Proceedings of the 7th Asia Pacific Conference on Industrial Engineering and Operation Management
Bangkok, Thailand, March 25-27, 2026

Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/AP07.20260189
Published: March 25, 2026

Improving Length Accuracy in Steel Sheet Production in a Mini Leveller Process: An Industrial Case Study

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Abstract

This study examines a length deviation problem in steel sheet production on a mini leveller shear line, leading to repeated quality nonconformities and customer complaints. A systematic root-cause analysis was conducted using a fishbone diagram based on the 4M framework to identify the primary sources of process variation. The study indicated that excessive machine vibration, caused by a loose and worn coupling component, was the key factor contributing to length inconsistency. To address this issue, the defective coupling was replaced to improve machine stability. Process capability analysis was then used to assess process performance before and after the improvement. For each condition, 100 data points were collected and analysed. The results show a clear improvement in process capability, with the Cpk value increasing from 0.47 before the corrective action to 1.93 after. This confirms that the process became stable and capable of meeting customer specifications. Overall, the study demonstrates that addressing a specific mechanical root cause, supported by basic quality tools, can effectively improve dimensional accuracy and quality performance in steel sheet levelling processes.

Keywords
Mini leveller shear, Process capability index (C_{pk}), Fishbone diagram.

1. Introduction
In steel sheet manufacturing, dimensional accuracy is a key quality requirement. When product length deviates from specifications, it can cause assembly difficulties, customer complaints, and higher production costs. Among different quality characteristics, length consistency is critical in levelling and shearing processes, where machine performance directly influences product conformity. For this reason, maintaining a stable, capable process is essential to ensuring that steel sheets consistently meet customer requirements.

A mini leveller shear line is widely used in steel processing to flatten coiled steel sheets and cut them to the required lengths. This process involves several mechanical components, such as uncoilers, levellers, measuring rolls, rotary shears, and conveyor systems. The condition of these components plays a vital role in process performance. Issues such as machine vibration, component wear, or mechanical misalignment can reduce the accuracy of length measurement and cutting, leading to increased process variation and unstable product quality.

Process capability analysis, particularly the process capability index (Cpk), is commonly applied in manufacturing to evaluate whether a process can reliably produce products within specification limits. A low Cpk value indicates a highly variable process that is unable to meet requirements consistently. At the same time, a higher Cpk indicates improved stability and better specification conformity. In practical industrial settings, process capability analysis is often used alongside basic quality tools, such as fishbone diagrams, to identify root causes of variation and support improvement efforts.

Although many studies have reported the use of process capability indices and quality improvement tools, much of the existing work is based on simulated data or laboratory-scale experiments. Fewer studies present clear industrial case studies that show how machine condition, particularly mechanical vibration, affects process capability in steel sheet levelling operations. As a result, there is a need for practical investigations that link specific mechanical root causes to measurable improvements in process performance under real production conditions.

This study addresses this gap by examining a real production problem involving length deviation in a steel sheet mini leveller shear process. The objectives are to identify the main source of length variation through systematic root cause analysis, implement a targeted mechanical corrective action, and evaluate the effectiveness of the improvement using process capability analysis. By presenting a practical case study from an actual manufacturing environment, this research offers useful insights for manufacturing engineers and quality practitioners seeking effective, low-cost ways to improve dimensional accuracy and process capability.

1.1 Objectives

The objectives of this conference paper are as follows:

1. To improve the capability of the mini leveller shear process by achieving a process capability index (Cpk) greater than 1.67, ensuring that the steel sheet length meets the specified requirements.
2. To reduce customer claims related to length nonconformities by addressing the underlying mechanical cause of variation in the production process.

2. Literature Review

Process capability analysis is widely used in manufacturing to evaluate whether a process can consistently produce products that meet specification limits. Among various capability indices, the process capability index (Cpk) is one of the most commonly used measures because it accounts for both process variation and the location of the process mean relative to the upper and lower specification limits. According to Montgomery (2013), Cpk provides an effective indicator of process stability and capability, particularly for dimensional characteristics that require strict tolerance control. In industrial practice, a Cpk value greater than 1.33 is generally regarded as acceptable, while higher values indicate improved process reliability and quality performance.

