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A Novel Tool Geometry Approach for Process Optimization in CNC-Based SMEs

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Abstract: Computer Numerical Control (CNC) machining retains relevance for unerring performance and productivity amid the volatile automobile scenario. Small and Medium Enterprises (SMEs) face the dilemmas of tool wear, thermal instability, and non-graded machining methods, which form the increased operational cost and lesser output. Under the ambit of the study, a thrust formulation was offered as a solution to Shubham Industries, a CNC-based SME located in Aurangabad, India, engaged in automotive component manufacturing, for process optimization and tool life enhancement. The study revealed that tool wear was very rapid, chip evacuation was very poor, and excess heat was generated due to the use of non-standard cutting tool geometries. Taking into consideration process parameters like tool material, rake, and flank angles and concentration of coolant, a novel standardized tool was designed. That is, details for a cutting tool have been provided with a rake angle of 8° and flank angle of 28°, as well as a specially prepared fixture to allow for re-sharpening. These implementations were then done on the CNC machines in actual production environments. An increase in tool life of 35% was reported with a 40% reduction in thermal loads imparted during cutting procedures. The immediate monthly cost savings were INR 13,440, with the yearly cost savings above INR 1.6 lakhs. Dimensional accuracy and quality of surface finish have shown improvements as well, which are prime requirements in automotive manufacturing. With a better design for the fixture, the re-sharpening becomes easier, therefore further reducing both operator dependency and downtime. CNC machining provides a scalable and economical paradigm for SMEs in the automobile industry so that these companies can work on standardizing cutting tool geometries and, in turn, process parameters to increase productivity and guarantee uniform quality at lower manufacturing costs for lean and sustainable production systems.

Keywords: *CNC Machining; Cutting Tool Life; Reduction in Tool Wear; Process Optimization; Rack Angle; Flank Angle; SME Productivity; Reduction of Thermal Load; Tool Re-Sharpening Fixture; Manufacturing Cost Saving; Standardized Tool Design.*

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I. INTRODUCTION

For achieving best performance, safety, and quality criteria in the automobile industry, precision manufacturing becomes paramount. CNC machines currently play a very crucial role in production, as there is demand for rugged and dimensionally accurate components. To keep improving efficiency of CNC operations is an ongoing challenge for many SMEs supplying components to the major automotive Original Equipment Manufacturers (OEMs). Among the principal problems are premature tool wear and tear, non-standard tool geometries, irregular re-sharpening procedures, or uncontrolled heat generation during machining. Shubham Industries, a small business located in MIDC Waluj's central area of Aurangabad, is dedicated to CNC machining automotive components. High tool consumption rate, irregular tool life, and inconsistent product quality resulted in higher operational cost, late production schedules, and unhappy consumers. Undefined cutting tool geometries, badly constructed chip evacuation systems, and thermal management problems resulted in these issues. Without consistent resharpened tools, the tool maintenance process was made even more inconsistent and dependent on the operator's skill level. At one of the central skill training center, Aurangabad, India a thorough investigation was initiated to solve the above-mentioned problems, so as to maximize the cutting process and improve tool life for tools used in CNC machines. This study lays greater emphasis on the standardization of important cutting tool parameters such as the rack and flank angles and developing a fixture-based re-sharpening method to ensure repeatability as well as correctness. Given the optimization of the rack angle to 8 and of the flank angle to 28, a cutting tool redesign was introduced alongside a standard re-sharpening fixture, achieving huge improvements in tool life, surface finish, and production rate. The developments yielded an immediate accounting profit of

INR 13,440 per month and prospective INR 1.6 lakhs annually. Besides improving the technical functioning of the machining operation, the study gave a solution scalable and affordable enough for SMEs in the automobile manufacturing industry. The paper describes the approach, application, and results of the Shubham Industries optimization project as a generic way for other industrial setups to seek CNC machining efficiency and tool performance improvement in the cut-throat industrial environment.

