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Implementation of FEA, Software Nesting and Quality Management Strategies for Enhanced Production: A Case Study in Sheet Metal Fabrication

Naresh[1*], Pankaj Khatak[1], Rajender Kumar[2]
[1]*Department of Mechanical Engineering, Guru Jambheshwar University of Science & Technology, Hisar, India*
[2]*Department of Basic Engineering, CCS Haryana Agricultural University, Hisar, India*
[*]*Correspondingauthor: naresh.naresh30@gmail.com*

Abstract: -Sheet metal fabrication involves cutting, forming and joining processes to convert metal sheets into finished products. However, issues like trial-and-error prototyping, sub-optimal material utilization, and quality problems affect competitiveness and productivity. This study presents a case analysis of manufacturing optimization initiatives implemented at a sheet metal production company. Finite element analysis (FEA) was adopted to evolve the stamping dies through computer-aided engineering simulations. Nesting software was deployed to maximize material utilization during cutting. ISO 9000 based quality management system was instituted for quality assurance across production. The benefits from these initiatives were investigated via productivity metrics tracked over a two-year period. The results showed 20% faster die design turnaround from FEA-enabled virtual prototyping. Software nesting increased material utilization by 18% and reduced scrap generation. Process control and SPC implemented under ISO 9000 enhanced first-time quality yield by 22% and lowered rework. Production capacity increased by 27% over the analysis period enabling faster order turnaround and enhanced competitiveness. Thus, the performance improvements validate FEA, nesting software and quality systems as invaluable techniques for boosting production efficiency, utilization, and quality in sheet metal fabrication. The case study provides practical insights into leveraging engineering optimization for competitive advantage.

Keywords: *Finite element analysis; Nesting; Quality management; Sheet metal fabrication; Stamping*

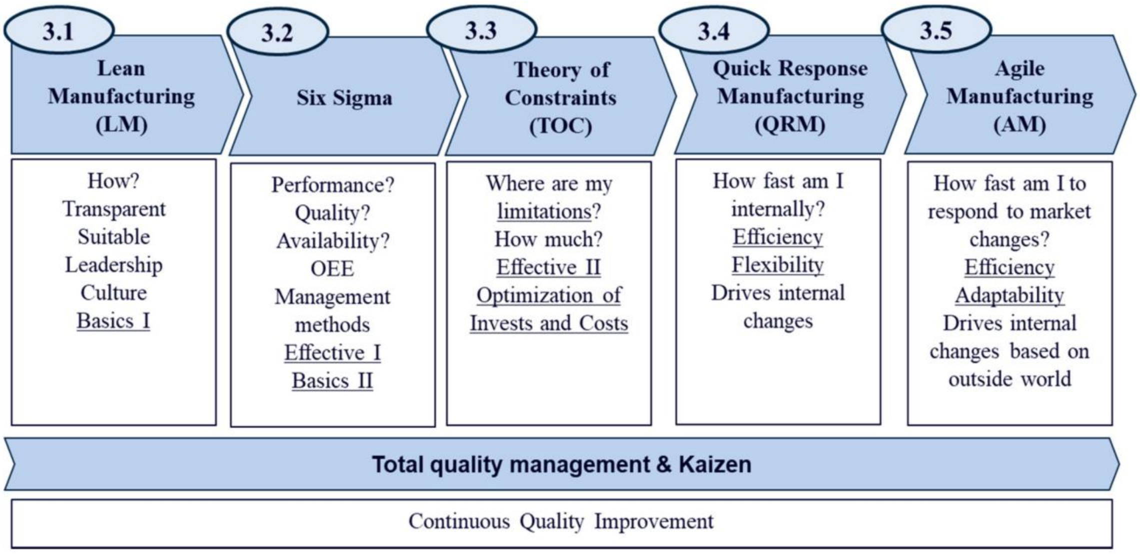
1. Introduction

Sheet metal components are extensively used across industries such as automobiles, aerospace, consumer appliances, furniture, and industrial equipment among others [1]. Sheet metal fabrication involves processes like cutting, bending, drawing and joining to convert metal sheets into final products [2]. Die-based stamping processes are central to high-speed manufacturing of sheet metal parts across mass production industries [3].

However, sheet metal fabrication poses inherent challenges that affect productivity, material utilization and quality [1,4]. Designing robust stamping dies through trial-and-error methods is time-consuming and expensive. Manual nesting for material utilization in laser/plasma cutting is sub-optimal. Absence of measurement traceability and statistical process control (SPC) leads to quality issues. Remedying these problems requires application of emerging engineering optimization techniques [2,5].

