Managing Engineering Design Changes in Manufacturing: A Systematic Review

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Abstract
Engineering design changes are inevitable in manufacturing industries due to evolving customer demands, technological advancements, regulatory requirements, and continuous improvement initiatives. Effectively managing these changes is crucial to maintaining product quality, minimizing production disruptions, and optimizing costs. This review explores various methodologies, tools, and best practices employed in managing engineering design changes in manufacturing environments.

Keywords: Engineering Changes, Manufacturing, Change Management, Process Improvements

INTRODUCTION

With the fast-paced life in today's times, manufacturing companies keep retooling to become competitive and make customers happy. Engineering design changes (EDCs) have become a part of the processes no matter whether it is for taking care of customer feedback, becoming technology friendly, or following trends in the marketplace. All such improvements can be initiated at any stage in the development life cycle of a product, starting with first stage design and prototyping till production and even post-product launch. Organizations understand that the early they implement such improvements, the less costly and less intrusive it will become. Delaying them to a later stage can cause rework, production delays, and wasted time.

With Industry 4.0, manufacturers and designers manage design changes are also undergoing a change. It is all about connecting the dots—merging big data, the Internet of Things (IoT), artificial intelligence (AI), and smart automation to deliver a smarter, faster, and leaner manufacturing configuration. All new technologies can enable manufacturers to detect any potential design faults before time which can help make smarter choices and make changeovers less when a change is must required. There is real-time feedback through smart systems and smart sensors, and therefore, teams can track the performance of a product and make design tweaks in anticipation, not in reaction. All this enables companies to beat the curve, enhancing product and customer happiness.

Regarding changes, they can be placed in two general categories: post- and pre-production. Pre-production changes are made when a product is in the planning, design, and testing phases, and changing them is less costly and less complicated. This helps to make improvements to the product prior to putting it onto the production line. Otherwise, post-production adjustments are implemented once production, or even distribution, begins, and even finished goods have reached hands. These types of adjustments can be a result of changing customer requirements, compliance requirements, or supply chain issues such as unavailability of components. Post-production adjustments can be challenging to manage, as they must be implemented with care not to cause disruptions and destroy product integrity.

To effectively deal with these alterations, manufacturers implement structured processes and tools to ensure order and prevent chaos. A standard methodology is the House of Quality, which enables teams to visualize how a proposed change in design will impact production, cost, and customer expectations. In addition to strategic planning methods, businesses employ formal processes, such as Manufacturing Change Requests (MCRs) and Engineering Change Requests (ECRs), to document, analyze, and implement changes. These formal processes gather various teams from engineering and quality control through procurement and manufacturing to bring all perspectives to the table before approving change. A good MCR describes what needs to be changed, why it is necessary, and what impact it can have on production and product quality.

However, effective management changes are not all about tools and processes; they are about individuals. Any change in design will involve coordination between different departments, suppliers, and customers. Communication and collaboration are key to smooth and effective changes. Without team coordination, miscommunication can lead to costly errors and delays. Fortunately, computer-based solutions such as Product Lifecycle Management (PLM) and Enterprise Resource Planning (ERP) systems have allowed us to monitor changes, exchange information, and keep everyone in sync—no matter where they are located globally.

Even with the best systems in place, engineering design change management is not without issues. Miscommunication, outdated records, and surprise costs are quickly major hurdles. Supply chain disruptions, such as raw material shortages or shipping holdups, can further exacerbate the problem. Regulatory requirements present another hurdle in that firms must stay on top of changing standards of quality and safety. With careful planning, cross-functional coordination, and the proper technology, however, firms can overcome these hurdles to continue producing high-quality products.

Looking to the future, the outlook is promising for working with design change. AI enhancements and digital twin technology, which provides virtual copies of actual products in the real world, are making it simpler than ever to experiment and test changes before implementing them. As Industry 4.0 revolutionizes manufacturing, it is the firms that embark on digital transformation that will be best suited to respond to change, increase efficiency, and maintain their competitive edge in an increasingly demanding marketplace by the day. It is the ability to stay nimble and responsive to change that will ultimately separate successful manufacturers from the rest.

