Reductions in the Prime Stock for Sales Generation in Steel Industry: A Lean Approach using DMAIC Tools

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The purpose is to suggest remedial actions using a DMAIC framework to reduce 'Prime Stock for Sales' (PSFS) in the steel manufacturing process. The specific analysis was conducted for a Plate mill in a steel manufacturing industry in India. It utilizes quality tools like 'Pareto analysis' and 'Fishbone diagram' for organizing data and its subsequent analysis. While the 'Pareto analysis' has identified factor(s) giving the highest impact, the 'Fishbone diagram' has helped to find root causes. Based on the recommendations, if root causes can be discarded from the system, a reduction of the PSFS generation gets delivered. It has been established that Non-Conformance of Order (NCO), Excessive Rolling, and Made to Stock (MTS) are the main factors resulting in over three-fourth of the problem. Several recommendations for corrective actions are also proposed for the reduction of PSFS generation, reinforcing that DMAIC 'Six-sigma' methodology is a practical framework for problem identification, remedial action and implementation. In future, based on a detailed experiment, such root cause analysis can be extended to other parts of the plant and any other steel plant facing a similar challenge.

Keywords: Six-sigma, DMAIC, Ishikawa Fishbone Analysis, Pareto analysis, PSFS, Plate Mill, Case-Study, Steel Industry, India

1. Introduction

The second-largest steel producer in the world is India. By 2021 the production capacities are estimated to increase to 128.6 MT from the current position at 106.56 MT. India's finished steel consumption is projected at 230 MT by 2030-31 (IBEF, 2020). However, it is important to monitor the supply and demand in the country. If the demand requirement keeps increasing, producers will have to add capacities, revamp, or increase productivity to meet the market demand. With matching demand and supply, blockage of inventory and Prime Stock for Sales (PSFS) could be avoided. However, PSFS is the result of a demand crisis and poor production planning and quality constraints. Elimination or minimizing of PSFS is always a primary task for any organization. However, some level of PSFS usually is seen in any manufacturing plant, and the organization adopts different methods to bring it below the set levels.

This case study is about one of India's steel plants manufacturing a wide range of products from long to flat products, which of late has been facing an increase in the PSFS generation of about 5 percent of total production, resulting in financial losses and an increase in total lead-time for customers' demand. This case study uses the 'Fishbone diagram' technique (also well-known as the Ishikawa fishbone diagram or the cause-and-effect diagram) to highlight the causes of generation of PSFS.

The 'Fishbone diagram' is a part of the Seven Quality Tools; it supports identifying and analyzing the root causes of the problems, particularly the quality issues. Invented in the 1960s by Kaoru Ishikawa and represented as a fish skeleton shape, it was first utilized in the quality management process at the Kawasaki Shipyards. The causes in every region are by a drill-down methodology and can be further broken into sub-causes for additional investigation (Krajewski et al., 2019) and be helpful in item improvement and investigating cycles. While first applications were in the field of improving managerial issues, it is further utilized widely in different fields, such as, from SME designing (Mazur, 1998), to medication (Frankel et al., 2005); to software engineering (Bjornson et al., 2009), and S&T Programs (Li and Lee, 2011).

Here, an attempt has been made for exploring and categorizing the root cause. Any technique applying graphical representation or tabulation of data makes the analysis more straightforward for using appropriate management of technology at a steel company. The graphical representation of contributing factors includes Non-compliance of Order (NCO), Excess Rolling, Made-to-Stock (MTS) Projection Plates and Defective Plates. For this purpose, the previous year's Rolling Plan schedule, Weekly PSFS generation schedule, PSFS dispatch schedule and Quality Inspection reports were studied. If appropriately implemented, the proposed plan is likely to ensure a reduction in PSFS generation to half of the current percentage. Since the product and the production process is not unique for this industry, the methodology of this study or even recommendations would be helpful in a similar business facing a similar problem of PSFS.

2. Literature Review

Business activities are a combination of plans, conflicts, resolutions, and corrective actions. Since disputes or problems are of the conventional type in most industries, any business's management team applies some standard quality control methods and customizes these to the specific problem to arrive at a solution. 'Six-sigma' is a quality control method that applies a systematic, statistical-based data-driven approach to minimize defects or variations in the process and to attain continual improvement. This process, first developed by Motorola in the year 1980 and promoted by General Electric (GE) in the management process (Neyestani, 2017; Krajewski et al., 2019), is an adopted technology in the industries. According to Kwak and Anbari (2006), the 'Six-sigma' method is specifically a customer-oriented approach. Financial results are generally measured or collected from the reported documents. Further, tools used for advanced data analysis or project management are utilized in the analysis methodology.

Analogous to 'Six-sigma', the method – 'Lean' is a combination of a mindset, philosophy and a set of tools. This popular method is used for streamlining manufacturing and transactional processes (Banga et al., 2020). This method helps in optimizing process flow and eliminating waste. 'Six-sigma' helps remove defects;

however, 'Lean' helps remove waste since the 'Lean' process also defines values, maps the stream, creates flow, and establishes pull (Giovanni and Cariola, 2020).

'Six-sigma' or 'Lean' or its combination, 'Lean Six-sigma', the application of DMAIC (an acronym for "Define, Measure, Analyse, Improve and Control") improvement cycle, has been identified as a core tool to drive the data-driven projects. By implementing DMAIC at a manufacturing unit, Singh and Singh (2014) have obtained a considerable decrease in quality rejection and substantial net savings per year. Khawar et al. (2016) researched a steel-bar manufacturing plant where production parameters were optimized using DMAIC, resulting in higher productivity and reduced wastage. In the same way, Nourbakhsh et al. (2013) were able to show profitability in the implementation of a six-sigma project determining the amount of 'purchase order' and 'inventory control' at the Khorasan steel plant control.

DMAIC methodologies determine the projects critical to quality characteristics. The first step defines all the apparent causes and then identifies the likely causes that lead to the Source of variation (Smętkowska and Mrugalska, 2018; Nandakumar et al., 2020). Any company can find the most cost-effective way to improve and utilize its resources by reducing defects by applying these methods (Jadhav et al., 2014). The primary tool used in Six-sigma projects is the DMAIC improvement cycle. Once the process's current performance is measured, the goal is to continually improve deviations (Montgomery and Woodall, 2008; Parmar and Desai, 2020).