II. LITERATURE REVIEW

Basically, the life of cutting tools means productivity in CNC machining systems in the stressful automotive manufacturing setup. Various studies have attributed tool wear, generation of heat, and surface finish to be phenomena influenced by any of the different parameters such as tool geometry, choice of materials, cooling as well as operational conditions such as feed rate and spindle speed. Therefore, due to the significant role SMEs are playing in the automotive supply chain, it is important to enhance these aspects using cheap yet efficient methods. Boothroyd and Knight (2005) opined that in tool geometry optimization, the rake and flanking angles particularly should be chosen to encourage chip flow and reduce friction and thermal stability. Generally, there is so much heat; the tools wear out fast, and dimensional accuracy is lost, the worst thing ever. Such a defect happens when these angles are either indefinite or incompatible. Hence for the SMEs, this problem continues to worsen ever more due to their informal mechanisms, nonstandard tools, and hand re-sharpening due to scarcity. With the regular calibration of angles and use of suitable tool materials, Kumar and Shunmugam (2010) have emphasized, in their study, longevity of the tool can be greatly improved. Their study illustrates how minor changes in geometry reduce wear and provide better surface finish, thus addressing the problems prevalent at Shubham Industries. For small and medium enterprises such as Shubham Industries, the existing literature sees a lack of real application-oriented case studies that are technically scalable and economically viable. This gap highlights the importance of an industry-academia partnership for the use of custom solutions to address real-world problems. Projects related to fixture design for tool re-sharpening and angle standardization show promise in easing maintenance, reducing costs, and improving repeatability. A bunch of small companies still tend to stay with most rudimentary tool setups with ill optimization and documentation for CNC developments at the paper mill. Furthermore, literature suggests that early tool failure during high-speed cutting of metals used for automotive parts is caused by a deficient use of coolant and improper distribution of thermal load. The present study attempts to bridge the theory-practice gap in a live production environment with the study of present methods through a constant cutting tool and a specially designed fixture. Thus, this paper intends to offer some solutions to SMEs working in precision machining by promoting a data-driven process improvement approach and endorsing objective benefits such as tool life, cost reduction, and thermal control.

III. PROBLEM IDENTIFICATION

Initial evaluations at Shubham Industries revealed a range of inefficiencies in the CNC machines, with the rack and flank angle issues being the most apparent. A wholly different and quite so prominent among the issues was the consistent and so standing cutting tool shape. The lack of defined angle parameters resulted in erratic and inconsistent tool performance and early tool wear further contributing to the issue.

Friction between the cutting tool and work piece was observed to be excessively high. It was a result of badly shaped tools coupled with chip evacuation and small gaps between cutting teeth. They prevented proper chip build up at the cutting temperature. It not only accelerated tool wear but also worsened the surface finish and dimensional accuracy of components.

In automotive manufacturing, any single performance, safety, or quality standard can only be met with precision manufacturing. Given the absence of a set fixture, reshaping tools evolved into a manual and skill-driven process, which led to inconsistent tool edge geometry and decreased repeatability. The intricate reshaping process also added to machine downtime and maintenance delays. The re-sharpening procedures were complex and added to maintenance delays and machinery down time.

Increased material waste and routine production stoppages, along with increased operating costs, were the consequences of all the issues mentioned above, and ultimately, a loss in productivity and profit. This paper aims to address the fundamental challenges that have caused production delays, more material waste, and financial losses arising from tool design through improvement and methodical standardization.

IV. METHODOLOGY

To fix problems in the CNC operations at Shubham Industries, a methodical two-step process was initiated. The objective of this process was to identify the key causes of tool failure and to implement standardized measures to extend tool life, reduce thermal impacts, and streamline the re-sharpening procedure.

➢ *Phase 1: Present Factors Analysis*

The initial phase required a detailed review of machine parameters, current cutting techniques, and tooling setups. The key factors considered were as follows:

- Cooling Fluid Performance: The efficiency of the coolant in removing heat during machining was assessed. Poor coolant concentration and flow rates were found to significantly increase thermal overloads and tool wear.
- Material Interaction: The review of the tool and work piece materials brought to light the wear-causing factors. Existing tools were failing prematurely due to incompatible material hardness and thermal conductivity.

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- Review of Tool Geometry: The findings highlighted that cutting tools, and especially their rack and flank angles, fell short of precisely defined geometric standards. The tools were unable to maintain a steady chip flow, resulting in lower cutting efficiency and increased friction.
- Operational Factors: Excessive feed rates and cutting speeds, in violation of tool-material combinations, led to increased wear and poor surface finish.
- Specialist reviews, operator insights, and CNC machine data logging revealed a consistent pattern linking non-standard shapes and poor process discipline to tool wear.