INDUSTRY TERMINOLOGY

A. Engineering Change Request (ECR) / Engineering Change Proposal (ECP)

ECP/ECR is a formal proposal to modify product's design, manufacturing process [1], specification or documentation change which is subject to approval. It is typically initiated to address issues such as design flaws, manufacturing inefficiencies, regulatory compliance, or customer feedback. The goal of an ECR is mainly to improve product quality, reduce costs, increase efficiency, and enhance customer satisfaction. Once an ECR is approved, next step is Engineering Change Order (ECO).

B. Engineering Change Order (ECO):

An approved document that specifies details of the changes to be implemented. In chip design, an ECO refers to inserting logic changes directly into the netlist after it has been processed by automatic tools. ECOs are used before chip masks are constructed to save time and avoid full ASIC logic synthesis, technology mapping, and layout extraction. Post-mask ECOs help save costs by modifying only a few layers, reducing the need for new photomasks, which are costly. Various Electronic Design Automation (EDA) tools facilitate this process through incremental modes of operation [2].

C. Manufacturing Change Request (MCR)

A formal request to modify manufacturing processes, tooling, or production workflows. MCRs are crucial for ensuring that any changes proposed to the manufacturing environment are carefully evaluated and documented before implementation. They typically address process improvements, material substitutions, and compliance with new regulatory requirements. MCRs help streamline communication between engineering, production, and quality teams to ensure that changes are thoroughly assessed for their impact on production timelines, costs, and product quality [3].

D. Product Change Notice (PCN)

A formal notification issued to inform stakeholders of a significant change in the design, manufacturing process, or materials of a product. In the telecommunications industry, the PCN is a formal process that combines elements of the ECO and other considerations to track, and report changes accurately. These changes can impact hardware, software, and firmware throughout a product's lifecycle. Reportable changes typically affect the form, fit, function, or technical specifications and are tracked to ensure regulatory compliance and operational efficiency [4].

E. Manufacturing Change Request (MCR)

A comprehensive list of parts, components, and assemblies required to manufacture a product. The BOM provides detailed information necessary for production planning, cost estimation, and inventory management. It ensures consistency and traceability across the product lifecycle by hierarchically organizing materials from raw materials to finished goods. An accurate BOM helps manufacturers maintain efficiency, avoid material shortages, and support change management processes by documenting all components affected by a design change [5].

F. Deviation Permit

A temporary approval that allows manufacturers to move forward with production even when a product or process doesn't fully meet the usual standards. It's used when minor issues come up that won't affect the overall performance, safety, or quality of the product. Instead of halting production, companies can use a deviation permit to keep things running smoothly while they work on a long-term fix. These permits help businesses avoid costly delays and are commonly used in industries like automotive, aerospace, and electronics when materials are unavailable, or small design tweaks are needed. [6].

Challenges in Managing Engineering Design Changes

Before Managing engineering design changes (EDCs) in manufacturing is a complex process that presents several challenges. These challenges can disrupt production workflows, increase costs, and affect product quality if not addressed effectively. Table 1 summarizes the key challenges and their impacts

TABLE I.

Challenge	Impact
Communication Gaps	Delays, errors, rework
Documentation Control	Non-compliance, use of outdated designs
Cost Implications	Increased material, labor, and operational costs
Supply Chain Disruptions	Bottlenecks, delays in material availability
Regulatory Compliance	Legal penalties, product recalls

Production Flow Disruption	Downtime, reduced efficiency
System Integration	Technical incompatibility, operational inefficiencies
Stakeholder Resistance	Delays, lack of buy-in

Each of these challenges is supported by real-world case studies, highlighting their significance and the need for effective management strategies.

1. Communication Gaps

Lack of coordination between design, engineering, and production groups tends to breed misunderstandings that result in delays. For instance, in the automotive sector, a key car maker experienced a 15% launch delay for a new model of car due to poor communication regarding a change in design. Production workers utilized outdated documentation, and non-conformity parts and a lot of reworks ensued [7].

2. Documentation Control

Accurate and current documentation is important but proves to be challenging, particularly in big-manufacturing environments with many stakeholders involved. In the aerospace sector, Boeing experienced a compliance problem when a change in a design failed to be documented. There was a six-month certification delay estimated and other cost indirect cost related to document control failure [8].

3. Cost Implications

Design changes, especially when executed at a later stage in the life of a product, can have a tremendous impact on cost. In a study in the electronic manufacturing sector, post-manufacturing design changes added 30% to costs through requirements for new tooling and retraining of operators. For a case in point, a smartphone maker re-engineered a board of circuits after production began, incurring an additional $5 million in expenses [9].

