International Journal of Research and Applied Innovations (IJRAI)

| ISSN: 2455-1864 | www.ijrai.org | editor@ijrai.org | A Bimonthly, Scholarly and Peer-Reviewed Journal |

||Volume 5, Issue 1, January – February 2022||

DOI:10.15662/IJRAI.2022.0501005

Transforming Diagnostics Manufacturing at Cepheid: Migration from Paper-Based Processes to Digital Manufacturing using Opcenter MES

Satish Kumar Nalluri

Camstar MES Engineer, Cepheid, 904 E Caribbean Dr, Sunnyvale, CA 94089, USA

Email id: satishk4official@gmail.com

ABSTRACT: Manufacturing of GeneXpert® diagnostic kits at Cepheid used to depend heavily on paper documentation. Paper travelers, handwritten entries, and manual checks caused delays, errors, and long review times. To solve these problems, Cepheid implemented Siemens Opcenter (Camstar) MES to move from a paper environment to a digital manufacturing process.

This paper explains how the transition was planned and executed, and how Opcenter improved day-to-day operations, including electronic Device History Records (eDHR), digital work instructions, barcode checks, automated data capture, and real-time quality control. The study covers improvements in accuracy, traceability, operator performance, and compliance. The results show that digital manufacturing provided faster production, fewer errors, and better audit readiness for regulated diagnostics manufacturing.

KEYWORDS: MES, Camstar, Opcenter, eDHR, Digital Manufacturing, GeneXpert Kits

I. INTRODUCTION

Before the digital transformation, Cepheid relied on paper-based documentation to produce GeneXpert cartridge kits and related consumables. Every batch had a large paper packet containing work instructions, data entry fields, quality checklists, and sign-off sections. Operators wrote measurements manually, signed documents, and passed the packet to the next step or to QA reviewers. While this approach worked when production volumes were relatively low, it became increasingly inefficient as global demand for GeneXpert assays grew.

Paper-based manufacturing introduced common issues such as missing entries, illegible handwriting, out-of-order sign-offs, and delays when QA had to review dozens of pages per batch. Investigations and audits also became harder because retrieving a complete history for a particular lot required manual searching through archived boxes of paper.

Around 2018–2020, many life-science and medical device companies began moving towards digital manufacturing solutions. Siemens Opcenter MES (previously Camstar) provides capabilities such as electronic workflows, secure electronic signatures, electronic batch and device history records, real-time quality checks, and complete traceability. These capabilities help manufacturers reduce documentation errors, shorten review times, and support compliance with FDA 21 CFR Part 11 and Part 820, as well as ISO 13485.

This paper describes how Cepheid used Opcenter MES to replace paper travelers and create a digital framework for GeneXpert kit manufacturing. It presents the background, the design of the migration, the methods used to evaluate the impact, and the observed improvements in manufacturing performance and compliance.

1.1 Background and Context

Diagnostics manufacturing, especially cartridge-based molecular assays like GeneXpert, requires consistent execution of many small steps such as material preparation, loading, assembly, torqueing, labeling, and packaging. Each step

| ISSN: 2455-1864 | www.ijrai.org | editor@ijrai.org | A Bimonthly, Scholarly and Peer-Reviewed Journal |

||Volume 5, Issue 1, January – February 2022||

DOI:10.15662/IJRAI.2022.0501005

must be documented accurately for traceability, quality control, and regulatory compliance. In a paper-based environment, this documentation burden grows rapidly with volume and product complexity.

Traditional MES deployments in medical device and diagnostics manufacturing were initially used mainly as systems of record, focusing on data collection and basic enforcement of process steps. Earlier generations of MES often mirrored paper forms in an electronic format, without fully leveraging the potential for automation, integration, and real-time decision support. As production requirements became more demanding, manufacturers started to treat MES as a central part of their digital manufacturing strategy rather than just a documentation tool.

At Cepheid, the motivation for moving away from paper included:

- Reducing manual transcription errors and missing data.
- Shortening QA review and batch release times.
- Improving traceability and genealogy for lots and components.
- Supporting rapid scale-up during periods of high global demand.
- Preparing for more advanced analytics and continuous improvement in the future.

Opcenter MES offered an integrated way to translate existing paper processes into guided electronic workflows, while introducing features such as barcode verification, eDHR, and automated checks. The project described in this paper focused on migrating key GeneXpert manufacturing lines from paper-based to digital execution using Opcenter.

1.2. Objectives

This work is guided by the following objectives:

- To migrate GeneXpert cartridge and kit manufacturing from paper-based documentation to a fully digital process using Opcenter MES.
- To reduce documentation and transcription errors by enforcing data entry and checks directly in the MES.
- To shorten QA review and batch release times through electronic records and automated rule checks.
- To improve traceability and genealogy for materials, components, and finished lots, enabling faster investigations and audit responses.
- To provide a reusable framework that can be applied to other lines and future products at Cepheid.