Fig 1 Cutting Tool.

➢ *Phase 2: Design and Implementation of Optimized Tool and Fixture*

Based on the findings from Phase 1, a standardized cutting tool geometry was designed to resolve the identified issues. The new design featured:

- Rack Angle: 8°
- Flank Angle: 28°

These values were determined through iterative calculations and trials to balance cutting force, chip evacuation, and heat dissipation. The wider spacing between the cutting teeth allowed for improved chip removal, thereby reducing heat build-up and minimizing friction at the cutting interface. In parallel, a custom fixture was designed and fabricated to aid in the re-sharpening process. The goal was to eliminate dependence on skilled labor by introducing a repeatable setup for grinding and angle alignment. The fixture ensured that the tool could be consistently re-sharpened to its original specification, improving tool longevity and reducing production downtime.

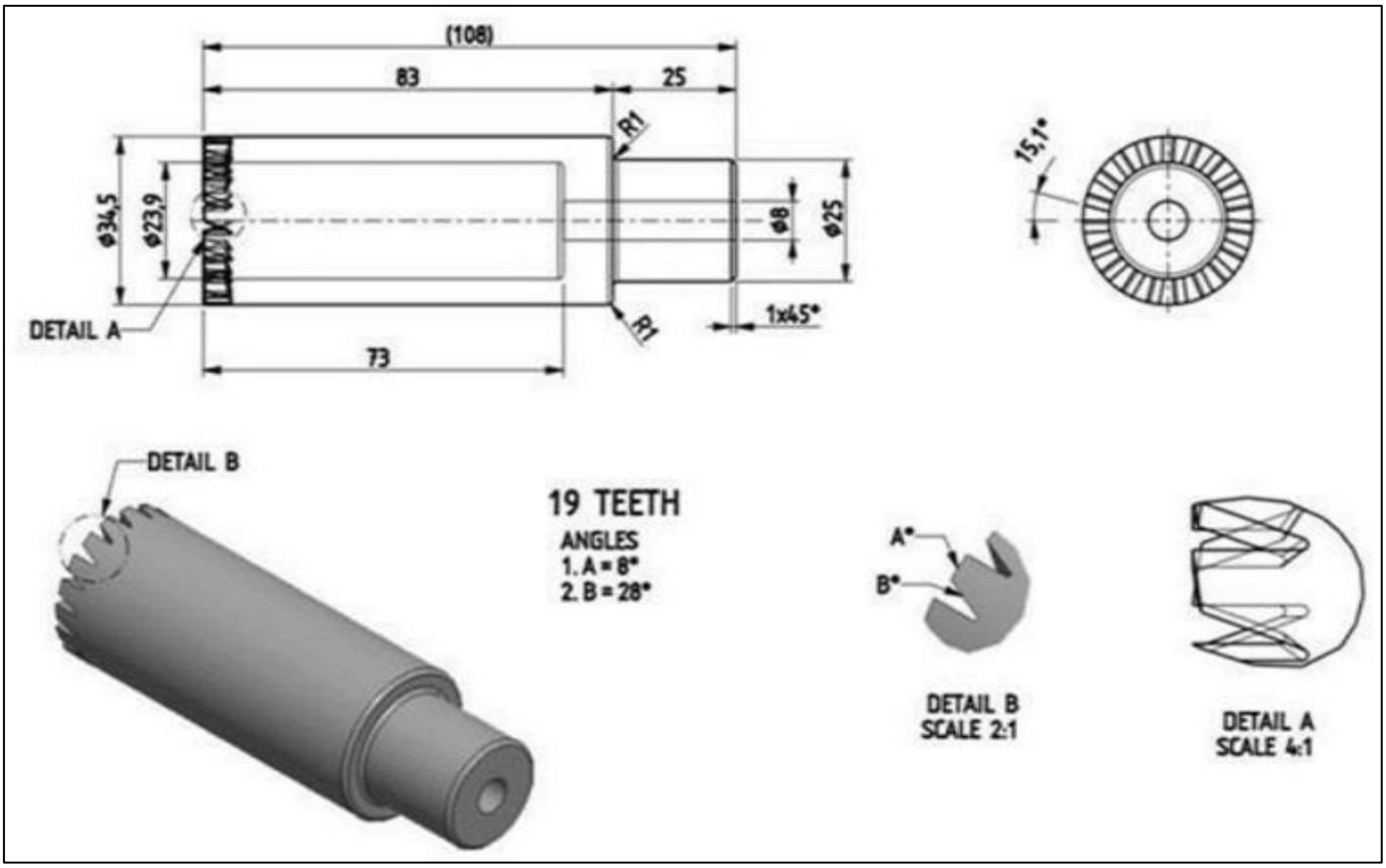

Fig 2 Updated Cutting Tool Design

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➢ *Phase 3: Coating of TiN on HSS tools*