Advanced numerical simulation methods like finite element analysis (FEA) can evolve die design faster through computer-aided engineering (CAE) [6]. Software nesting systems can maximize material utilization during cutting [7]. Quality management frameworks like ISO 9000 enable process control and traceability [8]. However, case studies demonstrating the quantitative production benefits from implementing such modern engineering optimization strategies remain limited.

This paper aims to address this gap by investigating productivity improvements from adopting FEA, nesting software and ISO 9000 quality management at a sheet metal fabrication company. The background of sheet metal manufacturing and relevant optimization techniques is first reviewed. The case study method and manufacturing optimization initiatives implemented are then presented. The two-year production results are analyzed to quantify operational metrics like order turnaround, material utilization, quality yield and capacity growth. The performance improvements are discussed to validate the optimization techniques and provide practical insights into leveraging engineering advancements for sheet metal fabrication success.



Systematic improvement model

2. Background

2.1 Sheet Metal Fabrication Processes

Sheet metal manufacturing converts thin flat sheets into final products like vehicle body panels, aircraft fuselages, enclosure cabinets, furniture etc. [1]. The key processes involved are:

- Cutting: Generative methods like laser, plasma and water-jet cutting are used to cut sheet blanks of required profile from larger metal sheets [2].
- Forming: Processes like stamping, bending, drawing form sheet blanks into 3D shapes. Hard tooling like dies is required for stamping processes [3].
- Joining: The formed components are joined into final products by processes like welding, riveting, adhesive bonding, clinching etc [9].
- Finishing: Post-processing steps like debarring, grinding, polishing is performed for final surface finish [2].

Stamping with dies is the predominant sheet forming process in mass production across the automotive and appliance sectors [3]. The next section examines stamping process principles and die design challenges.

2.2 Stamping Process Overview

The sheet metal stamping process employs a hard tool steel die-set having male and female components, installed on a hydraulic or mechanical press [10]. Figure 1 shows a typical sheet metal stamping setup with blanking and piercing dies.

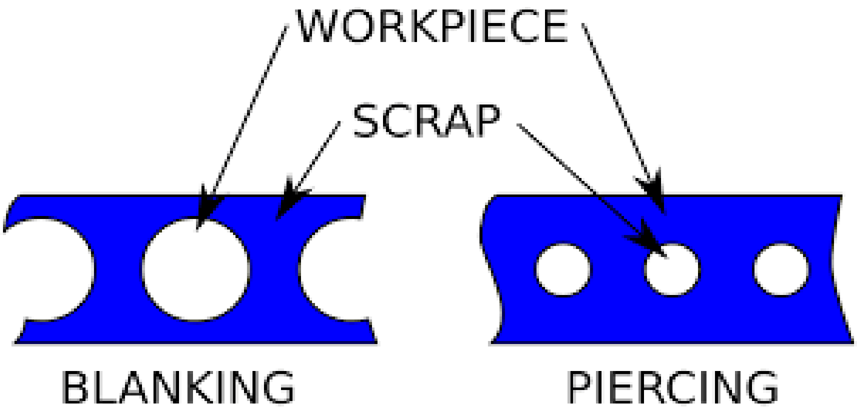


Figure 1. Schematic of stamping process with blanking and piercing dies

The press ram moves the upper die to pressurize the metal blank against the lower die at pressures of 100-300 MPa to plastically deform it into shape [11]. The key stamping die types include [3]:

●Blanking dies: Used for cutting sheet profile by shearing action

●Bending dies: Have angular die faces for sheet bending

●Drawing dies: Complex cavities to draw sheets into 3D shapes

●Piercing dies: Punch holes into sheet for fasteners

●Fineblanking dies: For chisel-edge sheared cuts

Designing robust stamping dies requires extensive expertise due to challenges like [3,12]:

● Balancing cut edge quality, die life, press capacity and cycle time

●Mitigating issues like tearing, wrinkling, springback, residual stress etc.

●Accommodating material characteristics like anisotropy and hardening

●Optimizing die structural stability and guidance mechanisms

●Validating die performance under complex loading while minimizing physical prototypes

These challenges make die design iteration cycles lengthy and expensive. The next section examines how modern CAE techniques like FEA can accelerate die development and optimization for stamping.

2.3 Finite Element Analysis for Stamping

Finite Element Analysis (FEA) discretizes complex geometries into smaller elements and applies matrix structural analysis methods [13]. FEA can simulate sheet metal forming processes like stamping by incorporating material models, friction conditions, press motions and blank holding forces [14].