2.1 DMAIC ("Define, Measure, Analyse, Improve, Control")

DMAIC road map has five intermediate targets. These five targets are defined and explained further in this study. Since the concept is inspired by the PDCA cycle, it becomes essential to get feedback in the implementation phase and readjust the measurement. Once the objective is defined, the necessary measure is taken and analyzed while implementing the improvement plant; it may happen that the results are not as expected due to certain missing links during the measurement phase. In case this feedback is captured, the measurement can be adjusted again so that the implementation can be made much more precise further. Five intermediate targets can be understood as below.

Define: In this phase, the team first defines the problem statement and scope of the project. It follows the identification of the resources that are likely to be used at the later stages. The problem statement is derived from the ongoing issues persisting in the whole process and hindering productivity. Based on the devised project plan, a process map is carved out. The team also has to identify the suppliers, inputs and processes required to define the desired output and customers.

Measure: In this phase, the team identifies the area where data collection is necessary, followed by streamlining a plan to collect data and what measurement standards are to be validated to ensure that the collected data is good enough for analysis. After finalizing the data management system, the next step is to collect data relevant to the problem. Data is also to be organized in such a way so that its representation becomes logical, and its usages in analysis tools such as the Control charts or Pareto analysis becomes effortless.

Figure 1 *DMAIC Process (author's view)*

Analyze: In this phase, data is analyzed using statistical tools and represented to aid visualization and brainstorming. The usual methods used include 'ANOVA' and 'Fishbone diagram' or '6M' (Men, Material, Machine, Method, Measurement, Milieu) (Krajewski et al., 2019). The analysis phase helps identify the root cause by using methodologies such as '5WHY's' for drilling down into a problem and '5HOW's' to develop the details of a solution to a problem. Both are designed to bring clarity and refinement to a problem statement or a potential solution and get to the root cause or root solution.

Improve: In this phase, the results of the analysis are used to plan necessary adjustments to control the deviations. In this phase, the orderly execution of the following three activities takes place.

1) To identify all the probable firsthand solutions.
2) To examine the chances of failure of the proposed solutions, a feasibility-cum-viability analysis of the proposed solutions.
3) To validate the solutions statistically, accompanied by launching a pilot project and mapping for implementation.

It is always advisable to implement the solutions on a smaller segment, a pilot project, and once adjusted and standardized, and can then be horizontally deployed in all sections. While validating the solutions, feedback is given to the earlier stage so that measurement and analysis can be modified to enhance later steps of Improve and Control.

Control: In this final phase, the team supports and maintains the solutions implemented in the improvement phase. It is generally achieved by proper documentation, training participants, and implementing 'statistical process control' and creating a 'process monitoring plan'.

3. Research Methodology

The research methodology is a problem-solving step. In this case study, the problem is the generation of *Prime Stock for Sales* (PSFS) in a Plate mill at the steel manufacturing company in Central India. Understanding the steps mentioned under

DMAIC (section 2.1 above), the first target is to define the problem statement and understand the process flow. Then by following other actions, the final stage of control is reached. The same five steps used in this study are explained below.

3.1 Definition

3.1.1 Prime Stock for Sales (PSFS)

Any production unit has some standard operating procedure. In an organization, overall production planning involves coordinating the sales department, finance department, production planning and sourcing. After formal approval by the finance ordering the sales department establishes, production planning prepares a systematic plan for the operations. The order specifications are checked first if a similar product is already available in Stock, or new production is planned.

In an ideal situation, to achieve just in time concept, production is planned only after receipt of the order and for the specified quantity. This helps in avoiding inventory blockage. However, such an ideal situation is not available all the time. As a result

- operation department produces even when there is no order,
- while producing for established orders, because of batch size, extra production takes place,
- during operation, functional issues result in the diversion of production to some other specification.

Such extra or additional production is acceptable as part of the production process, and it becomes the responsibility of sales to also look for orders which match the specification of the product already lying in the Stock, such as blocked inventory. There are other reasons also which add to blocked inventory. One major contributor is non-conformities (as per the production order). However, before dispatch and during the inspection, a part of the product does not match the desired/requisite specification. Such non-confirmed products of this order may be the right product for any other order. So, these are left as Stock for possible orders and future dispatch of the plates.

All these additional products are not 'rejects', but **Prime** product, kept in **Stock** and the Sales department is on the lookout '**For** its **Sale**'. Hence any such stock is termed as ***Prime Stock for Sales*** **(PSFS)**. Since orders and the dispatch of PSFS result in additional work for the sales department and chances of getting similar orders are also less, the target of any organization is to keep this quantity to a bare minimum.

Similarly, for this steel plant, on the one hand, demand raised from marketing via the production planning department decides the type of plates to be produced, while on the other hand, to keep the production equipment operating at threshold level, some production is done for which marketing department has to get proper orders to sell these MTS Plates. PSFS is the generation of plates still lying in the Stock since no matching sales order is available.

While demand raised from marketing department via production planning and control department decides the type of plates to be produced; on the other hand, to keep the production equipment operating at threshold level, some production is done for which marketing department has to get proper orders to sell the MTS Plates. PSFS is the generation of plates that are not the prime or finished product based on the customer's orders (specification and requirement). There are majorly three contributing factors to PSFS, such as:

- Non-Conformance to Order (NCO) and Defective Plates
- Projection/Made to Stock (MTS) Plates
- Excess Plates (due to slab's minimum order quantity)

Out of these three significant factors, NCO and Defective Plates are generated due to quality issues. Projection/MTS and Excess plates are due to non-quality issues mainly related to Orders (no. of plates). Figure 2 overleaf describes the analysis of PSFS.

General understanding of the problem is like above, where the steel-making process and coordination between marketing and production are to be analyzed.

3.1.2 Voice of the internal customer (target set by the organization)

a) The present level of PSFS: Monthly generation of PSFS is approximately 4 percent. When the dispatches are not met, the cumulative number goes up. The actual Figures are to be collected, and the collected data to be identified to place these under different heads.

b) The target level of PSFS: Since the plant production process itself results in a specific generation of PSFS, approximately 2 percent per month seems to be an acceptable level. However, monthly dispatches should be planned in such a way so that the cumulative number remains within this limit.