Previous studies have demonstrated the effectiveness of process capability analysis in metal manufacturing and forming processes. Kotz and Johnson (2002) reviewed the Development and application of process capability indices. They emphasized that inadequate process control and excessive variation can significantly reduce Cpk values. Similarly, Markulik et al. (2022) reported that low process capability is often associated with unstable production conditions and poor quality outcomes. Their findings highlight the importance of using Cpk as a quantitative tool to monitor process performance and support improvement initiatives in manufacturing environments.

In addition to capability analysis, root cause analysis tools are commonly used to identify the underlying sources of process variation. Among these tools, the fishbone diagram, initially proposed by Ishikawa, is widely applied in quality management to systematically categorize potential causes of problems using the 4M framework (Man, Machine, Method, and Material) (Ishikawa, 1986). Studies have shown that fishbone diagrams are particularly effective when combined with quantitative performance indicators, such as defect rates or process capability indices, as this approach directly links qualitative analysis to measurable process outcomes (Sokovic et al., 2010).

Machine condition has been identified as a critical factor influencing dimensional accuracy in manufacturing processes. Mechanical issues such as vibration, misalignment, and component wear can adversely affect measurement accuracy and process stability. Mobley (2002) explained that excessive vibration caused by worn or improperly installed mechanical components can lead to unstable operation and measurement errors, ultimately resulting in dimensional variation. In steel sheet levelling and shearing operations, such mechanical instability can directly affect

the performance of measuring rolls and cutting mechanisms, leading to length deviation and inconsistent product quality (White, 2016).
Although numerous studies have addressed process capability analysis and quality improvement methodologies, many existing works are based on laboratory experiments or simulated data. Fewer studies present detailed industrial case studies that quantify the impact of specific mechanical issues, such as vibration, on process capability in real production environments. Pearce (2015) emphasized the importance of industrial case studies for demonstrating how quality tools can be effectively applied under practical constraints, where resources and process conditions differ from those in controlled experimental settings. Similarly, Daniyan et al. (2022) highlighted that targeted corrective actions based on root cause analysis can significantly improve process capability when applied in actual manufacturing operations.
Based on the reviewed literature, there is a clear need for practical investigations that integrate root cause analysis and process capability evaluation to address quality problems in real production lines. The present study contributes to this area by examining a steel sheet mini leveller shear process under actual operating conditions. By identifying a mechanical root cause and evaluating the effectiveness of the corrective action using Cpk, this study provides empirical evidence that targeted mechanical improvements can enhance process stability and dimensional accuracy in an industrial setting.

3. Methods

This study employed a systematic problem-solving approach to identify the root cause of length deviation in a steel sheet mini leveller process and to evaluate the effectiveness of corrective action. The methodology consisted of two main stages: root cause analysis using a fishbone diagram and process performance evaluation using the process capability index (Cpk). All data were collected from an actual production line operating under normal industrial conditions.

3.1 Root Cause Analysis Using Fishbone Diagram

Figure 1 illustrates the fishbone diagram developed to identify the potential causes of length deviation in the mini leveller process. The analysis was structured based on the 4M framework, comprising Machine, Method, Material, and Man, with the problem statement defined as "length out of tolerance."

Machine-related factors include uncoiler and snubber roll tension, leveller roll condition, measuring roll slippage, and shear blade wear or improper cutting timing. Method-related factors cover feeding speed inconsistency, calibration procedures, sampling methods, and setup errors. Material-related factors involve coil tension and spring-back behaviour, material thickness variation, and surface contamination. Man-related factors include lack of operator training, inspection errors, and communication gaps.

The fishbone diagram was used as a systematic tool to screen and evaluate potential sources of process variation. Based on this analysis, machine-related factors—particularly those related to measuring roll stability and mechanical vibration—were identified as the primary contributors to the length deviation problem and selected for further investigation and corrective action (Figure 1).