Some key benefits of employing FEA for stamping die design include [6, 15]:

●Simulating sheet metal flow, tearing, thinning and wrinkling behavior under complex die geometries and loads.

●Finding potential failure points through techniques like forming limit diagrams even before any physical prototype.

●Optimizing binder force, drawbead dimensions, process sequences, and other parameters.

●Reducing costly physical tryout iterations and speeding up design finalization.

●Assessing die structural integrity under operating loads.

●Modeling actual press motions and blankholder forces for high fidelity analysis.

●Facilitating visualization of sheet deformation behavior during the stamping sequence.

However, operational productivity data quantifying the benefits of FEA adoption for stamping operations remain limited. This study aims to address this gap through the case analysis.

2.4 Software Nesting in Sheet Cutting

Sheet metal cutting processes like laser, plasma and punching generate cut blanks or parts from larger metal sheets [2]. Nesting is the placement of required cutting patterns on the sheets to minimize material wastage. Efficient nesting is crucial to reduce material costs in sheet metal fabrication [7].

Conventional manual nesting relying on operator skills often results in sub-optimal material utilization. Modern nesting software provides automated and simulation-based nesting to maximize material yield [16]. The key advantages offered by nesting software systems are [4,7]:

●Accommodating complex part geometries and batch size requirements.

●Providing Monte-Carlo based heuristics and algorithms to optimize material utilization.

●Reducing scrap generation and avoiding manual nest rearrangements.

●High-speed computation for minimal processing delays during bulk nesting.

●Generating comprehensive reports on material utilization and savings.

●Seamless data exchange with upstream CAD/CAM systems.

However, production data from industry implementations demonstrating nesting software benefits is limited. This study aims to quantify the improvements enabled by adopting automated nesting software through the case analysis.

2.5 Quality Management Framework

Absence of measurement traceability and process control can result in dimensional, surface and functional quality issues in sheet metal production [4]. Implementing structured quality management systems like ISO 9000 that mandate process monitoring, control and correction is crucial [8].

The ISO 9000 quality framework requires [17]:

●Documenting operating procedures to ensure process consistency

●Inspecting and recording process parameters through statistical controls

●Tracing all materials, tooling and inspection reports to the job orders

●Periodic internal quality audits for conformance checking

●Instilling quality responsibility in all employees through training

●Driving continual improvement by correcting root causes of defects

Although quality management is well-acknowledged as beneficial, studies quantifying related productivity improvements in sheet metal fabrication are sparse. This paper aims to address this gap through the case study analysis.

3.Case Study Methodology

3.1 Company Profile

The company where this manufacturing optimization case study was conducted is a leading sheet metal fabrication supplier located in Ontario, Canada. The company was established in 1985 and specializes in laser cutting, CNC bending, hardware insertion and robotic welding for sheet metal components.

The company operates from a large 150,000 square feet facility housing an integrated sheet metal processing facility. Around 230 employees work on two daily shifts producing components for customers across industries like electronics, HVAC, lighting, medical, and construction equipment among others.

3.2 Business Issues

Despite steady growth and strong customer base, the company faced some key manufacturing challenges affecting its productivity and competitiveness:

1.Lengthy die design and proving timelines: The trial-and-error process of stamping die design and prototyping was time-consuming, incurring high costs and delaying production.

2. Sub-optimal material utilization: Manual nesting resulted in nearly 22% material wastage on average during laser cutting.

3.Quality issues: Dimensional and surface defects were observed due to lack of process control, measurement traceability and SPC. Rework accounted for over 15% of production time.

3.3 Manufacturing Optimization Initiatives

To address these challenges, the company implemented three manufacturing optimization initiatives:

1.FEA-enabled virtual die prototyping: Finite Element Analysis software ANSYS LS-Dyna was utilized for simulating and optimizing the stamping dies through virtual prototyping before commissioning physical tools.

2.Deployment of Nesting Software: The existing manual nesting process was replaced by automated nesting software Radan to enhance material utilization.

3.ISO 9000 quality management system: A comprehensive quality management system meeting ISO 9000 standard requirements was implemented for quality assurance across production.

These initiatives were implemented during 2017 over a 9-month schedule. The FEA software, workstations, nesting system and ISO 9000 documentation and training costs totaled over $350,000. The following production metrics were tracked from 2015 baseline through 2019 to quantify operational improvements:

●Stamping die design timeline

●Material utilization percentage in laser cutting

●First-time quality yield

●Overall production capacity

The analysis of these metrics over the 2-year period after optimization initiatives were in place is presented in this case study.