1.3. Significance of the Study

This study addresses a critical gap at the intersection of digital technology and life sciences manufacturing. It moves beyond siloed applications of AI or RPA to propose a cohesive, scalable framework. The significance is threefold:

- **Operational:** It provides a practical example of how a diagnostics manufacturer can improve efficiency, reduce errors, and support higher volumes without proportionally increasing documentation workload.
- **Technological**: It shows how Opcenter MES can be configured not only to replace paper one-to-one, but to enhance process control through validations, barcode checks, and integrations.
- **Regulatory**: It demonstrates how digital records and electronic signatures can strengthen compliance and make audits and inspections more straightforward.
- **Reusability**: The migration approach, templates, and lessons learned can be reused for additional lines, sites, or products within Cepheid and in other regulated manufacturing environments.

II. LITERATURE REVIEW

The literature on digital transformation in medical device and pharmaceutical manufacturing highlights the growing role of MES as a backbone system for documentation, traceability, and process control.

Early MES implementations in the 1990s and 2000s focused mainly on electronic data capture and work-in-progress tracking. As standards such as ISA-95 matured, MES increasingly became the link between shop-floor equipment and enterprise-level systems like ERP and LIMS. ISA-95 describes a layered model where MES sits between process control systems and business systems, coordinating production and managing detailed scheduling, genealogy, and quality records (ISA, 2010).

| ISSN: 2455-1864 | www.ijrai.org | editor@ijrai.org | A Bimonthly, Scholarly and Peer-Reviewed Journal |

||Volume 5, Issue 1, January – February 2022||

DOI:10.15662/IJRAI.2022.0501005

Several studies have shown that paper-based batch and device history records are prone to errors and can delay product release. FDA guidance on data integrity, for example, has highlighted risks associated with manual transcription, backdating, and incomplete or illegible records (FDA, 2018). Industry articles and case studies have reported that electronic batch records and eDHR can significantly reduce documentation defects and speed up QA review (Lipsitz, 2016; Zipp, 2017).

In medical device and diagnostics manufacturing, MES solutions such as Camstar/Opcenter have been applied to assemble complex devices, enforce process steps, and generate eDHR that satisfy 21 CFR Part 11 requirements for electronic records and signatures. Case studies published by MES vendors and early adopters before 2021 reported:

• Elimination of paper travelers and associated storage costs.
• Reduction in documentation-related deviations.
• Faster retrieval of records during audits.
• Improved visibility into production status and bottlenecks.

Reviews of Industry 4.0 in life sciences manufacturing also position MES as a central element of the digital factory, connecting equipment data, quality systems, and analytics (Lee et al., 2015; Kumar & Salo, 2018). While many publications focus on pharmaceuticals and biologics, the same principles apply to diagnostic kit manufacturing, where traceability, process consistency, and rapid investigation of field issues are equally critical.

However, many of these works stop at a high-level view and do not detail the practical steps required to migrate from paper to digital execution in a live, regulated manufacturing environment. This paper contributes to the literature by presenting a concrete case study of such a migration at Cepheid, including methods, observed benefits, and lessons learned.

III. METHODOLOGY

3.1. Research Design

This study used a case-study design focused on Cepheid's GeneXpert manufacturing lines. The project combined practical implementation work with analysis of process and quality data before and after the migration. The approach was primarily qualitative and descriptive, supported by quantitative comparison of selected key performance indicators (KPIs).

The research design consisted of four main phases:

- As-is process assessment and paper record analysis.
- Design and configuration of digital workflows and eDHR in Opcenter.
- Deployment and validation of the MES solution on selected lines.
- Post-implementation evaluation based on KPIs and feedback from users.

3.2. Datasets

Data for this study came from multiple sources:

- Historical paper DHR packets and deviation reports from the pre-MES phase.
- Opcenter MES configuration documents, workflows, and validation protocols.
- Production and quality data exported from MES and supporting systems after go-live.
- Informal feedback and structured comments from operators, supervisors, and QA personnel who used the system.

The data covered a period of several months before and after the MES implementation, allowing for comparison of error rates, review times, and other metrics.

3.3. Data Collection Methods

During the as-is assessment, representative batches and their paper DHRs were reviewed to identify:

- Common error types (missing signatures, incomplete fields, illegible values).
- Steps with frequent clarifications or rework.
- Activities that were repetitive and suited for standardization in MES.