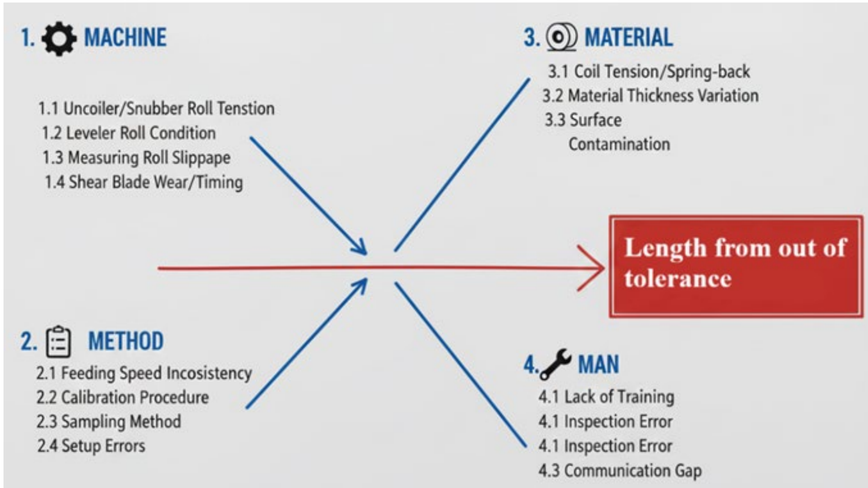

Figure 1. Fishbone diagram for root cause analysis of length deviation in the mini leveller process

3.2 Process Capability Analysis (Cpk)

To quantitatively evaluate process performance, the process capability index (Cpk) was used as the primary performance indicator. Length measurement data were collected from the production line before and after the corrective action was implemented. A total of 100 data points were collected for each condition under the same operating parameters.

The Cpk value was calculated using the process mean, standard deviation, and the specified upper and lower specification limits for sheet length. The capability results were interpreted according to commonly accepted industrial criteria, where Cpk values less than 1.0 indicate an incapable process, values between 1.0 and 1.33 indicate marginal capability, and values greater than 1.33 indicate a capable process. In this study, a Cpk value greater than 1.67 was considered indicative of excellent process capability.

To support the numerical analysis, histogram plots with fitted normal distributions were used to visualize the process distribution and variation before and after the improvement. The combination of fishbone diagram analysis and process capability evaluation provided a structured, data-driven framework for identifying root causes and assessing the effectiveness of corrective actions.

4. Results and Discussion

This section presents the results of the investigation into length deviation in the steel sheet production process, with particular emphasis on the relationship between machine condition and length measurement accuracy. The findings are discussed by linking the root cause analysis results to the actual process flow of the mini leveller shear line.

4.1 Results of Root Cause Analysis

The fishbone diagram shown in Figure 2 was developed to identify potential causes of products with lengths out of tolerance using the 4M framework (Man, Machine, Method, and Material). Several possible factors were initially identified, including operator-related issues, work instruction accuracy, and material characteristics.

Among these factors, the **Machine** category was found to be the most significant contributor to the problem. In particular, coupling shake was identified as a critical issue. Excessive vibration originating from the coupling was observed during machine operation, indicating mechanical instability. While other factors, such as operator fatigue, incorrect work instructions, and material variation, were considered, they were not found to have a direct or consistent impact on the length deviation problem.

The fishbone analysis, therefore, narrowed the focus to machine-related causes, providing a clear direction for further inspection and corrective action.

