the last responsible moment" through modularity, but not limitless changes.[12]
Long Lead Times for Specialized Components: Agile production needs to work within the constraints of long lead times for custom or exotic materials and parts. This requires sophisticated planning and strong supplier relationships.
Highly Regulated Environment: Semiconductor equipment must meet stringent quality and safety standards. Agile processes must be rigorously documented and auditable.[13]
Upfront Design Still Critical: While iterations are key, a solid upfront architectural design for the entire equipment is still vital. Agile helps refine and build upon this architecture.
By carefully adapting Agile principles to the unique demands of semiconductor equipment manufacturing, companies can achieve greater responsiveness, higher quality, and ultimately, a more competitive edge in a fast-paced, high-stakes industry.

IV. JIRA SET UP

By carefully adapting Agile principles to the unique demands of semiconductor equipment manufacturing, companies can achieve greater responsiveness, higher quality, and ultimately, a more competitive edge in a fast-paced, high-stakes industry. Before jumping into more details, understanding Jira hierarchy is critical. Following are the default issues types within Jira but customized fields can be created.

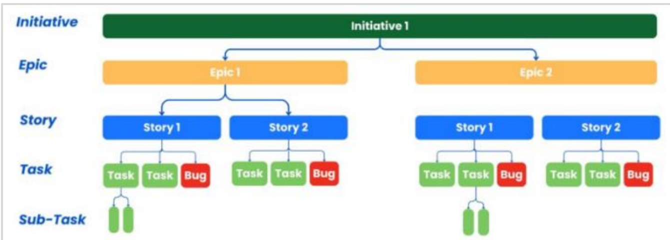

Fig. 1. Hierarchy of Issue Types in Jira[14]

A. Jira Issue Types

1) ***Initiatives***: Long-Term Product Development Goals
At the highest level, Initiatives define strategic objectives that span multiple engineering and operations teams. For example, an Initiative like "Launch Next-Gen Wire Bonder Platform in 2025" may encompass multiple development areas—such as mechanical design, software upgrades, and manufacturing readiness.
2) ***Epics***: Major Workstreams or Systems
Epics break Initiatives into major workstreams. For example: Design New Assembly Module, Develop Control Software for New Motion System, Validate Prototype for Production Transfer etc.
Each Epic represents a substantial chunk of work involving multiple disciplines—mechanical, electrical, controls, and manufacturing engineering.
3) ***Stories and Tasks***: Engineering and Operational Activities. Below Epics, Stories and Tasks capture the actual work:

- **Stories** describe user or stakeholder needs, e.g., "As a test engineer, I want the HMI to log bonding cycle time for traceability."

- **Tasks** represent general engineering work, such as “Model thermal shield brackets in CAD” or “Create assembly procedure for new feeder arm.”

These items are critical for tracking progress within each Epic and aligning teams on deliverables.

*4) **Sub-tasks**:*Executable Steps on the Ground

Sub-tasks break down Stories or Tasks into actionable steps, such as:

- For the Task “Model thermal shield brackets in CAD”, sub-tasks might be e.g. “Review thermal specs with thermal analyst”, “Create 3D CAD model in SolidWorks” and “Generate drawing for DFM review”

This granularity ensures clarity and accountability across design and manufacturing teams.

5) Other Issue Types

Jira allows customization with additional issue types relevant to equipment manufacturing:

- Bugs – For design or integration defects, e.g., “Axis stalls during homing sequence.”
- Improvements – Suggestions for existing systems, like “Reduce changeover time by redesigning feeder access panel.”
- Incidents – Track unexpected events, such as “Prototype unit failed thermal cycling test.”
- Service Requests – Common in factory support, e.g., “Request new tool fixture for Assembly Station X.”
- Change Requests – Manage scope shifts like “Update motor spec due to supplier phase-out.”

B. Implementation Example

The following is one of the examples from manufacturing industry where PLM (Product Life Cycle Management) is managed in Jira workspace.

1) *Jira Default Fields*

- **Epic:** Represents a major milestone in the process of the machine build so it can machine modules, machine integrations, power up, system calibrations and packing. Try to use epic names which are more obvious and easier to understand for a team.
- **Story/Task:** Represents a specific, tangible deliverable within an Epic. In production environments it can be built step or a work order. These must be created in a way that belongs to that epic, or one can think of these as sub assembly steps.
- **Sub-task:** For detailed steps within a Story/Task (e.g., "Order custom part from Vendor A," "Calibrate XYZ sensor"). Sub-tasks often inherit fields from their parent task or have simpler fields

2) *Custom Fields in Jira:*

You'll need to create these as custom fields in Jira. Here's a suggestion for their types and descriptions:

- **Machine Configuration:** Text Area (multi-line) or potentially a "Table Grid" custom field or can be a drop down for structured data like component serial numbers, firmware versions, or specific hardware settings. Detailed configuration parameters, serial numbers, and specific hardware/software versions for the machine.
- **Operations Number:** Unique identifier for the specific production operation or build step (e.g., a Work Order number, a specific process step ID). Links the Jira ticket directly to a physical manufacturing step in an MES (Manufacturing Execution System) or production tracking system.
- **Instructions:** Text Area (Rich Text for formatting, links). Step-by-step instructions for performing the task, including links to external documents, CAD drawings, or process guide. Can link to Confluence pages for detailed procedures or any shared drive links.
- **Specification:** Key technical specifications, design parameters, tolerances, and quality requirements for the component or assembly. Ensures adherence to engineering standards. Can link to a specific version of a design document.
- **Data Report:** Location or summary of test results, measurement data, quality control reports, and other critical data generated during the operation. Attachment field, URL field (linking to a file share or data analysis platform), or Text Area (for summary). Provides evidence of completion, performance, and quality.