Workshops were held with manufacturing, QA, and IT teams to map the existing process steps and documentation requirements. Based on this, electronic workflows and eDHR templates were designed in Opcenter.

International Journal of Research and Applied Innovations (IJRAI)

| ISSN: 2455-1864 | www.ijrai.org | editor@ijrai.org | A Bimonthly, Scholarly and Peer-Reviewed Journal |

||Volume 5, Issue 1, January – February 2022||

DOI:10.15662/IJRAI.2022.0501005

After go-live, data was collected through:

- Standard MES reports showing completion status, exceptions, and rework.
- Manual logs of documentation-related deviations.
- QA records on batch review duration and issues found.
- Operator and QA feedback gathered through meetings and email comments.

3.4. Data Analysis Procedures

The analysis focused on comparing key measures before and after the MES implementation. These included:

- Number of documentation-related deviations per month.
- Number of missing or incorrect entries per batch.
- Average QA review time per batch.
- Time required to retrieve a complete history for a given lot during an investigation.

The data was summarized descriptively (e.g., averages, counts) and expressed as percentage changes where appropriate. Qualitative feedback was grouped into themes such as ease of use, clarity of instructions, and perceived impact on day-to-day work.

3.5. Ethical Considerations

All data used in this study came from internal manufacturing and quality systems. No patient data or personally identifiable health information was involved. Access to production and quality information followed Cepheid's internal policies and role-based security controls. The purpose of the analysis was continuous improvement and sharing of best practices, in line with the company's quality management system.

IV. RESULTS

4.1. Quantitative Simulation Results

After the implementation of Opcenter MES for GeneXpert kit manufacturing, several improvements were observed in documentation quality, review time, and traceability. Table 1 summarizes the key KPIs before and after the migration.

Table 1: Comparison of Key Metrics Before and After Opcenter MES Implementation

KPI	Before MES	After MES	Approx. Change
Documentation-related deviations	Frequent (baseline = 100%)	Reduced to ~35–40% of baseline	~60–65% reduction
Missing/incorrect entries per batch	Several per batch	Rare, usually 0–1 per batch	Significant reduction
Average QA review time per batch	2–4 days	Same day or next day	~50–70% faster
Time to retrieve full DHR/lot history	Hours (manual search)	Minutes or less (electronic search)	>90% faster
Rework due to documentation issues	Noticeable portion	Minimal	Clear reduction

The move to MES-enforced data entry fields, mandatory checks, and electronic signatures significantly reduced the number of missing or incorrect fields. QA no longer had to chase operators for clarifications or corrections as frequently, which translated into shorter review times and more predictable batch release.

The ability to search for a lot, component, or serial number in MES and retrieve its complete device history record reduced investigation time from hours of manual paper searching to minutes, especially during internal audits and external inspections.

International Journal of Research and Applied Innovations (IJRAI)

| ISSN: 2455-1864 | www.ijrai.org | editor@ijrai.org | A Bimonthly, Scholarly and Peer-Reviewed Journal |

||Volume 5, Issue 1, January – February 2022||

DOI:10.15662/IJRAI.2022.0501005

4.2. Qualitative Case Study Results

Feedback from operators, supervisors, and QA staff highlighted several themes:

- **Clarity of Instructions:** Operators reported that on-screen instructions, along with required fields and prompts, made it easier to follow the correct sequence of steps. Pictures and structured data fields further reduced confusion compared to long paper documents.
- **Error Prevention**: Automated checks, such as preventing progression when required fields are empty or when barcode scans do not match expected materials, helped catch issues at the point of use instead of later in QA review.
- **Confidence in Records**: QA personnel expressed greater confidence in the completeness and consistency of digital records. The electronic audit trail, time stamps, and user identification made it easier to verify what happened at each step.
- **Learning Curve:** Some initial resistance and learning effort were present when switching from paper to MES screens. However, after training and a short adjustment period, most users preferred the digital system.

V. DISCUSSION

5.1. Interpretation of Results

The results demonstrate that migrating from paper-based documentation to Opcenter MES at Cepheid achieved the main objectives of the project. Documentation errors, missing entries, and related deviations were substantially reduced, which directly contributed to shorter QA review times and fewer delays in batch release.

The improvements in traceability and genealogy are particularly important in a regulated diagnostics environment. Fast access to complete DHRs and lot histories supports more efficient investigations when quality issues or field complaints arise. Instead of searching through archives of paper documents, personnel can retrieve the required information directly from the MES.

The combination of structured digital work instructions and enforced checks turned the MES from a passive record-keeping tool into an active process guide. This reduced the reliance on memory and individual habits, supporting more consistent execution across operators and shifts.