From (a) & (b) above, the average PSFS is approximately 4 percent (current level – verified by data collection), and the target is to achieve a scale of 2 percent maximum.

3.1.3 Contributors to PSFS

a) Steel-making process: As shown in Figure 2, the steel-making process itself contributes to PSFS since the significant cause of deviation in chemical properties initiates at steel making; it is crucial to understand the process flow of steel making. On the flowchart (Figure 3), an attempt has been made to link PSFS to the steel-making process flow. As seen in Figure 3, the steel-making process mainly contributes to the slab's chemical properties, as they are rolled to make a plate. These slabs are then kept in the slab yard for storage or sent to the Plate mill for further rolling to make Plates as per the order's requirement. In case chemical properties are not matching with order specification but are within limits or match other steel grades, these slabs are still rolled at the rolling mill but still result in PSFS.

The Plate mill has a wide variety of plates of thickness ranging from 5 mm to 150 mm and width ranging from 1.5 to 5 meters.

b) Plate mill: As shown on the process flow in Figure 4, once plates are rolled and inspection is done, the steel plates are then taken to dispatch Stock as PSFS.

c) Standard operating procedure (SOP) for production planning: As Figure 2 indicates, the degree of coordination between sales and production is also responsible for PSFS; understanding SOP for production planning becomes essential. The explanation is as mentioned below:

- A Sales order upon its booking by the sales department is cleared commercially by the finance department. It then moves into the production planning department, which checks suitable Slabs as per the requirement (of

the order). The existing slabs are matched as per specifications, then slabs are considered for rolling, and the rolling schedule is planned to make plates. If existing slabs do not match the requirement (of the order), the production planning department makes a casting plan as per the requirement and communicates it to the steel-making team.

- After receiving the casting plan, the slab is cast as per the grade specified in the order, and then the quality of the slab is checked for chemistry, surface quality and dimensions. If the slab's quality is cleared, the slab is sent to the Plate mill slab yard for scheduling for rolling. The Quality control team cross-checks the rolling schedule before giving clearance to Plate mill's Production department. This ensures that the customer's technical specifications match with product characteristics and can include the slab's storage location, the internal and external grade of the finished product, slab dimension, plate dimension as per the order, the customer's requirement in the order, and heat treatment.
- The Rolling schedule, which has information on each slab, is mapped with the sales order, ensuring that each product should pass through the appropriate process route as per the order's required specification. The rolling schedule is provided to the plate mill operation department to produce plates as per the standard operating procedure.

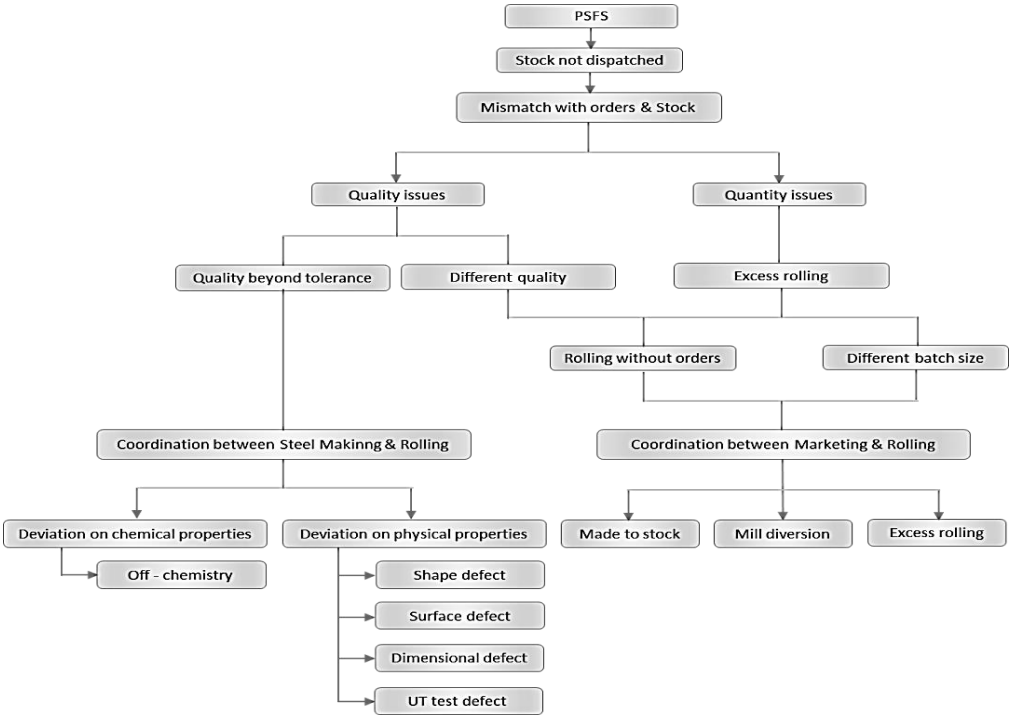

Figure 2: *Analysis of PSFS (author's view)*

Once the plate is produced, it goes for the quality check; and if the plate is ready for dispatch, it is termed the prime product or finished product. The plate cannot be dispatched if quality personnel reject it due to any reason, including NCO, Defective, or under quality hold. The NCO plates can be rolled again for another equivalent pending orders. The production planning department plans the rolling after scrutinizing the pending orders.

With further analysis and as represented in Figure 2, it is clear that the steel-making process and slab casting may result in precise production where chemical properties of the slab become a reason for no /delayed dispatches. Similarly, plate mill operation contributes to the physical properties of plates. In case marketing and production planning are not advanced enough, sometimes plate mill and caster have to produce some general grades of steel and declare the same as MTS, lying in the stockyard for an extended period in the form of PSFS. The three significant factors leading to PSFS are a) Quality beyond tolerance, b) Different quality, and c) additional Rolling.