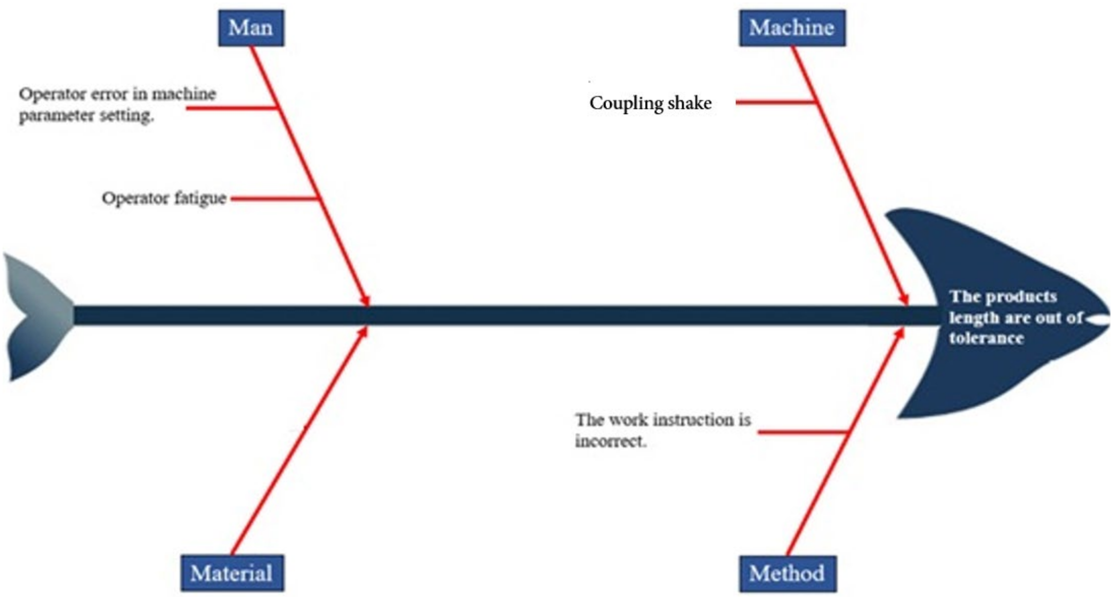

Figure 2. Fishbone diagram for root cause analysis of length deviation in the mini leveller process

4.2 Relationship Between Process Flow and Length Deviation

The process flow of the mini leveller shear line is illustrated in Figure 3. The steel sheet production process begins with coil feeding through the uncoiler and snubber roll, followed by levelling, length measurement, and cutting by the rotary shear. Among these stages, the **measuring roll** plays a critical role in determining the final cut length of the steel sheets.

