WHITE PAPER

Where the Most Significant Optimization Opportunities in Electronics Manufacturing Lie Today

How the economically most important optimization levers have shifted across the electronics manufacturing process

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Introduction

Few terms are used more frequently in electronics manufacturing than **optimization**. For decades, faster equipment, higher placement rates, shorter changeover times, and more efficient production processes have been regarded as the primary drivers of productivity and competitiveness. As a result, many companies continue to focus their investments and improvement initiatives primarily on the manufacturing line.

For many years, this approach was entirely justified. Continuous advances in manufacturing technology have significantly improved the efficiency of electronics production while increasing quality, process stability, and cost-effectiveness.

Today, however, the situation has changed. Many of the traditional optimization opportunities within modern SMT production lines have already been largely realized. Although each new generation of equipment continues to deliver higher performance and may provide economic benefits, further process optimization within existing SMT production systems often results in only limited additional gains.

At the same time, some of the most significant opportunities for improving manufacturing performance now arise well before production begins. Decisions made during product development, PCB design, and the early collaboration between product development teams and EMS providers often have a greater impact on manufacturing efficiency and total cost than further optimization of the SMT line itself. In addition, through-hole technology (THT) and manual manufacturing processes continue to offer substantial improvement potential in many companies, as these areas are often less systematically optimized than highly automated SMT production.

This shift in economic importance is the focus of this White Paper.

> **The Central Thesis**
> *Electronics manufacturing has achieved remarkable productivity gains over the past decades. At the same time, the areas with the greatest economic optimization potential have shifted. Today, the most significant opportunities for improving manufacturing performance often no longer lie within the production line itself, but in product development, PCB design, and the early collaboration between product development teams and EMS providers.*

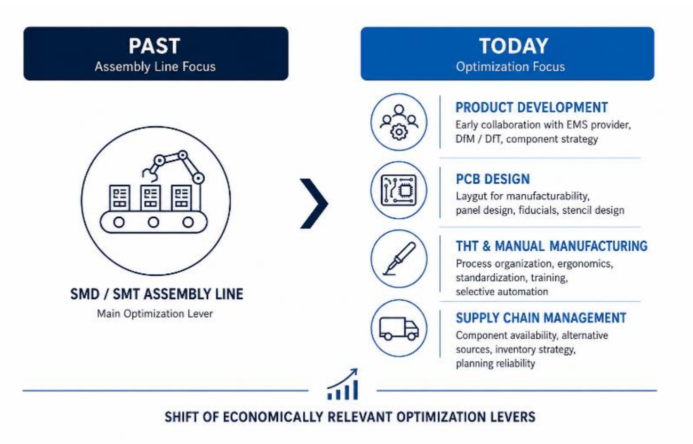

Figure: *EMS Strategy Group, 2026. AI-assisted illustration.*

For industrial companies, this shift is of considerable strategic importance. Decisions on investments, manufacturing technologies, continuous improvement programs, and the selection of EMS partners should focus on the areas where meaningful economic improvements can still be achieved. Companies that continue to concentrate their resources primarily on areas where traditional optimization opportunities have already been largely realized may overlook more significant opportunities elsewhere. Conversely, decisions made during product development and manufacturing planning can have a lasting impact on manufacturing costs, process stability, product quality, and time-to-market.

The achievable improvements vary from one company to another. They depend on factors such as manufacturing technology, process know-how, the level of automation, the product portfolio, and the overall organization of production. The following assessment therefore identifies general trends rather than universally applicable rules. Every optimization strategy should be based on a thorough evaluation of the company's specific manufacturing environment.

This White Paper examines the key areas of electronics manufacturing from the perspective of their current economic relevance. It highlights where significant optimization opportunities remain and where the traditional optimization potential within existing manufacturing processes has already been largely realized.

1. The Most Effective Optimization Lever Lies Before Production.

The greatest opportunity for improving manufacturing performance often lies not on the production floor, but during product development. Decisions made regarding product architecture, component selection, PCB layout, and mechanical design have a decisive influence on how efficiently, robustly, and cost-effectively a product can later be manufactured. Once a design has entered volume production, correcting weaknesses typically requires significantly more time, effort, and cost than addressing them during development.