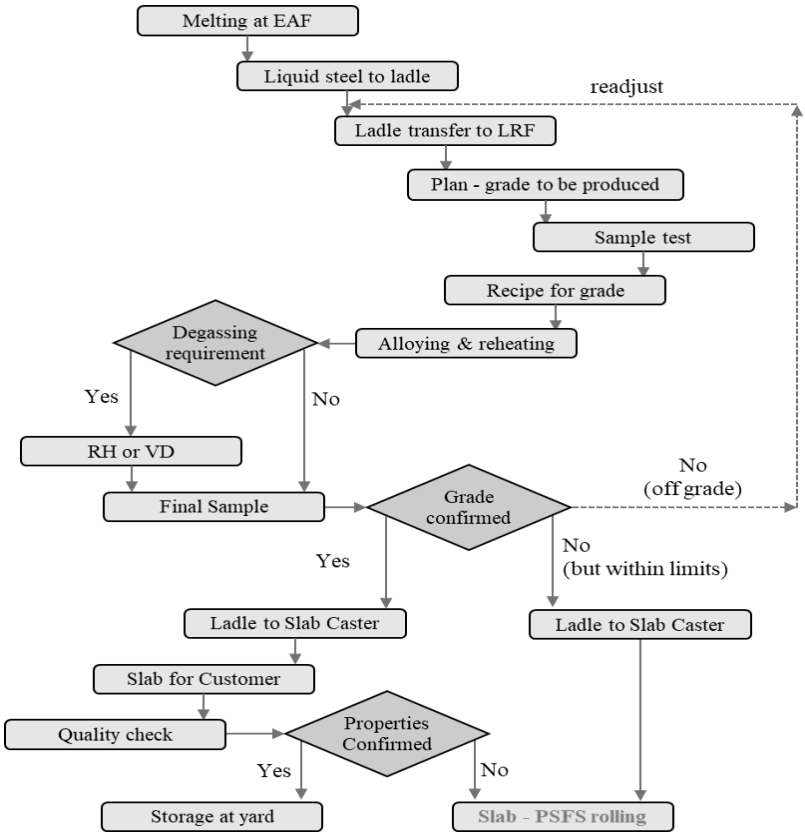

Figure 3: *Steel-making Process Flow & PSFS (author's view)*

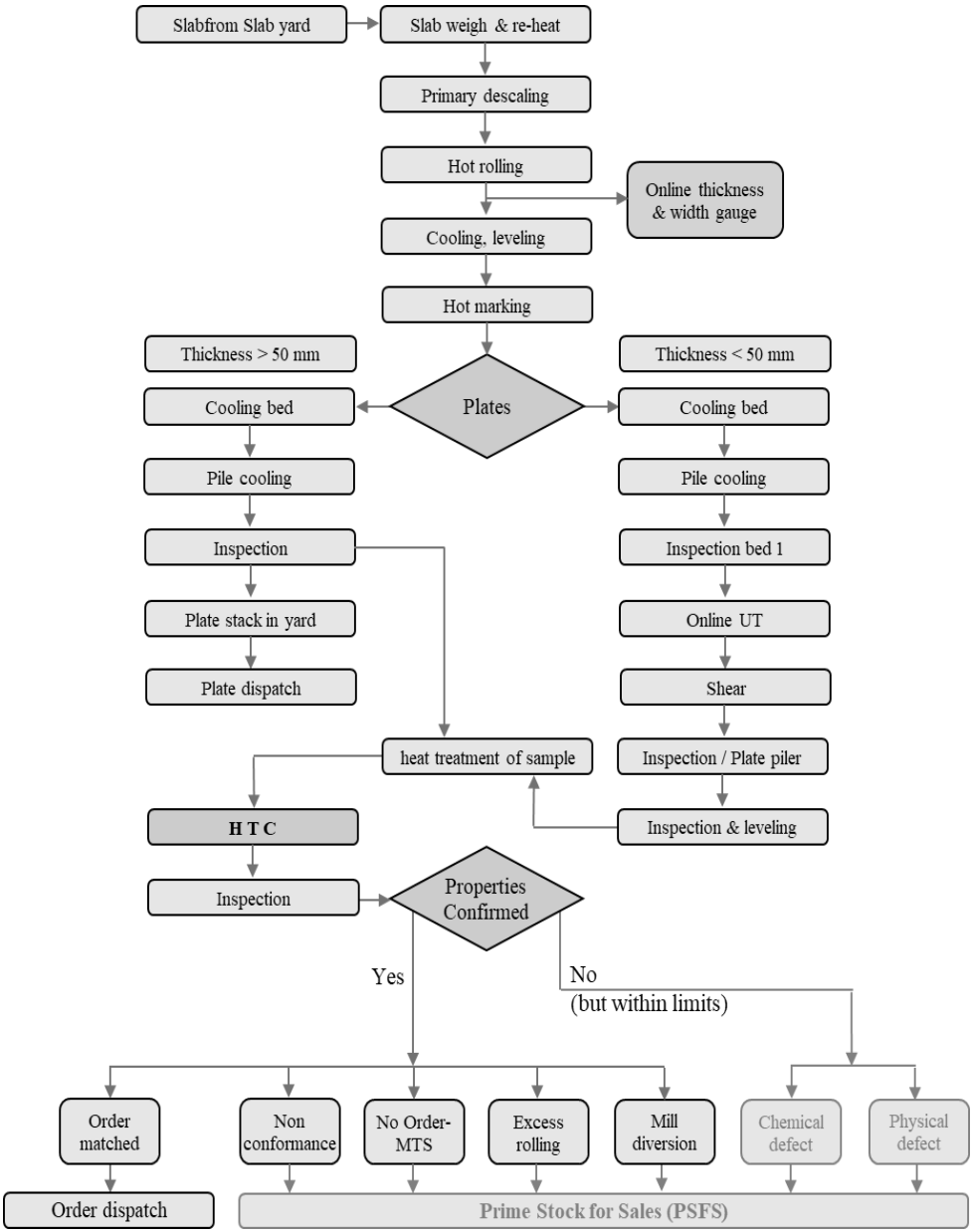

Figure 4: *Plate mill Process Flow and PSFS (author's view)*

3.2 Measure

Having understood PSFS and its factors, this section attempts to collect the relevant data from different stages and later analyze it.