Boosting efficiency with HSS tools involves applying a suitable coating to drills and cutters, such as TiN (Titanium Nitride), which may be applied using Physical Vapor Deposition (PVD) or the Chemical Vapor Deposition process. These coatings improve the resistive wear and lubricity at the cutting point significantly. They enable the use of higher speeds and feeds and increase tool life. TiN coated tools are easily recognized by the characteristic golden coating on HSS tools. The rake angle maintains the coating even after regrinding. To some extent, the coating is still effective although diminished.

Fig 3 Modified Cutting Tool

➢ *Phase 4: Maintain the Temperature of the Cutting Zone*

Tool teeth wear also depended on the temperature of the cutting zone and the feed rate and depth of cut. Tool life can be increased by reducing the cutting zone temperature which has been done here by using cold cutting fluid in the form of mixed according to the system requirement.

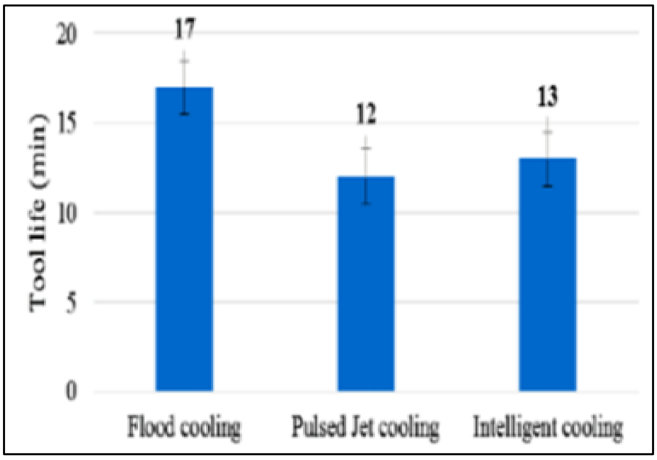

Fig 4 Cooling Impact on Temperature of Tool

➢ *Validation and Testing*

The updated tool and fixture system were installed on CNC machines at Shubham Industries' Plant 1 and Plant 2. Tests were run in kind with production in order to gauge:

- Tool wear rate
- Heat generation using thermal imagery
- Surface finish quality
- Dimensional accuracy of machined components
- Operator feedback on tool maintenance

All the results obtained confirmed the success of the new design in achieving tool performance and repeatability. The approach was economically viable and technically sound for small and medium enterprises in the automotive manufacturing industry.

Fig 5 Cutting Rotary Machine

Fig 6 Actual Cutting Existing Cutting Tool

V. IMPLEMENTATION AT SHUBHAM INDUSTRIES

At both Plant 1 and Plant 2, the newly designed cutting tool and fixture were put into use. It was important to conduct the trials under monitored conditions in order to evaluate the new tools performance in terms of the tool life, heat generation, chip evacuation effectiveness, and overall cost impacts. The feature to allow operators to perform re-sharpening enabled them to do so with precision and eliminated the need for a skilled technician. This, therefore, contributed to the process standardization.

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VI. RESULTS AND ANALYSIS

The results obtained after changing the design of the tool can be seen in Table 1. Thereafter, the overall savings can be seen as below:

➢ *Cost of Saving Report: Per Piece Cost:*

2.99-1.81=1.18………. Per Piece

➢ *Per Day Cost Saving for 3 Machine:*

1200*3=3600…………. Per Day Production

3600*1.18=4248……. Per Day Profit

➢ *Per Month Profit:*

4248*30=127440……. Per Month

➢ *Per Year Profit:*

127440*12=1529280.......Per Year

Table 1 Calculation After Changing the Design of Tool

Cutting Tool	Cutting Tool Use Cycle	No. Of Pieces Cut by Tool	Cost Of Tool	Cutting Tool Re-sharpening Cost	Per Piece Cost to Process	Output
Total	1	400	3200		8	Per Pieces 1.81 To cut Object
	2	500		80	0.16	
	3	500		80	0.16	
	4	500		80	0.16	
		1900		240 3200+240=3440	1.81	