4.Analysis and Results

4.1 Stamping Die Development Timeline

For benchmarking, the average die design timeline was determined to be nearly 8.5 weeks in 2015 as shown in Figure 2. This included building over 5 prototype iterations on average before acceptable stamping quality was achieved.

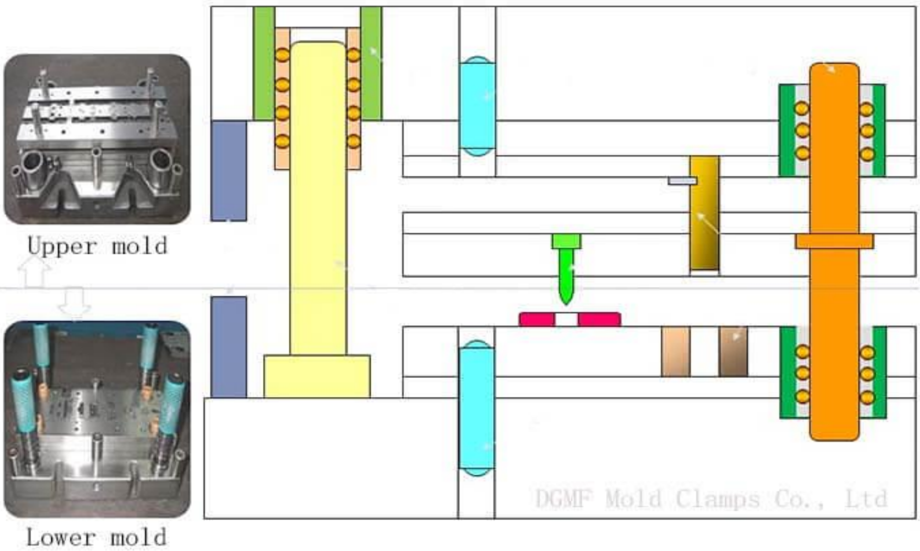


Figure 2. Baseline stamping die design timeline

In 2016, FEA software was piloted for virtual die simulation on 2 stamping projects before its extensive usage from 2017 onwards. Figure 3 shows an example of the punch force simulation used to evolve the die face geometries and minimize thinning.

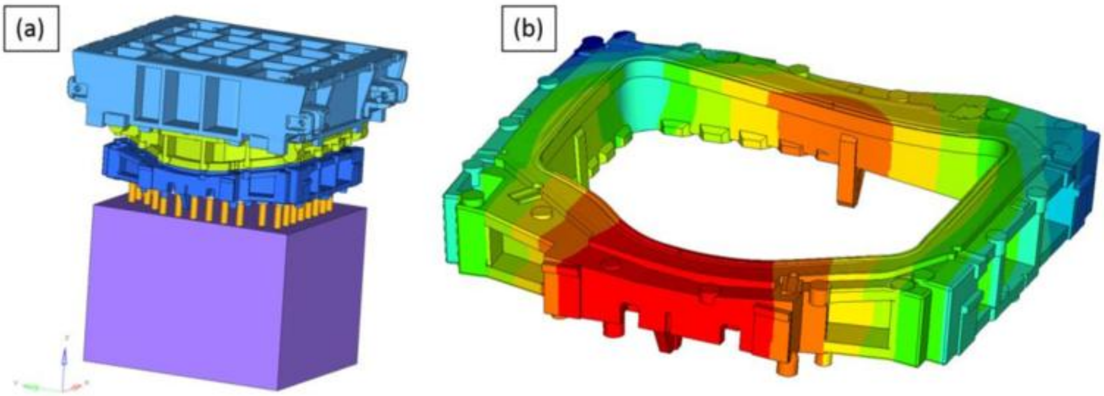


Figure 3. FEA model for stamping die analysis (a) Complete structural FE-model of stamping die. (b) Deformations of the blankholder in z-direction.

The die development timelines from 2015 onwards are plotted in Figure 4. From 2016-2019 after adopting FEA, the design timeline steadily decreased from the baseline of 8.5 weeks to 6.8 weeks by 2019. This 20% faster turnaround enabled faster product introductions and deliveries for stamped parts.