Table 1: *PSFS – last six months*

Sl No	Reasons for PSFS	PSFS (t)
1	Bow	77
2	Buckling	3
3	Head and tail up	192
4	Levelling not working	4
5	Waviness in Shape	21
6	Burr	1,520
7	Crack	5,992
8	Dent	546
9	Mark	80
10	Roll mark	3
11	Rolled on foreign material	36
12	Scab	188
13	Scale formation	6
14	Sliver	531
15	Surface burst	4
16	Camber	412
17	Cut mark	21
18	Damage	12
19	Edge bend	130
20	Edge burst	138
21	Edge damage	92
22	Length	804
23	Thickness	160
24	Width	310
25	Wrong cut	6
26	Lamination	30
27	Ultrasonic tests (UT) failure	829
28	Off chemistry	30
29	Wrong planning	284
30	MTS	4,439
31	Mill diversion	1,110
32	Excess Rolling	8,589
33	Chemical defect	2,773
34	Physical defect	2,241
35	Order short closed	94
	Total PSFS	31,704
	Total Production	**537,364**

The respective flow charts, as indicated in Figure 2, 3, & 4, explain the factors that can lead to PSFS. Requisite data was collected from the ERP system at the steel plant. The daily report of quality inspection for the last year was scrutinized to find the percentage of NCO and Defective Plates. Further, to identify the root causes of the process, the process flows of the Slab caster and the Plate mill rolling sequence were examined with the steel plant's respective operations team.

While the standard operating procedure provided order planning, the sales and marketing department's functioning indicated a synchronization between sales, production planning and control, and the marketing department. Departments helped in collecting data, and the same is at Table 1.

During the six months period, the total quantity of PSFS stands at 31,704 t, with the entire production from the plate mill recorded as 537,364 t. The steel plant uses all these 35 reasons (terms) for PSFS as a standard to identify the reasons because of which a particular product/plate is lying as part of PSFS.

3.3 Analyze

Since the organizational target is to bring down the average PSFS from the current 4 percent per month to below 2 percent; for analysis of collected data, it becomes essential to verify the PSFS levels. Hence, the data collected as per Table 1 was analyzed further to identify 'What is the percentage of PSFS in the last six months?' It was executed by categorizing the data on significant heads and then using a 'Pareto chart' to identifying the primary cause.

Data analysis indicates that the percentage of PSFS in the six months is 5.90 percent (not 4 percent as expected by the steel plant team). The analysis (Table 2) also helps in classifying the leading factors under seven main causes for PSFS.

1) NCO: When the specification as demanded in the order does not match with rolled plates' specification,
2) Excess rolling: Chemical and physical properties are as per standards but no fresh order for these small quantities and rolled due to batch size,
3) MTS: Chemical and physical properties are as per standards, but no fresh customer order for such specifications leading to high inventory carrying cost,
4) Chemical defect: Chemical properties are not as per standards,
5) Physical defect: Physical properties are not as per standards,
6) Mill Diversion: When some rolling is going on, and due to specific operational reasons, some different rolling is planned,
7) Order short closed: Dispatched quantity is a little lower than the rolled quantity.

Table 2: *PSFS – six months – Data Analysis*

Sl. No	Reasons	PSFS (t)	Causes	PSFS (t)	Cause classification	PSFS (t)	Percent of total PSFS	Percent of total Production
1	Bow	77	Shape defect	297	Non-Conformance of Order	12,460	39.30%	2.32%
2	Buckling	3						
3	Head and tail up	192						
4	Levelling not working	4						
5	Waviness in Shape	21						
6	Burr	1,520	Surface defect	8,907				
7	Crack	5,992						
8	Dent	546						
9	Mark	80						
10	Roll mark	3						
11	Rolled on pit	36						
12	Scab	188						
13	Scale formation	6						
14	Sliver	531						
15	Surface burst	4						
16	Camber	412	Dimensional defect	2,083				
17	Cut mark	21						
18	Damage	12						
19	Edge bend	130						
20	Edge burst	138						
21	Edge damage	92						
22	Length	804						
23	Thickness	160						
24	Width	310						
25	Wrong cut	6						
26	Lamination	30	UT failure	859				
27	UT failure	829						
28	Off chemistry	30	Off chemistry	30				
29	Wrong planning	284	Wrong planning	284				
30	Made-to-stock (MTS)	4,439	Made-to-stock (MTS	5,549	Made-to-stock MTS)	4,439	14.00%	0.83%
31	Mill diversion	1,110	Mill diversion		Mill diversion	1,110	3.50%	0.21%
32	Excess Rolling	8,589	Excess Rolling	8,589	Excess rolling	8,589	27.09%	1.60%
33	Chemical defect	2,773	Chemical defect	5,014	Chemical defect	2,773	8.75%	0.52%
34	Physical defect	2,241	Physical defect		Physical defect	2,241	7.07%	0.42%
35	Order short closed	94	Order short closed	94	Order short closed	94	0.29%	0.02%
	Total PSFS	31,704		31,704		31,704	100%	5.90%
	Total Production	**537,364**		**537,364**		**537,364**		

The summary of the data is in Table 3.

Table 3: *PSFS – summary quantity and percentage – causes*

Sl. No.	Cause classification	PSFS quantity (t)	PSFS cause percentage	PSFS percentage of production
1	NCO	12,460	39.30%	2.32%
2	Excess Rolling	8,589	27.09%	1.60%
3	MTS	4,439	14.00%	0.83%
4	Chemical defect	2,773	8.75%	0.52%
5	Physical defect	2,241	7.07%	0.42%
6	Mill diversion	1,110	3.50%	0.21%
7	Order short closed	94	0.29%	0.02%
	Total PSFS	31,704		
	Total production	**537,364**		

Data is further analyzed using a 'Pareto Chart' to understand the severity of the causes.

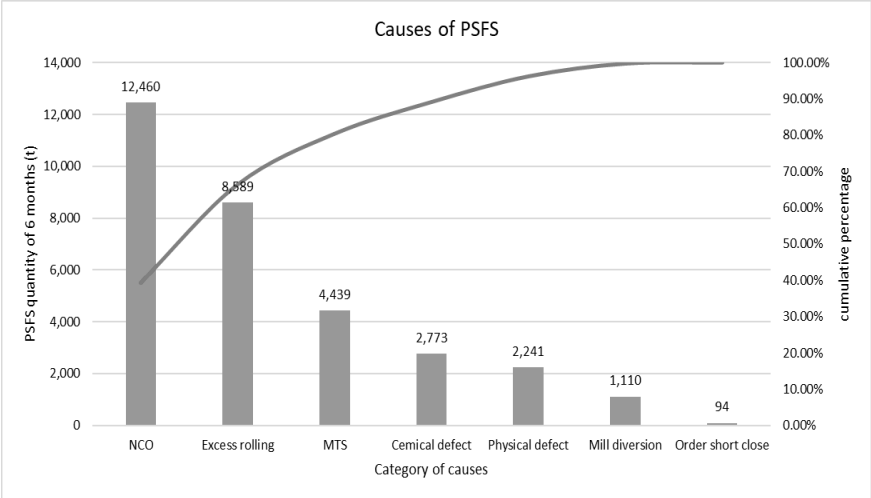

Figure 5: *Pareto Chart*

From the Pareto analysis in Figure 5, it can be concluded that generation of 80 percent PSFS is due mainly to NCO Plates (contribution at 39.30 percent), followed by excess rolled plates (27.09 percent) and MTS (14.00 percent).