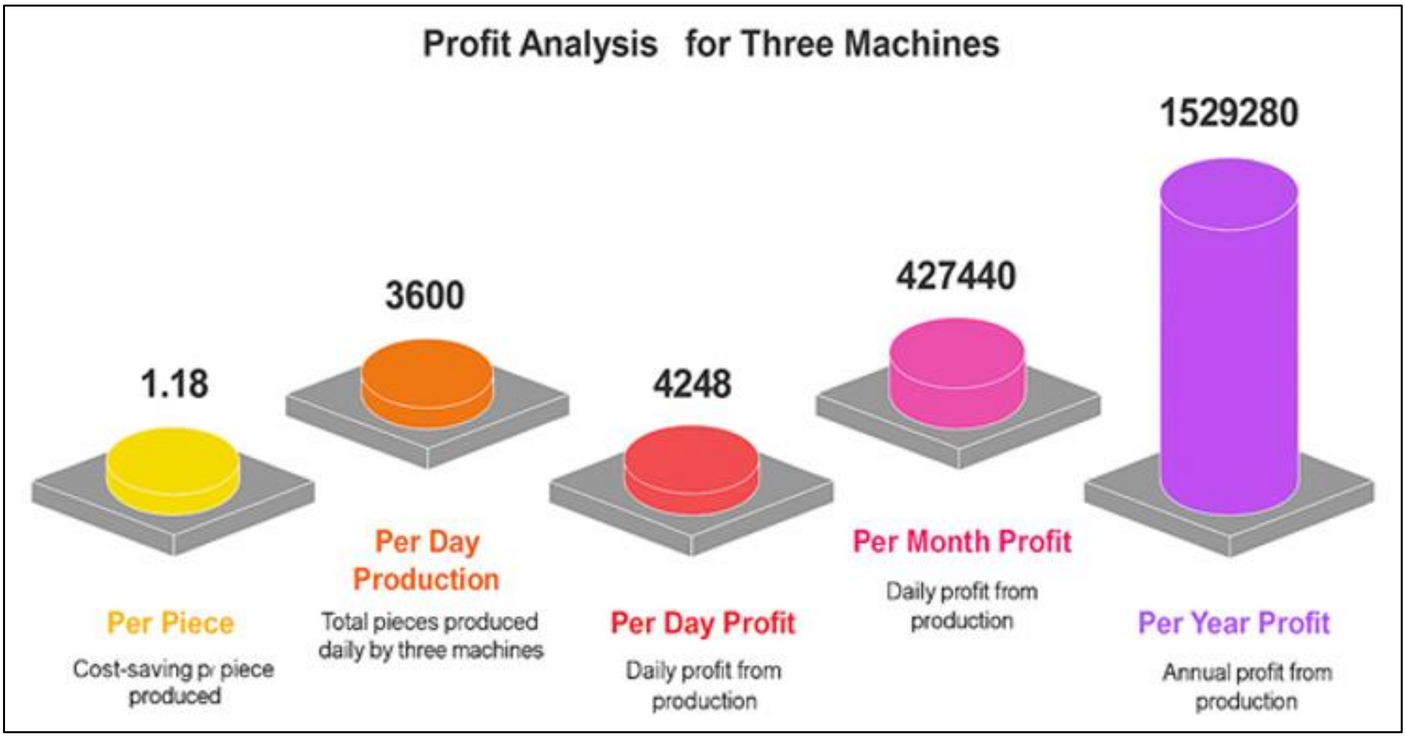

Fig 7 Profit Analysis in Indian Rupee

➢ *Other Benefits Gained were as Follows:*

- Tool life improved by approximately 35% compared to the baseline.
- Heat generation during cutting reduced by 40%, improving operator safety and environmental conditions.
- Monthly savings: INR 13,440. Annual savings: INR 161,280.
- Surface finish and tolerance accuracy significantly improved.
- Enhanced chip evacuation reduced secondary operations.
- Overall, standardization led to better control of quality and reduced variability in production

VII. BROADER IMPACTS ON SMES

The case study at Shubham Industries offers a viable framework for other SMEs facing similar machining inefficiencies. Key takeaways include:

- Low-cost innovation through local resources.
- Importance of tool geometry standardization.
- Training operators with standardized procedures.