Design for Manufacturing (DfM) and Design for Test (DfT) have been established principles of manufacturing-oriented product development for decades. Their real value, however, goes far beyond automated design-rule checks within a CAD system. The greatest benefits are achieved through close collaboration between product development teams and the EMS provider from the earliest stages of the design process. This collaboration allows potential manufacturing issues to be identified and resolved before they affect quality, production costs, or manufacturing efficiency.

Key elements of this early collaboration include:

- Coordinating component placement, spacing, and orientation to support efficient assembly and soldering processes
- Evaluating component availability and qualified alternative parts to reduce future redesigns caused by obsolescence or supply shortages
- Aligning thermal management, component mass, and mechanical loads with the intended manufacturing and soldering processes
- Defining test access, test points, and programming interfaces at an early stage of development
- Involving the EMS provider during PCB layout reviews and before final design release rather than after prototype completion

If an EMS provider becomes involved only after the PCB layout has been completed and the manufacturing data has been released, optimization opportunities are typically limited to minor improvements. In contrast, early collaboration during product development enables many design weaknesses to be eliminated before they affect manufacturing quality, process stability, throughput, or production costs.

> **Assessment**
> *Today, one of the most economically significant optimization levers often lies not within the manufacturing line itself, but in the structured collaboration between product development and the EMS provider. Companies that establish this collaboration early create the foundation for more stable manufacturing processes, lower production costs, and higher product quality. At the same time, they systematically shift the cost of correcting design-related issues from expensive volume production to the far more cost-effective development phase.*

2. SMT Assembly – Yesterday's Primary Optimization Lever

For many years, automated SMT assembly was the primary optimization lever in electronics manufacturing. More powerful placement equipment, higher placement accuracy, shorter changeover times, and continuous improvements in soldering processes significantly increased productivity, quality, and manufacturing efficiency. As a result, investment strategies and continuous improvement programs were largely focused on the production line.

This development continues today. Equipment manufacturers continuously introduce new machine generations offering higher placement speeds, faster changeovers, improved process monitoring, and enhanced capabilities for increasingly complex assemblies. Investments in modern SMT equipment can therefore continue to deliver significant economic benefits, particularly when replacing older systems or expanding manufacturing capacity.

The situation is different, however, when looking at optimization opportunities within existing SMT production lines. Modern SMT systems have reached a level of technological maturity where traditional process optimization often delivers only limited additional benefits. Placement speed, accuracy, and process stability have already been optimized to such an extent that, for most industrial applications, they are no longer the primary factors determining manufacturing performance or overall production costs. Instead, the efficiency of the entire manufacturing process has become the decisive factor.

Consequently, today's optimization efforts are typically focused less on the placement equipment itself and more on the conditions under which it operates. Typical examples include:

- Reducing changeover times and optimizing feeder management in high-mix manufacturing environments
- Optimizing placement programs and component sequencing
- Matching solder paste printing and reflow profiles to different PCB assemblies
- Integrating SPI, AOI, and other inline inspection systems for early defect detection
- Using production data and process analytics to further improve process stability and manufacturing consistency

These measures make an important contribution to manufacturing quality, process stability, and operational efficiency. Their economic impact, however, is often smaller than it was in previous decades because the core performance of modern SMT production systems has already reached a very high level.

This does not mean that SMT manufacturing has reached the end of its development. On the contrary, every new generation of equipment continues to improve productivity and manufacturing capabilities. The key difference is that, within an existing modern production environment, further optimization of the SMT process itself often yields comparatively limited economic benefits. Today, substantially greater improvements frequently result from the interaction between product development, PCB design, manufacturing planning, supply chain management, and stable production processes.

Assessment

SMT assembly will remain the technological core of electronics manufacturing. Investments in new machine generations can continue to provide significant economic advantages, particularly when modernizing existing production facilities or increasing manufacturing capacity. Within already modern SMT production lines, however, the traditional optimization opportunities have largely been realized. As a result, many companies can achieve greater economic benefits by focusing on upstream development and planning activities, as well as on manufacturing areas that have historically received less attention than highly automated SMT production.