Root Cause Analysis

The Ishikawa fishbone diagram shows probable prospects for identifying bottlenecks and increasing production in the steel industry. Problems causing the most delay were in the production process while other problems such as shift changeover, less

skilled/insufficient workers and communication gap could be sorted out right away (Vaishya and Baraiya, 2016).

Tegegne and Singh (2013) have used the Ishikawa diagram to analyze the root causes and have found plausible solutions behind surface imperfections in the projecting cycle for assembling parts, both for vast and trim parts. Gandhi et al. (2016) utilized the Ishikawa fishbone diagram to classify possible causes and outline the degrees of causation for bearings, a fundamental workpiece in hardware gadgets. The steel ball's surface nature is the principal factor that influences the bearing's accuracy and life span.

For root cause analysis of PSFS generation, the application of the Ishikawa fishbone diagram is considered. Here, all the seven leading causes are evaluated for reasons so that corrective actions can be planned to minimize or eliminate them. While discussing with the operation and maintenance team, these causes were listed and linked (Figure 6 a, b, c and d). Since causes are known (Annexure 1), their present status is also known, and hence during the control phase, corrective actions can be planned.

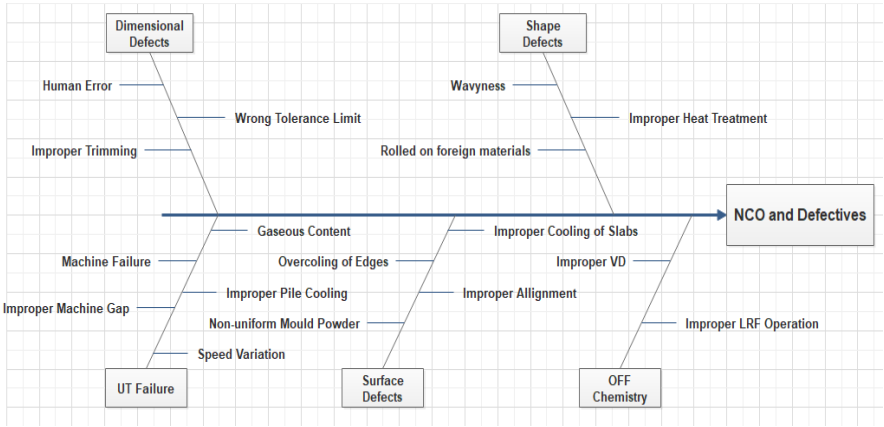

Figure 6 a: *Fishbone diagram (NCO and Defectives as the leading causes) [Source: based on Annexure 1]*

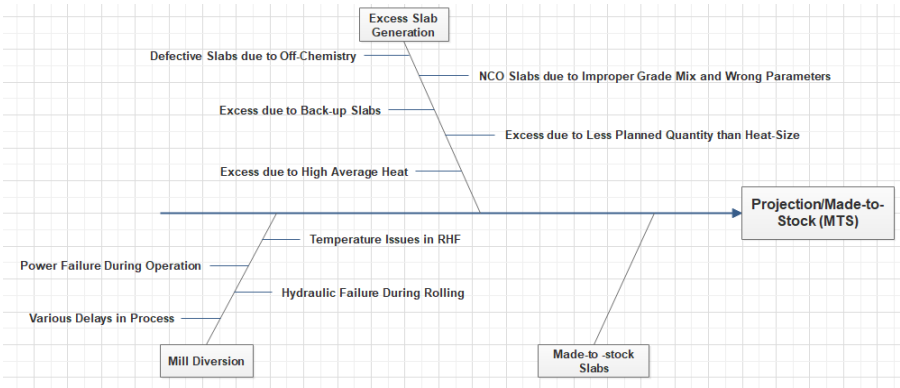

Figure 6 b: *Fishbone diagram (Projection/MTS as the leading cause) [Source: based on Annexure 1]*

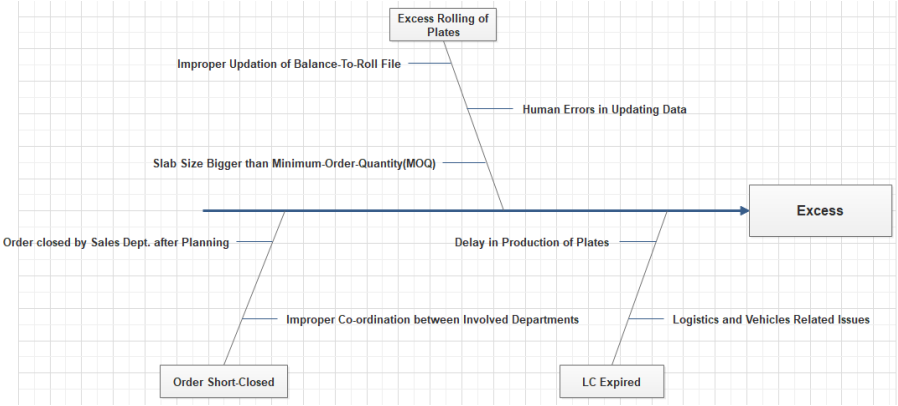

Figure 6 c: *Fishbone diagram (Excess rolling as a leading cause) [Source: based on Annexure 1]*