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3) *Workflow States and Transitions:* This workflow is a hybrid, combining Agile's iterative nature with the need for structured manufacturing steps. Proposed Jira Workflow (Fig. 2) for a "Production Build Task" Issue Type:
(Start with "Open" or "To Do")

1. To Do: Task is ready for planning, with basic information such as operations number and initial instructions provided.
2. Ready for Build: All prerequisites (parts, tools, instructions, validated design) are confirmed. The task is assigned to an engineer or technician.
3. In Progress (Assembly/Process): The physical build or assembly is underway. Machine configurations and instructions may be updated as work progresses.
4. Blocked: Work is paused due to issues like missing parts or equipment problems. The reason for the block is documented, and related issues are linked.
5. Ready for Test/Inspection: Assembly is complete, and the product is prepared for formal testing or quality checks.
6. In Testing/Inspection: Testing and validation are performed, with results and test logs documented.
7. Pending Review/Approval: Completed tests await review and approval by a lead engineer or quality assurance.
8. Approved (Quality Gate): The product passes all quality checks and is cleared up for the next stage, such as integration.
9. Rework/RMA: If the product fails quality checks, it is sent for rework or replacement, with reasons documented and new tasks created as needed.
10. Done: The task is fully completed, integrated, or shipped**.**

Transitions between these states ensure traceability, accountability, and clear documentation at every stage of the production process.

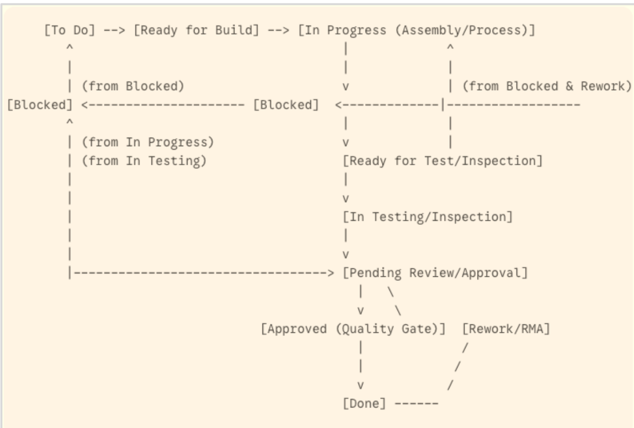

Fig. 2. Example of a Workflow

Confluence Integration: For detailed "Instructions" and "Specifications," link to Confluence pages. Confluence has excellent versioning, and linking ensures that the Jira ticket always points to the latest relevant documentation.

C. Workflow Diagram (Simplified):

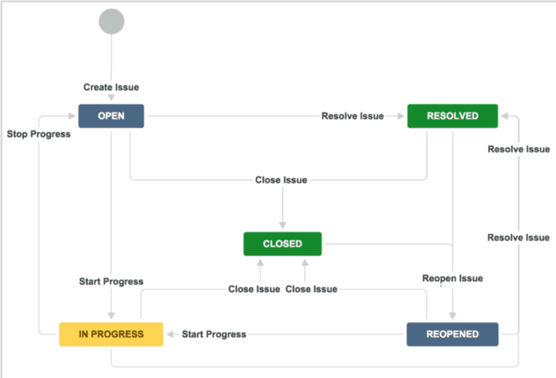

Fig. 3. Jira Default Workflow[16]

This Agile-influenced Jira workflow provides the structure and visibility needed to manage the complex production build sequence of semiconductor equipment while maintaining the flexibility and responsiveness of Agile methodologies.
Jira standard workflow for issues creation is well used for the early adopters as in Fig 3 below
Agile teams implement multiple tools together with specific practices which help them maintain proper document versioning to support accurate collaborative documentation during their iterative development cycles. The combination of version control systems (VCS) including Git with platforms GitHub, GitLab and Bitbucket works effectively for text-based documents that have code-like management requirements such as user stories and API specifications and architecture decisions. The tools enable branching capabilities which let team members develop different document versions or features independently from the main version and commit features that record all modifications with author and timestamp information. Merge or pull requests establish a formal process to review and integrate changes while diffing capabilities enable users to easily compare document versions and spot specific modifications.
Agile teams use collaborative documentation platforms with built-in versioning capabilities through tools such as Confluence and Google Docs and Microsoft SharePoint and their equivalents. These platforms provide advanced version tracking features which let users examine previous document versions and restore them while allowing real-time collaborative editing for multiple contributors. Confluence provides direct integration with Agile project management tools including Jira which enables streamlined documentation workflows.
The emerging practice of "Documentation as Code" (Docs-as-Code) treats documentation in the same way as source code by using lightweight formats (e.g., Markdown) and storing it in a VCS before publishing with static site generators Sphinx or Docusaurus. The approach provides all code versioning advantages including branching and automated checks and pull requests for documentation.[17]
To conclude, many organizations are finding ways to implement this in manufacturing to run operations smoothly. Though it might sound like challenging initially but its benefits outweigh the overhead effort required.

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