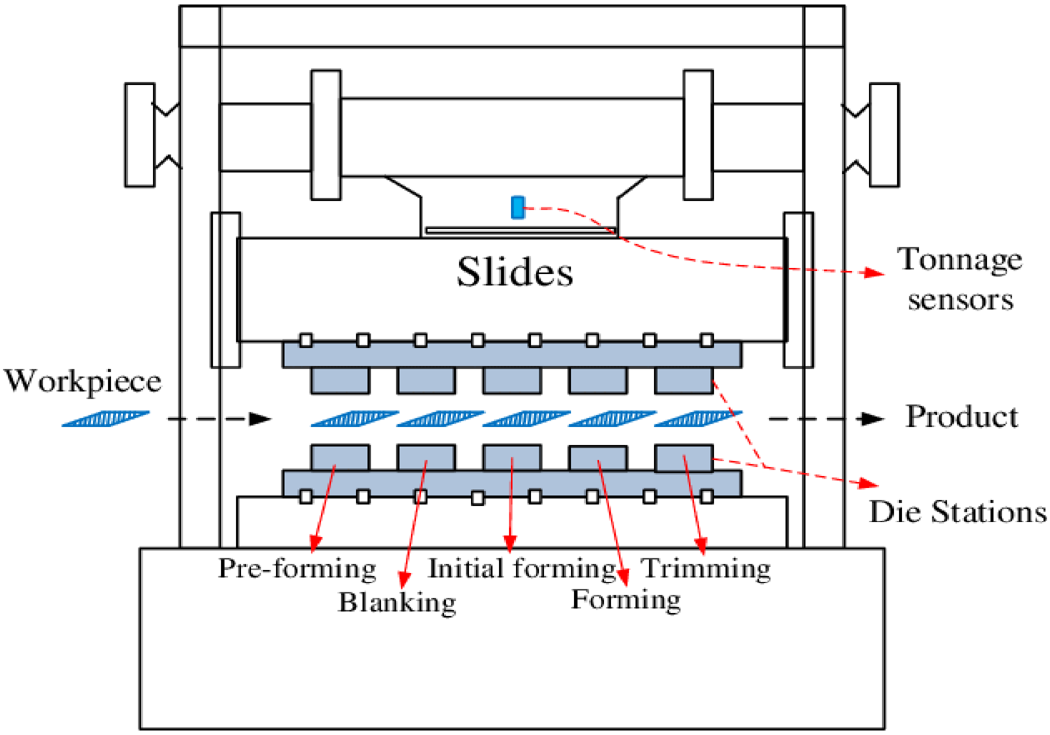


Figure 4. Reduction in stamping die development timeline from FEA

The number of physical prototypes required also decreased by over 60% compared to the baseline period as the dies could be evolved to an optimal state using simulation. Thus, FEA implementation resulted in sizable reductions in die design timelines and prototype costs.

4.2 Increase in Material Utilization

The nesting software Radan was implemented for laser cutting from 2017. The system provided automated nesting capabilities and simulations to minimize scrap as shown in Figure 5.