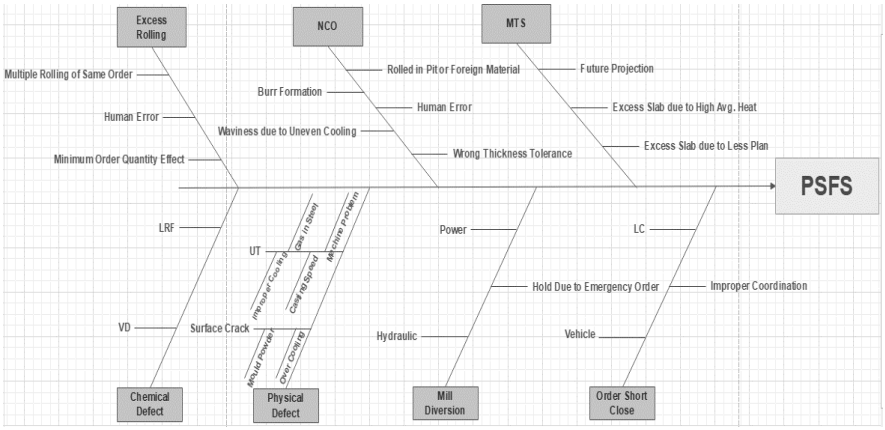

Figure 6 d: *Fishbone diagram (showing the linked seven leading causes)*

3.4 Improve

After finding out all possible root causes, and after going through the overall process of plate production, SOP of production planning, product dispatch, sales and marketing of plates, the proposed recommendations are detailed in Annexure 1.

Referring to the results of Pareto analysis, generation of 80 percent of PSFS is primarily due to NCO Plates (contribution at 39.30 percent), followed by excess rolled plates (27.09 percent), and MTS (14.00 percent). Hence, primary emphasis is to be given to these three cause classifications.

NCO Plates: As extracted from Table 2 and recommended in Annexure 1, the main reasons for NCO Plates are Cracks, Burrs, UT, Length and Width.

- Cracks are generated during the casting process at Slab Caster. Improved maintenance on the slab casting machine and monitoring of water spray nozzles will help maintain uniform cooling during the casting process. If necessary, preventive maintenance schedule and cooling parameters are to be revisited to achieve the results.
- Burr on the rolled plates is the result of the rolling process at the plate mill. These are generated when there is a temperature difference on the two sides of the plate during rolling. Prevention of any such condition requires adherence to SOP for maintaining temperature uniformity on the plate during rolling.
- Gaseous contents in steel slab, machine failure during casting, roll gap, variation in casting speed and pile cooling procedure are parameters that may result in non-conformities in UT failure. A review of these under SOP can quickly help in eliminating UT failures.
- Length and width are dimensions based on fed setpoints governing the rolling process. When these setpoints are fed manually, human errors are the leading cause of variation in length and width. Either a cross verification of fed setpoints is necessary, or the next level of automation system will be helpful.

Excess Rolled Plates: Human error and multiple rolling for the same order can be avoided by eliminating manual working by employing software packages, such as "Manufacturing Execution System" or production planning control under industry 4.0. When order quantity is too low, production planning can look for appropriate slab size or accumulate several such orders to minimize excess rolling.

MTS: Since slab caster and rolling mill have to maintain certain production levels, it becomes a prime responsibility of the marketing team to keep sufficient orders to avoid MTS.

In most cases, these are revision and adherence to SOP only.

3.5 Control-Phase - Implementation

In this final phase, recommendations have to be implemented, if and as feasible. So, the proposed recommendations are given to the respective departments to consider the viable and essential points to achieve in the system to reduce the generation of PSFS. Since significant recommendations are related to the revision of SOP, these can be prioritized. Updated SOP and its implementation will help achieve process improvements by the Plate mill, Slab caster, and Ladle Refining Furnace (LRF) (refer to Figure 3) operation and maintenance teams.

Hence, implementation can be taken up for 1) updating SOPs, 2) implementing updated SOPs (maintenance scheduling, operational parameters, control setpoints), 3) implementing the next level of automation, and 4) implementing control software packages (Manufacturing Execution System (MES); industry 4.0). Implementation of MES in the production planning of plate mill shall ensure an error-free process. Even industry 4.0 and digitalization provides several similar options for adopting a process control model.

4. Conclusions

This case study at a steel plant was studied to reduce its *Prime Stock for Sales* (PSFS). Currently, at this plant, the monthly PSFS percentage is 4 percent of the total plate production. By implementing the suggested recommendation, a significant reduction of the PSFS generation is possible. The main recommendation identified was for NCO, Excessive Rolling and MTS. After utilizing the 'Pareto analysis' and 'Fishbone diagram,' these were identified as the main factors resulting in over three-fourth of the problem. Overall data collection, analysis, and recommendations for implementation were framed under the DMAIC 'Six-sigma' methodology. In future, based on a detailed experiment, such root cause analysis can be extended to other parts of the plant and any other steel plant facing a similar challenge.

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Annexure 1

CAUSES: UT FAILURE	CURRENT PRACTICE	RECOMMENDED PRACTICE
Gaseous content in steel	Improper Vacuum De-gassing operation forms gaseous content in steel	In Vacuum De-Gassing Process, the hot material should be held for a minimum of 16 minutes with vacuum pressure not exceeding two (2) mbar
	Open casted slabs may have gaseous content. Plates out of this type of slab will fail in Ultrasonic Testing.	The open casted slab should be rolled for non-UT ordered plates. PPC should check those slabs before rolling them into plates
	Sometimes non-VD slabs go for Ultrasonic testing.	Before rolling, PPC and plate mill process should ensure that non-VD slabs should not go for Ultrasonic testing
Machine Failure at any stage of the process	Improvement required in the maintenance of the machines involved in the casting process	TPM should be implemented, and all FUGAIs related to the process should be identified and rectified
	Power failure in between the casting process	UPS Supply should be available for critical equipment. The process team should identify the equipment's critical for the process.
Improper Pile Cooling	Slabs are stacked in the open area, and pile cooling is done in an open area. That may lead to the ingression of moisture into the steel	Pile cooling can be done using box cooling or underground cooling
Improper Machine Gaps at different segments	Improper frequency of Gap checking.	For each thickness change, Gap checking of the segments should be done before casting.
	Availability of one gap checker (VATRON), which may malfunction at times	One spare gap checker (VATRON) should be maintained for contingency.
Casting Speed	Variation in Casting Speed	Casting speed to be maintained for a specific width by maintaining the superheat temperature as per casting speed 'vs' superheat temperature chart.