4. Supply Chain Disruptions

EDCs can have a ripple impact in the supply chain, impacting availability of materials through new design introductions with high lead times, and logistically make production cumbersome. In the consumer goods sector, a change in the design in a household appliance necessitated a new part, with a single-source vendor providing it. There was a two-month delay and a 20% rise in production expenses [10].

5. Regulatory Compliance

Manufacturers have to ensure that design changes comply with evolving regulatory standards as they can vary across regions and industries. In the medical device industry, if a design change to a surgical instrument fails to meet updated FDA regulations, it can cause millions of loss and reputation of the company.

6. Production Flow Disruption

Implementing design changes during production can disrupt workflows, leading to downtime and reduced efficiency. For instance, in the semiconductor industry, a design change requiring equipment recalibration caused a 20% reduction in daily output for two weeks. This resulted in a revenue loss of $2 million in revenue [11].

7. System Integration

Integrating design changes into existing manufacturing systems can be technically challenging, particularly in highly automated environments. In the automotive industry, a design change to a car's braking system requires significant modifications to robotic assembly lines. The integration process took three months, delaying production and increasing costs by $3 million [12].

8. Stakeholder Resistance

Stakeholders' resistance, including employees, suppliers, and customers, can hinder the implementation of design changes. For example, in the aerospace industry, a proposed design change to reduce weight was met with resistance from suppliers that were unwilling to invest in new tools. This delayed the project by several months and increased costs by $1.5 million [13].

Potential Solutions

A. Tools and Technologies

In today's world of AI, adopting tools and technologies is not important, but soon it can become a necessity so some of the tools in detail, highlighting its role in managing EDCs. Table 2 summarizes the key challenges and their impacts

TABLE II.

Tool/Technology	Application
Product Lifecycle Management (PLM)	Centralized platforms for tracking design versions, approvals, and changes
Enterprise Resource Planning (ERP)	Integration of design changes with procurement, production planning, and inventory management
Computer-Aided Design (CAD) Software	Real-time collaboration, visualization, and validation of design modifications
Workflow Management Tools (e.g., JIRA)	Tracking change requests, approvals, and implementation status
Digital Twins	Virtual testing and simulation of design changes to predict impacts

- **Product Lifecycle Management (PLM) Systems**: PLM platforms offer a single, centralized platform for controlling product information, including design modifications, during the life of a product. PLM platforms allow departments to collaborate, have versioning, and maintain a whole record of modifications. For instance, Siemens Teamcenter is extensively utilized in aerospace to maintain complex design modifications and compliance with regulatory requirements. Integration with ERP platforms maximizes efficiency through integration with production planning and materials planning [14].
- **Enterprise Resource Planning (ERP) Systems**: ERP systems integrate design changes with business processes such as procurement, production planning, and inventory management. This ensures that changes are implemented without disrupting supply chains or production schedules. For instance, SAP ERP is used in automotive manufacturing to synchronize design changes with material requirements and production workflows [14]. By linking design changes to real-time data, ERP systems help manufacturers to optimize costs and minimize delays. Figure1 shows details of the attributes that can be shared across PLM & ERP systems.

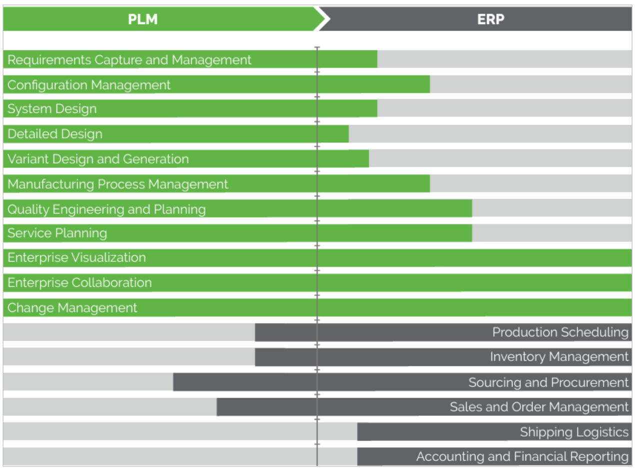

Fig. 1. PLM and ERP [14], Source: PTC Inc.