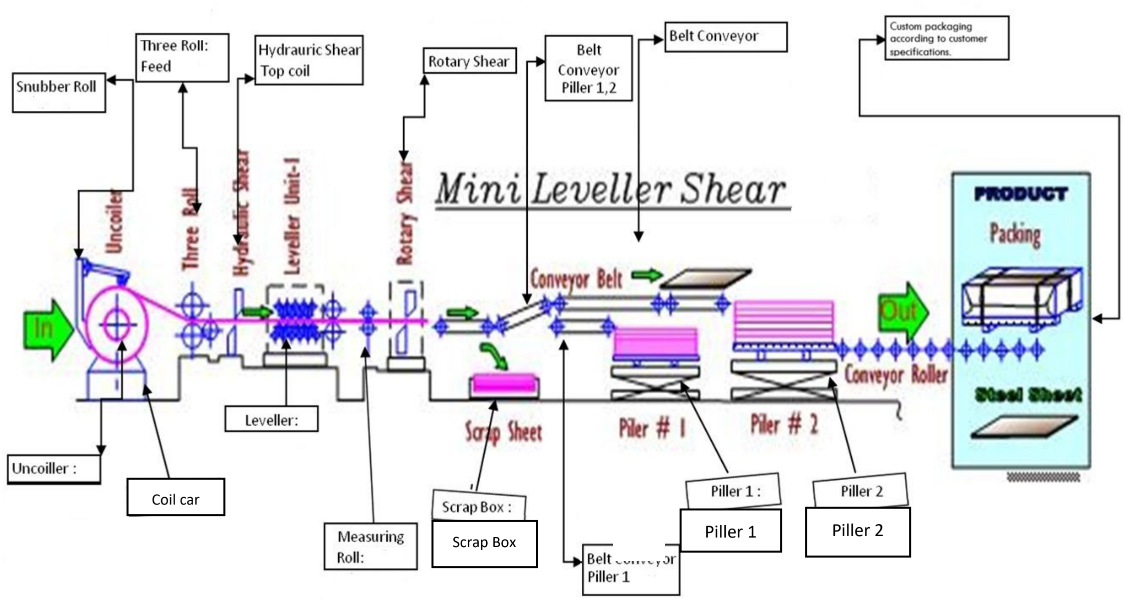

Figure 3. Process flow of the mini leveller shear line

The results indicate that vibration generated at the coupling affected the stability of the measuring roll during operation. As shown in the process flow, any instability in the measuring roll directly influences the accuracy of length measurement before cutting. Consequently, discrepancies arose between the machine setpoint and the actual cut length, resulting in products with lengths outside the specified tolerance.

4.3 Impact on Process Performance

The combined analysis of the fishbone diagram and process flow demonstrates that mechanical vibration at a critical transmission point can propagate through the system and directly affect dimensional accuracy. The coupling shake caused unstable rotation of the measuring roll, increasing process variation and reducing process capability.

These results confirm that the length deviation problem was not caused by isolated human or material factors but was primarily driven by mechanical instability within the mini leveller shear process. This finding provided the basis for implementing targeted corrective action, which is discussed in the subsequent sections.

4.4 After changing the coupling

Figure 4 shows the coupling component used in the mini leveller machine. The worn and loosened condition of this component was identified as the primary source of excessive vibration, which affected the stability of the measuring roll and contributed to length measurement errors before corrective action.

Figure 4. Coupling component of the mini leveller machine

Table 1 compares the process capability index (Cpk) values before and after replacing the coupling component under different machine settings. Before improvement, all operating conditions exhibited low Cpk values, indicating an incapable and unstable process. After the coupling replacement, Cpk values increased significantly across all settings, exceeding the acceptable threshold and indicating improved process stability and reliability.

Table 1. Comparison of process capability before and after coupling replacement

Before			After		
Setting M/C	Tolerance (Min Max±0.50mm.)	Cpk	Setting M/C	Tolerance (Min-Max±0.50mm.)	Cpk
730	729.480-730.920	0.47	1164	1164.510-1165.480	1.79
728	727.500-728.860	0.86	555	554.770-555.260	1.51
668	668.585-669.550	0.49	441	440.635-441.280	1.93

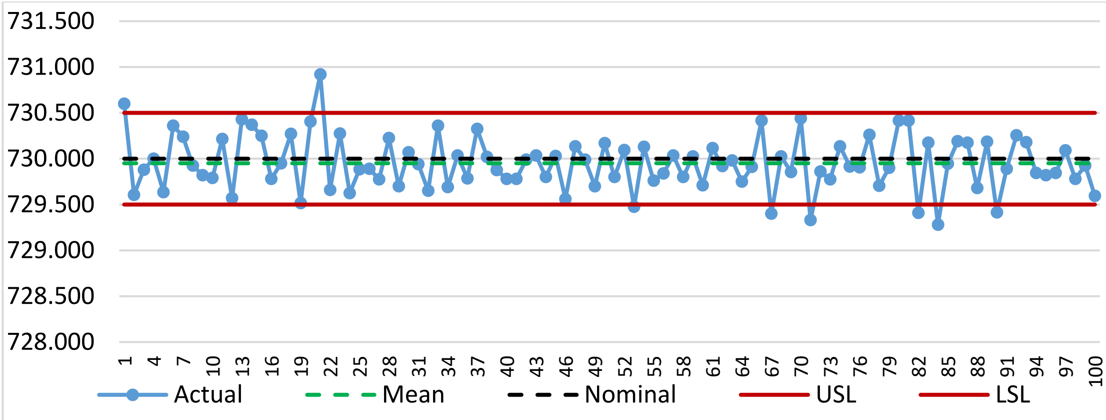

Figure 5. Process distribution analysis of steel sheet length after improvement (N = 100)

Figure 5 presents the process distribution analysis of steel sheet length measurements based on 100 data points collected after the coupling replacement. The distribution shows that the measured values are well contained within the specification limits, with improved centering around the nominal length and reduced variability. This indicates a stable and well-controlled process, supporting the significant improvement in process capability observed after the corrective action. The process mean is closely aligned with the nominal length, and the variation of measured values is relatively small and consistent throughout the sampling period. This behavior confirms that the measuring roll operates with stable rotation after mechanical vibration is eliminated, resulting in reliable length measurement and improved process control.