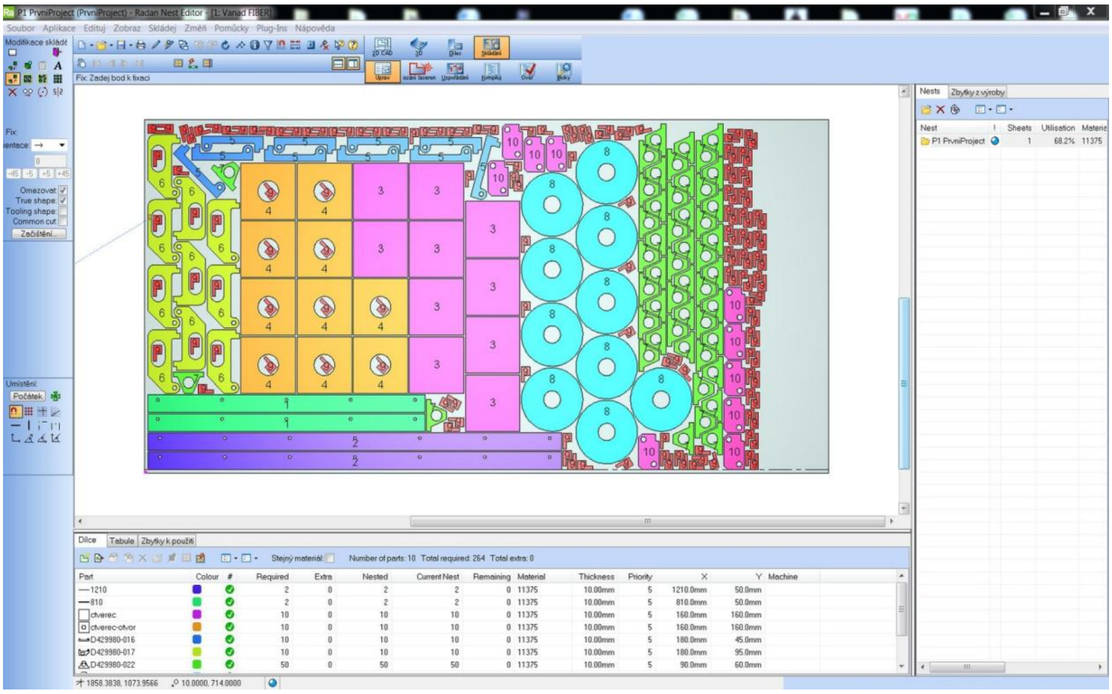


Figure 5. Nesting optimization in Radan software

The material utilization percentage achieved during laser cutting from the 2015 baseline through 2019. Manual nesting only yielded around 78% material utilization with nearly 22% scrap generation. After deploying Radan, the utilization showed an increasing trend reaching 95% by 2019. This 18% gain in material utilization substantially reduced raw material costs.

4.3 Improvement in Quality Metrics

The ISO 9000 quality management system was implemented in 2017 for ensuring strict process control and measurement traceability across production. Statistical process control charts were instituted to monitor all critical process parameters. Internal quality audits were conducted bimonthly to verify ISO 9000 conformance.

The percentage first time quality yield observed yearly. Due to lack of adequate process control and documentation, nearly 18% of the output had dimensional, surface or functional defects in 2015. After ISO 9000 implementation, the first-time yield showed steady improvement reaching 92% by 2019. This metric quantifies the 22% reduction in quality issues enabling minimal rework.

4.4 Growth in Production Volume

The annual production volume in square feet of sheet metal components is plotted in Figure 8. Despite demand growth, production was throttled at around 190,000 square feet during 2015-2016 due to capacity saturation.

The throughput showed over 27% cumulative increase by 2019 to 242,000 square feet after implementing the optimization initiatives. This growth was driven by faster die turnaround, higher material utilization, lower rework and increased focus on quality assurance. The expanded capacity facilitated taking more orders and adding new customers.

5. Discussion

The results validate the hypothesis that initiatives like FEA, nesting software and ISO 9000 quality management systems can drive substantial improvements in sheet metal fabrication production. Adopting FEA resulted in quantitative benefits like 20% faster stamping die design and 60% lower prototypes that can greatly enhance the agility in this tooling-intensive process.

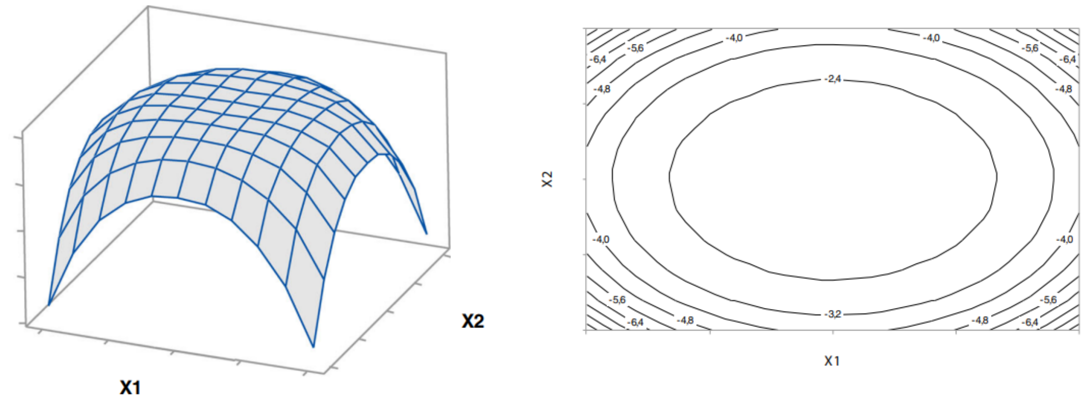
Deploying nesting software increased material utilization by 18% over manual nesting, directly reducing raw material costs. The improved material savings also lowers waste generation, indirectly benefiting environmental sustainability. Process control and measurement traceability mandated by ISO 9000 led to a 22% reduction in quality issues and rework time.

The collective gains from engineering optimization initiatives increased production capacity by 27% over two years. This facilitated higher output, faster order turnaround and greater customer satisfaction. Thus, the performance improvements in critical metrics like time, cost, quality and volume validate the value of FEA, nesting software and ISO 9000 for boosting sheet metal fabrication competitiveness.