3. THT and Manual Manufacturing – Today's Often Overlooked Optimization Lever

While the economic optimization potential within modern SMT production lines has diminished in many companies, THT assembly and manual manufacturing processes continue to offer substantial opportunities for improvement. In most cases, these opportunities are determined less by the available technology than by the way manual processes are designed, organized, and continuously improved.

Fully automated THT assembly has been technically feasible for many years. In practice, however, it is economically viable primarily for high-volume production, standardized products, and stable PCB designs. As a result, a significant proportion of industrial electronic assemblies still rely on manual THT assembly, rework, wiring, final assembly, cable assembly, and mechanical integration. Many of these activities can only be automated to a limited extent or cannot be economically automated at all.

This is where THT and manual manufacturing differ fundamentally from SMT production. Highly automated SMT lines have been systematically optimized over many years through advanced equipment, software, and process automation. Manual manufacturing processes, on the other hand, depend much more heavily on workplace design, workflow organization, standardized procedures, and the skills of the operators. Consequently, many companies still have considerable opportunities to improve productivity, quality, and manufacturing efficiency in these areas.

Typical optimization measures include:

- Line balancing to improve workload distribution across manual workstations
- Ergonomic workplace design to reduce operator fatigue and minimize errors
- Poka-Yoke solutions to prevent assembly, wiring, and installation errors
- Digital work instructions with visual guidance instead of paper-based documentation
- Selective automation of individual process steps, for example through selective soldering, robotic soldering, or automated screwdriving systems
- Standardization of tools, fixtures, and work procedures across multiple product families
- Systematic employee training and qualification to ensure consistent process quality

Unlike SMT manufacturing, improvements in these areas are typically achieved not through faster equipment but through better process organization, standardized workflows, and the targeted support of manual operations. Even relatively modest investments in workplace design, production organization, or employee qualification can often lead to measurable improvements in productivity, quality, and throughput time.

The actual optimization potential varies considerably from one company to another. Organizations that have systematically developed and standardized their manual manufacturing processes over many years will naturally have less room for improvement than companies where these areas have received comparatively little attention. For this reason, the economic significance of THT and manual manufacturing can only be assessed in the context of each company's specific production environment.

Assessment

For many electronics manufacturers, THT assembly and manual manufacturing represent some of today's most attractive opportunities for economic optimization. Unlike highly automated SMT production, improvements in these areas are driven primarily by better process design, standardized workflows, effective workplace organization, and employee expertise rather than by investments in faster equipment. Where these opportunities have not yet been systematically exploited, they can often deliver greater economic benefits than further optimization of an already modern SMT production line.

4. PCB Design – The Structural Optimization Lever

Alongside early collaboration between product development teams and EMS providers, PCB design offers the greatest opportunity for structural optimization in electronics manufacturing. Decisions made during PCB layout development directly influence the efficiency of the subsequent manufacturing process. They determine not only the electrical functionality of the assembly, but also its manufacturability, process stability, throughput, and overall production costs.

Many of these decisions can only be corrected with considerable effort once the design has been released. For this reason, manufacturing requirements should be considered from the earliest stages of PCB layout development, with the EMS provider actively involved throughout the design process.

Assembly Strategy

One of the earliest design decisions is whether a PCB will be assembled on one or both sides. This choice has a significant impact on the manufacturing process. Single-sided assembly reduces the number of process steps, simplifies production, and minimizes potential sources of error.

Where double-sided assembly is unavoidable for functional or design reasons, component placement and the manufacturing sequence should be planned to ensure a stable and reliable soldering process. Particular attention should be paid to thermal loading, component weight, and the placement of larger or mechanically sensitive components.

Panelization and Panel Design

Panelization is another key factor influencing manufacturing efficiency. The way individual PCBs are combined into a manufacturing panel affects material utilization, handling, transportation, assembly efficiency, and depanelization. Consequently, panel design should not be treated as a downstream manufacturing task but should be considered during PCB layout development.

Important design aspects include:

- Optimizing the arrangement of individual PCBs to minimize material waste
- Selecting the most suitable depanelization method, such as V-scoring, routing, or punching
- Maintaining sufficient clearance between sensitive components and board edges
- Considering tooling rails, gripper areas, and conveyor requirements of the manufacturing line
- Optimizing overall panel dimensions for efficient manufacturing and material handling

Early consideration of these factors helps avoid compromises later in production while improving material utilization, throughput, and process stability.