5.2. Comparison with Existing Literature

The findings are consistent with earlier reports that electronic batch records and MES reduce documentation-related deviations and improve review cycle times in pharmaceutical and medical device environments (Lipsitz, 2016; Zipp, 2017). The observed gains at Cepheid align with case studies that emphasize the value of replacing paper travelers with electronic records to enhance data integrity and compliance (Siemens, 2016; FDA, 2018).

The results also support the view of MES as a key enabler of digital transformation and Industry 4.0 in life sciences manufacturing, as described in broader reviews (Lee et al., 2015; Kumar & Salo, 2018). While many publications focus on drug substance or biologics manufacturing, this case study shows that similar benefits can be realized in diagnostics kit production.

5.3. Implications

For practitioners, this study provides a practical example of how to approach paper-to-digital migration in a regulated diagnostics setting. Key implications include:

- Start with a detailed review of existing paper processes and documentation requirements to ensure that the MES configuration covers all necessary fields and approvals.
- Involve QA early in the design of eDHR templates and workflows to ensure that records meet regulatory expectations and support efficient review.
- Use MES capabilities such as barcode scanning, mandatory fields, and validation rules to prevent errors at the source rather than detecting them later.
- Provide adequate training and support for operators to minimize resistance and help them understand the benefits of the new system.

For future MES projects, the Cepheid experience suggests that digital migration can be phased by line or product family, allowing lessons from early deployments to be applied to later ones.

| ISSN: 2455-1864 | www.ijrai.org | editor@ijrai.org | A Bimonthly, Scholarly and Peer-Reviewed Journal |

||Volume 5, Issue 1, January – February 2022||

DOI:10.15662/IJRAI.2022.0501005

5.4. Limitations of the Study

This study has several limitations. The analysis is based on a single organization and a specific product family (GeneXpert diagnostic kits), which may limit the generalizability of the results. The quantitative data uses approximate ranges and relative changes rather than formal statistical testing. In addition, external factors such as staffing changes or parallel process improvements may have influenced some outcomes.

Despite these limitations, the magnitude and consistency of improvements across several KPIs, combined with user feedback, strongly indicate that the MES implementation played a central role in the observed gains.

5.5. Directions for Future Research

Future work at Cepheid and in similar environments could include:

- Extending the MES deployment to additional product lines, sites, or processes such as reagent preparation or packaging.
- Integrating more equipment directly with MES to automatically capture measurement data (e.g., torque tools, scales, environmental sensors).
- Connecting MES data with higher-level analytics platforms to enable trend analysis, process capability studies, and predictive maintenance.
- Exploring further integration with ERP and quality systems to close the loop between planning, execution, and continuous improvement.

VI. CONCLUSION

This paper presented a case study of transforming diagnostics manufacturing at Cepheid by migrating from paper-based processes to digital manufacturing using Siemens Opcenter MES. The project focused on GeneXpert kit manufacturing and aimed to reduce documentation errors, shorten QA review times, and improve traceability and compliance.

The results showed substantial reductions in documentation-related deviations, faster batch review and release, and greatly improved access to complete device history records. Feedback from operators and QA staff indicated that digital work instructions and enforced checks improved clarity and confidence in the process.

Overall, the implementation of Opcenter MES at Cepheid demonstrates that digital manufacturing is not only a technical upgrade but a strategic step towards more reliable, scalable, and audit-ready diagnostics production. The lessons learned from this migration can guide similar initiatives in other regulated manufacturing environments.

REFERENCES

[1] FDA. (2018). Data Integrity and Compliance With Drug CGMP: Guidance for Industry. U.S. Food and Drug Administration.
[2] ISA. (2010). Enterprise-Control System Integration: Part 1–5 (ISA-95 Series). International Society of Automation.
[3] Lee, J., Bagheri, B., & Kao, H. A. (2015). A cyber-physical systems architecture for Industry 4.0-based manufacturing systems. Manufacturing Letters, 3, 18–23.
[4] Kumar, S., & Salo, J. (2018). Impact of digitalization on pharmaceutical and biopharmaceutical manufacturing. Journal of Pharmaceutical Innovation, 13(2), 85–94.
[5] Lipsitz, J. (2016). Electronic batch records: Reducing errors and speeding batch release. Pharmaceutical Technology, 40(9), 38–44.
[6] Zipp, G. (2017). Implementing eBR in a GMP environment: Lessons learned. Pharmaceutical Engineering, 37(6), 24–32.
[7] Siemens. (2016). Camstar Medical Device Suite: Enabling Electronic Device History Records (eDHR). Siemens Industry Software White Paper.
[8] ISPE. (2017). GAMP® Good Practice Guide: Manufacturing Execution Systems. International Society for Pharmaceutical Engineering.