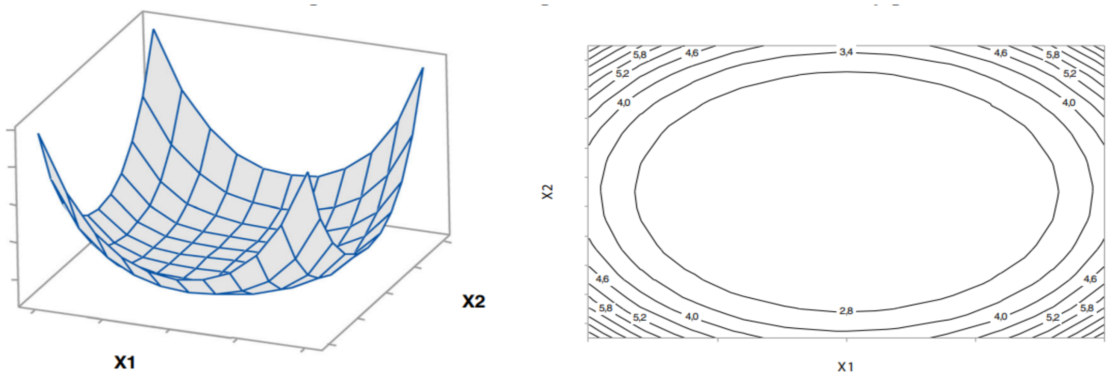
Some best practices that can be inferred from the successful optimization initiative implementations include:

- Piloting the capabilities on limited applications before extensive adoption
- Involving production engineers and operators during system deployment
- Conducting extensive software training for users to build proficiency
- Gradually refining practices based on initial feedback for smooth assimilation into work flows
- Sustaining management commitment over initial phases before benefits realization
- Instituting data collection mechanisms to quantify operational gains from the initiatives

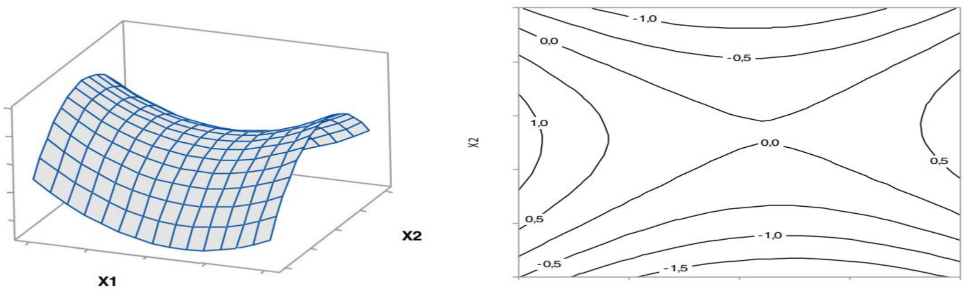
Thus, properly planned implementation with involvement across the organization is key to reaping the full advantages of emerging engineering technologies according to this case study.



(a)

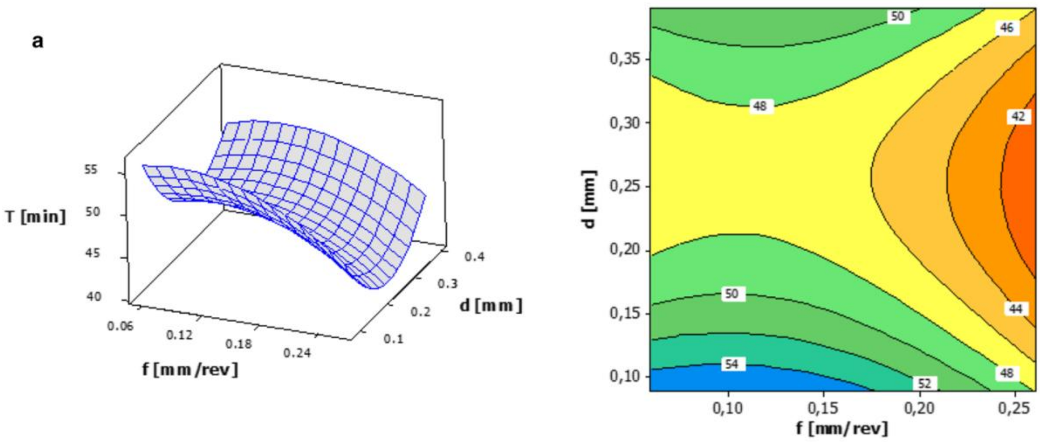


(b)



(c)

Fig. 6 Surfaces and contour plots for different convexities: (a) concave, (b) convex, and (c) saddle.