Fiducial and Reject Marks

The correct implementation of fiducial and reject marks also contributes significantly to manufacturing efficiency.

Global and local fiducial marks enable accurate optical alignment within SMT placement systems and are essential for reliable placement accuracy, particularly when processing fine-pitch components or complex PCB assemblies.

Reject marks allow defective individual PCBs within a panel to be clearly identified during production. This prevents unnecessary assembly, testing, or rework of assemblies that have already been classified as defective, thereby improving production efficiency and material flow.

Stencil Design

Stencil design should likewise be considered an integral part of product development rather than a downstream manufacturing activity. Stencil thickness, aperture geometry, and solder paste volume have a direct influence on solder paste printing quality and, consequently, on solder joint reliability.

Important design considerations include:

- Selecting stencil thickness according to the component mix
- Using stepped stencils where different solder paste volumes are required
- Applying surface coatings to improve paste release from fine apertures
- Optimizing aperture geometry to match the solder paste, component package, and manufacturing process

A stencil designed specifically for the requirements of the PCB assembly minimizes subsequent process adjustments and contributes significantly to stable, repeatable volume production.

PCB Design as an Integrated Manufacturing Concept

The examples above demonstrate that manufacturing-oriented PCB design is not a collection of isolated optimization measures. Assembly strategy, panelization, fiducial and reject marks, and stencil design all influence one another and should therefore be considered as an integrated manufacturing concept rather than as independent design decisions.

Early collaboration between product development teams and the EMS provider ensures that these interdependencies are addressed during the design phase, significantly reducing the need for costly engineering changes once production has begun.

Assessment

Today, PCB design represents one of the most economically significant optimization opportunities in electronics manufacturing. Many of the decisions made during PCB layout development have a greater influence on manufacturing efficiency, process stability, and production costs than subsequent optimization measures implemented within production itself. Companies that integrate manufacturing requirements into the design process from the outset and involve their EMS provider at an early stage establish the foundation for stable manufacturing processes, lower production costs, and economically sustainable volume production.

5. Supply Chain Management – The Foundation for Economical Manufacturing

Supply chain management is not a manufacturing optimization lever in the strict sense. It does not increase placement speed, improve soldering quality, or directly influence PCB layout. Nevertheless, it determines whether the optimization potential created during product development and manufacturing can actually be realized.

Efficient manufacturing depends on having the right materials available at the right time, in the required quality, and in the necessary quantities. Material shortages, long lead times, or the lack of qualified alternative components can disrupt even highly automated production lines and force short-term changes to manufacturing schedules. In many cases, the resulting costs exceed the savings achieved through optimizing individual production processes.

For this reason, strategically aligned supply chain management begins during product development and continues throughout the entire product lifecycle. Key elements include:

- Assessing the long-term availability of critical components during product development
- Qualifying alternative components and second sources to reduce procurement risks
- Developing inventory strategies that balance security of supply with working capital requirements
- Creating transparency regarding lead times and material availability for realistic production planning
- Coordinating material supply, lot sizes, and production schedules to minimize waiting times and unnecessary setup activities
- Continuously monitoring obsolescence, supplier performance, and procurement risks throughout the product lifecycle

Recent years have demonstrated how strongly geopolitical developments, component shortages, and increasing dependence on individual supply chains can affect manufacturing performance. Economical production is therefore no longer determined solely by efficient manufacturing processes. It also depends on resilient procurement structures and close collaboration between engineering, purchasing, supply chain management, and manufacturing.

Supply chain management should therefore not be regarded as an isolated business function alongside production, but as an integral part of an overall manufacturing strategy. Only the coordinated interaction of all disciplines enables stable production processes, reliable delivery performance, and sustainable manufacturing competitiveness.

assessment

Supply chain management does not replace process optimization, but it determines whether its economic benefits can be fully realized in day-to-day manufacturing. Companies that integrate engineering, purchasing, supply chain management, and manufacturing from an early stage create the foundation for resilient supply chains, stable production processes, and long-term competitiveness.

