RETHINKING ENGINEERING IN THE AGE OF MUSK

Henry Ford revolutionized the automobile industry by implementing conveyor belts and the assembly line, while Toyota implemented operational streamlining to remove inefficiencies. Today in the neural network era, Elon Musk has transformed the factory by redefining manufacturing processes rather than making products.

Source: Magic Wand Media

Elon Musk once famously said, "The factory is the product, the car is the output." What he meant by this was that his core mission is to make his companies the best at creating and managing manufacturing processes and facilities, rather than solely focusing on building electric cars, rockets, etc. This philosophy aligns with Musk's strategy of vertical integration, controlling most aspects of the manufacturing process.

Musk's companies view manufacturing operations as a fundamental strategic capability instead of treating them as a basic cost management function. The factories at Tesla and SpaceX use advanced software systems with real-time monitoring and data optimization to build flexible production systems that continuously improve.

The companies practice vertical integration through their development of proprietary manufacturing technologies which enable fast process development and improvement. The production lines operate with flexible design features which allow process and product changes through performance data analysis and engineering feedback.

The facilities operate as testing sites through which manufacturing processes receive continuous improvement alongside product development.

Vertical Integration

The return of vertical integration at Musk-owned companies appears to be a step backward to supply chain and BOM logic-trained engineers. But in reality, this action represents a revolutionary step toward simplicity. At Tesla's Giga factory in Texas, Tesla produces 4,680 battery cells and vehicle assemblies under one roof. SpaceX is widely reported to be 85 percent vertically integrated, building most rocket hardware in-house.

REJI VARGHESE
President
RV Forms & Gears
fngreji@gmail.com

This is not merely about control. It's about intimacy. The feedback loop between production tools and their components becomes immediate when these tools belong to one's system, allowing endless possibilities for improvement. Through engineering advancements, SpaceX has decreased the cost of satellite launches exponentially.

Tesla delivered 1.79 million vehicles and generated US$ 97.69 billion in revenue in 2024. The term Gigafactory evolved from its original grandiose meaning into a new concept.

Not Just Automation, but Cognition

The late 20th century gave us automation. Intelligent automation appears to be the direction of the 21st century instead of traditional automation. Quality control exists as an integral part of production activities rather than being located at the production endpoint. Machines function autonomously by both receiving instructions and actively listening before they respond to enhance their performance.

One of Tesla's critical pivots was to build, rather than buy, much of its automation technology. The company acquired several specialized automation and tooling firms, including German engineering company Grohmann Engineering GmbH that became its in-house Tesla Automation division. This vertical integration meant the company could rapidly design, prototype, and deploy custom manufacturing equipment tuned specifically for its vehicles and battery systems.

This strategy reduced dependency on external suppliers, shortened development cycles, and ensured that proprietary manufacturing processes remained closely guarded competitive assets.

The engineering field worldwide recognizes system cognition as a basic requirement because it has transitioned from an experimental concept to an essential industrial need. One estimate puts the Industrial Automation market at US$ 233.8 billion (2024), reaching US$ 569 billion by 2034. Intelligence outpaces capital growth as the fundamental resource which drives modern business operations. The intelligence needs to be integrated throughout both machine systems and the manufacturing systems that create them.

"If Things Aren't Failing, You Are Not Innovating Enough"

Musk is also known for saying, "If things aren't failing, you're not innovating enough." Fear of failure is part of the problem; it discourages executives from taking risks and being innovative. Business cultures have understandably become first and foremost about being safe and steady. The irony of course is that it is risk that often creates a stronger business through creativity, innovation, and revenue generation in new ways.

SpaceX has transformed the industry's approach to testing and iteration. Rather than following the traditional aerospace model of extensive ground testing before flight, the company embraces a rapid prototyping philosophy where it builds, tests, fails fast, and iterates quickly. This is exemplified in its Starship development program, where it rapidly constructs full-scale prototypes and test them to destruction to gather real-world data.

Its manufacturing facilities are designed for flexibility, allowing the company to implement design changes quickly across its production lines. This approach has enabled SpaceX to achieve manufacturing rates that were previously unthinkable in aerospace, producing Falcon 9 rockets at a pace of roughly one every two weeks while maintaining the reliability standards necessary for human spaceflight.

Musk advocates for technical experts to lead factories and criticises the over-reliance on business graduates who, he believes, focus on financial optimization and taking safe decisions rather than focus on innovation and improving production processes.

Musk's declaration that "The factory is the product, the car is the output", marks the end of engineering traditions that have persisted for centuries. The object is no longer king. The system that creates the object is.

Key Areas of Modern Industrial Development

Designing for Adaptability and Iteration

Instead of aiming for flawless first designs, engineering methods should focus on creating systems that can adapt and evolve. Engineers must create modular systems which adapt to changing needs, but these systems need thorough planning.

Software Integration as Core Infrastructure

The current Manufacturing industry depends on software systems to manage its operations. Digital twins (virtual models of physical systems), Manufacturing Execution Systems (MES) with cloud connectivity, and predictive analytics have become essential components rather than optional add-ons. Software now performs at the same level as mechanical components in determining production capabilities.

Collaborative Partnerships and Specialization

The advanced nature of modern industrial systems goes beyond the capabilities of single companies to develop independently. The successful implementation of projects needs partnerships between experts who specialize in artificial intelligence, robotics, sensor technology, and systems integration. The importance of cross-disciplinary collaboration has increased because manufacturing systems now use a wide variety of technologies.

The Factory is the Product

SpaceX has revolutionized aerospace manufacturing through several groundbreaking approaches that have dramatically reduced costs and production timelines. One of its most significant innovations is vertical integration, where it manufactures approximately 85 percent of its components in-house rather than relying on traditional aerospace suppliers. This allows it to maintain tight quality control, reduce costs, and accelerate development cycles. SpaceX's Hawthorne facility operates more like a high-tech automotive assembly line than a traditional aerospace manufacturer, with components moving efficiently through streamlined production processes.

The company has pioneered advanced manufacturing techniques including extensive use of friction stir welding for creating seamless fuel tanks, 3D printing for complex engine components like injectors and turbopumps, and automated fiber placement for carbon composite structures. Its Raptor engines utilize innovative manufacturing methods such as hot isostatic pressing and single-crystal superalloy casting techniques that were previously reserved for military applications. SpaceX also developed proprietary alloys and manufacturing processes specifically optimized for its engines, allowing itself to achieve higher performance while reducing production complexity.

Musk's declaration that "The factory is the product, the car is the output", marks the end of engineering traditions that have persisted for centuries. The object is no longer king. The system that creates the object is.

Reji Varghese is the President of RV Forms and Gears, one of India's oldest fixture building companies. He is also a guest writer for a number of national newspapers and magazines.