- **Computer-Aided Design (CAD) Software**: CAD software allows engineers to model, modify, and verify design changes in virtual settings. This eliminates the use of physical prototypes and enables real-time collaboration between design and production departments. Autodesk Inventor and SolidWorks are examples of CAD software utilized to introduce design changes in industries such as consumer goods and heavy machinery [15]. High-end CAD platforms also integrate simulation and analysis, allowing for performance and safety standards to be met for design changes.
- **Workflow Management Tools:** Workflow management tools such as Atlassian JIRA make it easier to monitor and manage change requests, approval, and implementation tracking. These tools promote transparency and make everyone aware of the progression of design changes. For instance, JIRA is utilized in software and hardware development for managing engineering change orders (ECOs) and tracking impact on project timelines [16]. By automating workflows, these tools save administration overhead and enhance efficiency.
- **Digital Twins**: Digital twins make virtual copies of real-life products or systems, and with them, manufacturers can simulate the effects of design change prior to implementation. This lessens the risk of mistakes and ensures optimized changes for performance and cost. Many organizations like General Electric (GE),IBM(monitoring & efficiency), Siemens(power grid modeling and Red Bull (Formula 1 Racing) are utilizing digital twins for service. Deployment of digital twins is most beneficial in industries such as aerospace and automotive, where design change can have high safety and financial consequences [17].

B. Case Studies

In one of the case studies[18] done by McKinsey & Company on improving the change management, companies can adopt a two-step approach: introducing transparency and accelerating the change order process as shown in Figure 2 . For example, an automotive company facing a delayed launch established a cross-functional team with clear roles and responsibilities. Daily check-ins and biweekly reviews ensured quick decision-making, ultimately rescuing the launch. This case demonstrates the effectiveness of structured processes and cross-functional collaboration in managing change orders.

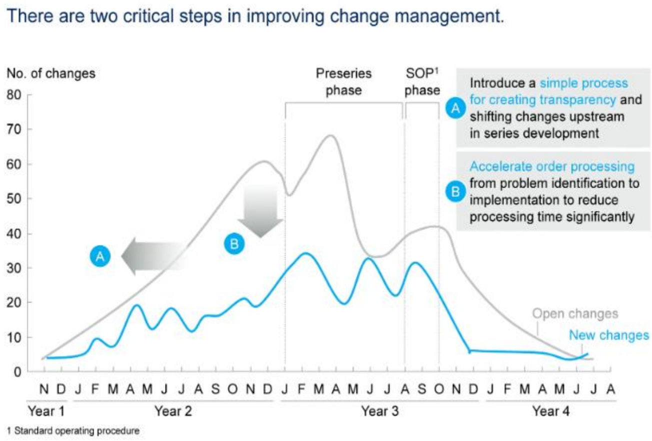

Fig. 2. Two critical steps in change management [19], Source: McKinsey & Company

Another case study [19] automotive manufacturing firm (Mercedes-Benz) , a global leader in the automotive industry, transformed its internal processes by migrating over 30,000 users from an on-premises Atlassian Data Center to Atlassian Cloud. This shift allowed the company to reduce the burden of system maintenance, freeing up valuable IT resources to focus on strategic initiatives without compromising security, performance, or flexibility. By leveraging cloud-based Jira, employees gained self-service capabilities, enabling them to create projects and workspaces instantly, significantly improving efficiency and reducing bottlenecks. The migration was carefully planned and executed in phases, with extensive training and close collaboration with Atlassian's support team to ensure smooth transition. This move resulted in better system performance, higher security with features such as multi-factor authentication (MFA), and the ability to scale operations without annual licensing negotiations. With fewer resources dedicated to maintenance, Mercedes-Benz has now focused on innovation and has expanded the use of Atlassian tools to enhance customer support operations, demonstrating how cloud technology can drive efficiency, flexibility, and growth in a competitive industry.

CONCLUSION

The management of engineering design changes (EDCs) in production is a complex but imperative one. With proper tools, methodologies, and best practices, organizations can strike a balance between innovation and efficiency in operations. Cross-functional collaboration platforms in the cloud, cross-functional teams, automation, and integration of PLM and ERP software are imperative solutions for overcoming EDC management issues. Real-life case studies, such as Mercedes-Benz's switch to Atlassian Cloud, have proven effective in enhancing performance, cutting costs, and collaboration. As production continues to evolve, proactive management of design change is imperative in staying competitive in the market.

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