6. Conclusion

Electronics manufacturing has undergone remarkable technological progress over the past decades. More powerful production equipment, increasing automation, and continuous process improvements have significantly enhanced productivity, quality, and manufacturing stability. This development will continue as new machine generations provide additional performance, greater flexibility, and further economic advantages.

What has changed, however, is the relative economic importance of the different optimization levers.

While major productivity gains were historically achieved primarily through improvements within the production line, today's greatest economic opportunities often arise much earlier. Decisions made during product development, manufacturing-oriented PCB design, and early collaboration between engineering teams and EMS providers frequently have a greater influence on manufacturing costs, process stability, and production efficiency than further optimization of an already modern SMD production line.

At the same time, THT assembly and manual manufacturing continue to offer considerable improvement potential in many organizations. Unlike highly automated SMT processes, productivity gains in these areas are often achieved through better work organization, standardized procedures, employee qualification, and selective automation rather than through additional investments in machinery. These measures are complemented by strategically aligned supply chain management, which provides the material and organizational foundation for reliable and economical manufacturing.

None of the methods described in this white paper are new. What has changed is their economic relevance. The key question today is therefore no longer which optimization methods are available, but where they generate the greatest business value under current technological and market conditions.

The achievable improvement potential varies considerably from one company to another. It depends on factors such as manufacturing technology, process know-how, product portfolio, production organization, and the existing level of automation. Consequently, every optimization strategy should begin with an objective assessment of the company's individual situation.

Recommendation for action

Companies aiming to strengthen their long-term competitiveness should regularly reassess where their optimization efforts generate the greatest economic return. Investments in modern manufacturing technologies remain an important element of industrial competitiveness, particularly when replacing older equipment or expanding production capacity. At the same time, organizations should evaluate whether greater business benefits can now be achieved in other parts of the manufacturing value chain.

Particular attention should be given to early collaboration between engineering teams and EMS providers, manufacturing-oriented PCB design, and the systematic improvement of THT and manual manufacturing processes. Supported by strategically aligned supply chain management, these areas provide the foundation for stable production processes, reliable delivery performance, and sustainable manufacturing competitiveness.

Ultimately, economic success depends less on the number of optimization initiatives than on their prioritization. Companies that focus their resources on today's most economically relevant optimization levers—and manage product development, procurement, and manufacturing as an integrated system—create the conditions for sustainable improvements in competitiveness.

Additional Scientific References

The strategic considerations presented in this white paper are consistent with recent publications from leading research institutions addressing manufacturing competitiveness, production strategy, and the design of resilient global value creation networks.

Fraunhofer Institute for Production Technology IPT

Fraunhofer IPT emphasizes that industrial competitiveness increasingly depends on transferring innovations into robust manufacturing processes more rapidly and efficiently. This underlines the importance of integrating manufacturing requirements, process planning, and Design for Manufacturing (DfM) early in the product development process.

Reference:
Fraunhofer Institute for Production Technology IPT. *Industry demands faster transfer of innovations into production.* 2026.

Machine Tool Laboratory WZL of RWTH Aachen University

The WZL of RWTH Aachen University highlights that global production networks must become more resilient, flexible, and sustainable in response to increasing geopolitical uncertainty and volatile supply chains. This supports the strategic perspective that manufacturing, product development, and supply chain management should be considered as an integrated production system rather than as isolated disciplines.

Reference:
Machine Tool Laboratory WZL of RWTH Aachen University. *Expert Forum Global Production 2026.*

About the Author

Dirk Kaussen is Founder and Managing Director of EMS Strategy Group. With around 40 years of experience in the electronics industry — including founding and managing his own electronics manufacturing company in Germany — he brings deep expertise in manufacturing processes, EMS partner selection, supply chain stability, relocation projects, and risk management. His approach combines practical solutions with a direct connection to industrial reality.

About the EMS Strategy Group

EMS Strategy Group supports industrial enterprises in the strategic and operational advancement of their electronics manufacturing. Our core expertise lies in the strategic relocation of manufacturing volumes, the selection of qualified EMS partners, the establishment of new production capacities, and the expansion of existing manufacturing structures.

Furthermore, we design resilient supply chain frameworks, conduct comprehensive risk assessments, and guide dual-sourcing strategies, with operational support through to a successful series production ramp-up.

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