Such measures not only enhance productivity but also reduce ecological impact by minimizing scrap and improving energy efficiency.

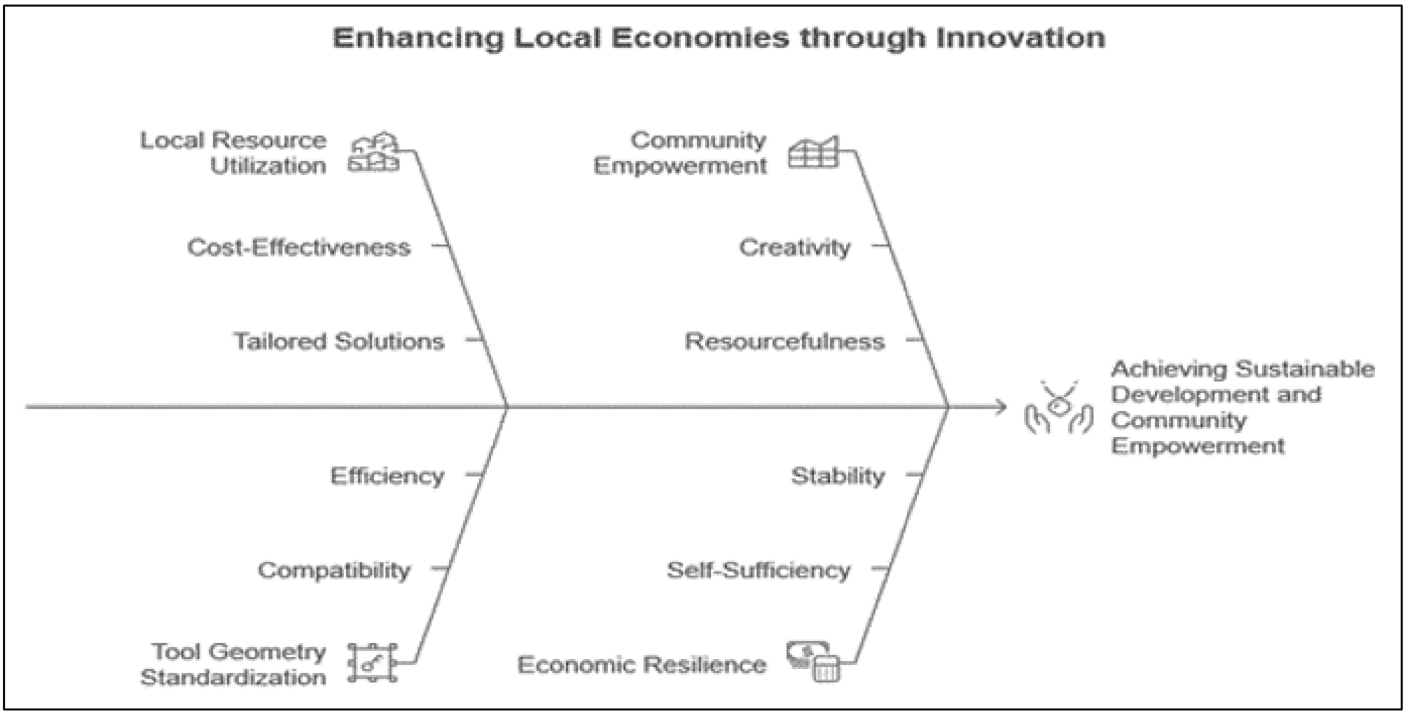

Fig 8 SME Impact

VIII. CONCLUSION

This paper conclusively demonstrates that standardizing cutting tool parameters and introducing fixture-based sharpening mechanisms significantly improve tool longevity, reduce costs, and increase production quality. The approach aligns well with industry 4.0 practices promoting lean manufacturing. SMEs in the metal cutting domain are encouraged to adopt similar optimization strategies to remain competitive and sustainable.

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influence tool temperature, cutting force, and wear; e.g., optimal rake ~5°, flank ~8° for minimal thermal load.

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