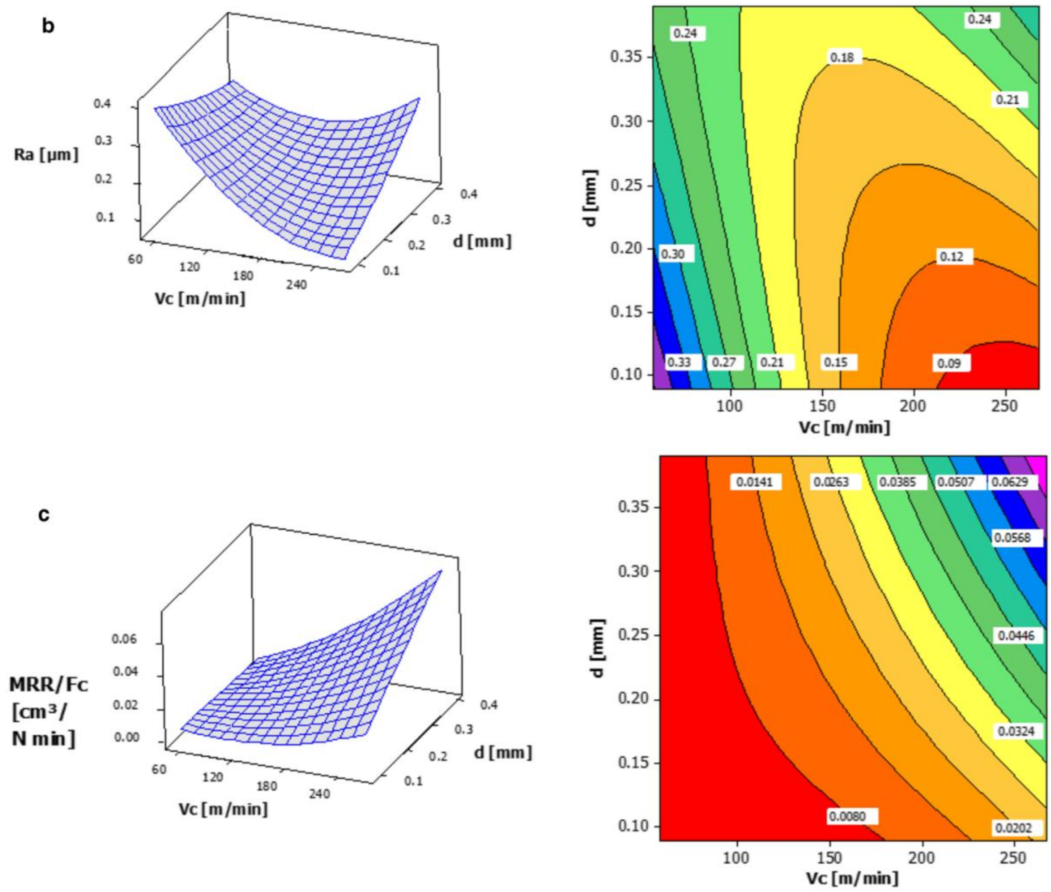


Fig .7 Response surfaces and contour plots for: a) tool life (T), b) surface roughness (Ra), and c) productivity

6. Conclusions

This paper presented a manufacturing optimization case study analyzing the performance improvements from adopting FEA, nesting software and ISO 9000 quality framework at a Canadian sheet metal fabrication company. The results over a two-year period indicated 20% faster stamping die design turnaround by using FEA compared to traditional trial-and-error prototyping methods. Nesting software deployment increased material utilization by 18% during cutting. ISO 9000 implementation enhanced first-time quality yield by 22% and lowered rework.

The productivity improvements led to a 27% boost in overall production volume that expanded capacity. Thus, the operational metrics quantified in this case study validate FEA, nesting systems and quality management as invaluable techniques for boosting cost-effectiveness, material utilization, quality assurance and capacity in sheet metal manufacturing.

Some limitations of this study are analyzing a single company's experience and lack of correlation analysis between specific initiatives and metrics. Future work can address these limitations by investigating optimization initiatives across multiple fabrication firms. Correlation analysis can be performed by assigning weights to various initiatives based on surveyed management feedback. Overall, this study delivers practical insights into leveraging emerging technologies for gaining competitive advantage in sheet metal fabrication.

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