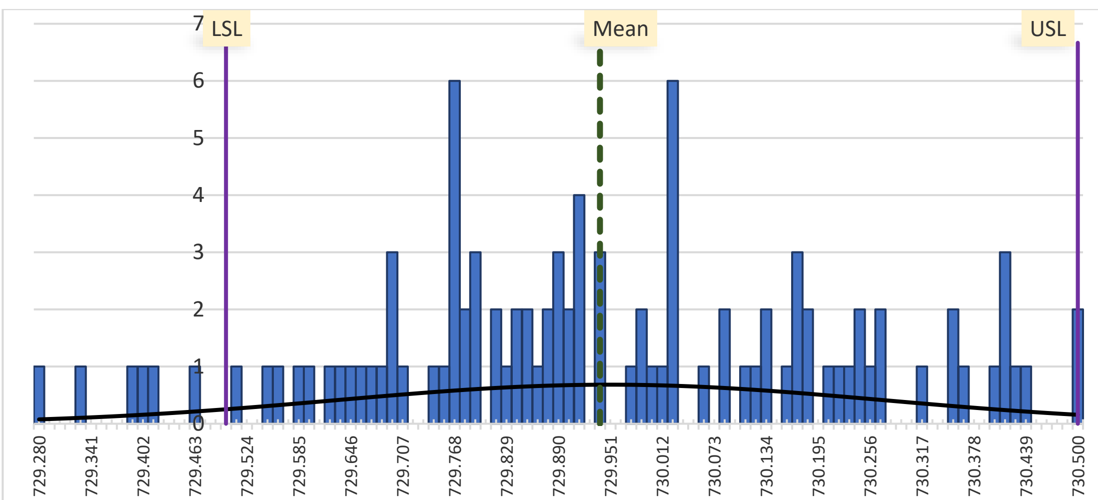

Figure 6. Histogram with fitted normal distribution curve after improvement (N = 100)

Figure 6 shows the histogram of steel sheet length measurements based on 100 data points collected after the coupling replacement, together with a fitted normal distribution curve. The distribution demonstrates a reduced spread and improved centering of the process mean within the lower and upper specification limits, indicating enhanced process stability and capability. The distribution shape is consistent with the improved process capability index, confirming reliable, consistent length control after the corrective action.

6. Conclusion

This study investigated the problem of length deviation in a steel sheet production line operating with a mini leveller process. Through systematic root cause analysis using a fishbone diagram, machine-related factors were identified as the primary contributors to the problem. In particular, a loosened coupling in the power transmission system was found to generate excessive vibration, directly affecting the stability of the measuring roll and leading to inaccurate length measurements and cutting errors.

After replacing the defective coupling, a significant improvement in process performance was observed. The process capability index (Cpk) increased markedly from 0.47 before improvement to 1.93 after the corrective action. This improvement indicates a substantial reduction in process variation and improved centering within the specified tolerance limits. From an engineering perspective, eliminating mechanical vibration restored stable transmission and consistent rotation of the measuring roll, which are essential for accurate length control in the mini leveller process.

Given that a Cpk value greater than 1.67 is commonly regarded as an indicator of excellent process capability in industrial practice, the results confirm that the mini leveller process is now stable, capable, and reliable for production. The findings demonstrate that effective quality improvement can be achieved by addressing the underlying mechanical root cause rather than relying solely on procedural adjustments or increased inspection.

This industrial case study highlights the importance of integrating root cause analysis with process capability evaluation to diagnose and resolve dimensional accuracy problems in manufacturing environments. The approach presented in this study provides practical guidance for manufacturing engineers and quality practitioners seeking cost-effective and sustainable solutions to improve process capability and product quality in steel sheet production.

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