CAUSES: SURFACE CRACK	CURRENT PRACTICE	RECOMMENDED PRACTICE
Improper Cooling of Slab due to clogging in any water spray nozzles	There is no proper schedule for maintenance of the water spray-nozzles	Scheduled maintenance to be done during an ideal time by taking the operation team in line. The function of Nozzles to be checked before each casting.
Over cooling of Edges	More water spray on the edge of slabs than other areas.	The caster operation team has to ensure uniform cooling during the process.
Improper Segment Alignment	Uneven alignment in the bottom part of the segment causes a bend in the surface of the slabs.	Maintenance team to take care of the alignment (bottom part of the segment)
Non-uniformity of mould-powder use for lubrication	Different varieties of mould-powders are used for different grades, and non-uniformity is occurring due to powders' chemistry variation.	By using standard quality of mould-powder and discarding the use of a variety of sub-standard mold powders

CAUSES: OFF-CHEMISTRY	CURRENT PRACTICE	RECOMMENDED PRACTICE
Improper VD Operation	Improper Vacuum De-gassing operation forms gaseous content in steel	In Vacuum De-Gassing Process, the hot material should be held for a minimum of 16 minutes with vacuum pressure not exceeding two (2) mbar.
Improper LRF operation during Ferro-alloy addition	The presence of inappropriate Phosphorus content causes off chemistry in a grade of the slab	Phosphorous content should be maintained below 0.02gram/kg of steel.

CAUSES: NCO/DEFECTIVE DUE TO MILL PROCESS	CURRENT PRACTICE	RECOMMENDED PRACTICE
Human Error in Cutting/ Trimming of Plates resulting under length/width	A calculated setpoint is fed manually by operators during the operation.	SOP to be followed with parameters and set-points cross verified with a rolling plan
Wrong tolerance of thickness resulting under length	The tolerance limit is fed manually during the process. The tolerance limit becomes wrong sometimes due to human error.	Proper SOP to be followed with parameters and set-points cross verified with a rolling plan
Formation of burr due to improper Rolling	Burr is formed due to the temperature difference between both sides of the plate.	SOP for controlling SKI control to be followed and operated to control both sides of the plate's speed to make the temperature uniform across the plate
Waviness due to uneven cooling and roll gap	Uneven cooling at mulpic often results in waviness.	Uniform mulpic cooling should be ensured by the plate mill process
	An uneven roll gap between the rollers sometimes causes waviness in the plate	The uniform Roll gap should be taken care of by the maintenance team during idle time. Roll gap checking schedule should be followed in each shift during the idle condition
Rolled in pit, scales or foreign materials	There is no proper inspection of the rolling bed during idle time	A schedule for inspection of the rolling bed should be made and followed before each rolling. Thorough checking of the foreign materials on the working platform need to be done during the idle time between rolling

CAUSES: PROJECTION/ MADE-TO-STOCK	CURRENT PRACTICE	RECOMMENDED PRACTICE
Excess Slabs are rolled, and plates made to Stock for the future (Projection)	Excess slabs generated, i.e. No plan slabs are rolled to make plates and stored as Stock for future orders.	The marketing team has to actively search for orders as per projection stock from the day of rolling. Auction bidding can be done to sell the made to stock plates

CAUSES: EXCESS SLAB GENERATION	CURRENT PRACTICE	RECOMMENDED PRACTICE
NCO/Defective slab due to off chemistry	The presence of incompatible Phosphorus content causes off chemistry in a grade of the slab	Phosphorous content should be maintained below 0.02gram/kg of steel.
	Grade mismatch due to either wrong planning of slab or bad grade against the planned order.	Coordination between the Production planning, LRF and VD departments
Excess slab generation due to less plan quantity	When the order quantity is less than average **heat-size**, the excess slab is produced, which adds to no plan slab.	Processing of order as per the **heat-size** and clubbing of order if possible
		The marketing team has to look for the plate orders with specifications matching with the excess generated slab with immediate effect
Excess slab generation due to high average heat	If there are different grades during continuous casting, then either of the grades is cast more than requirement causing excess slab generation.	LRF operation has to take care during the continuous casting process.

CAUSES: MILL DIVERSION	CURRENT PRACTICE	RECOMMENDED PRACTICE
Power Failure	Power failure stops the rolling at any point, and the plate is diverted from the mill.	UPS supply and DG supply to critical equipment as per load capacity
Hydraulic Failure	Hydraulic operated equipment sometimes fails during the process, stopping the rolling at any point, and the plate is diverted from the mill.	Regular maintenance of the hydraulic system and identifying the root cause Implementation of TPM in such equipment's
Holding a rolling due to an emergency order	Sometimes, due to critical orders, the normal scheduled rolling is hold and diverted from the mill.	Rolling decisions should be taken by involving higher management.

CAUSES: EXCESS ROLLING OF PLATES	CURRENT PRACTICE	RECOMMENDED PRACTICE
Balance to Role file not updated as per the rolling schedule plan and multiple rolling occurs for a single order	Sometimes, the balance to roll file is not updated after the scheduling of a rolling plan. This results in multiple rolling for a single order.	The manual operation needs to be more accurate and error-free. Implementation of Manufacturing Execution System (MES)
Human error in planning	Error due to manual operation while entering the orders for planning.	Orders in ERPs should be entered as per the details in the Excel tool.
Excess plate generation after Minimum order quantity	Currently, a slab of thickness 200mm is used for 8mm and 10mm thickness plates.	The slab of thickness 200 mm can be used to make plates of thickness up to 40mm to reduce excess generation after minimum order quantity.
	A slab with a thickness of 200 mm, 260 mm and 300 mm is currently used for making plates from the thickness of 8 mm to 80 mm.	Slabs with 300 mm thickness can solve the purpose of 260 mm thick slabs. So, slabs with a thickness of 200 – 300 mm can be made only, and it will reduce the excess generation of slabs and excess generation of plates after minimum order quantity.

CAUSES: PSFS-SALES ORDER CLOSED	CURRENT PRACTICE	RECOMMENDED PRACTICE
Sales Order closed by the Sales & Marketing department after planning due to improper coordination between the departments.	Orders are received from customers without any advance payment.	Advance payment (20-30 percent) from customers after receiving the order.
	The sales team sometimes cancels the order after planning the order or Rolling the order.	The sales team should ensure the order's non-cancellation after planning is given to the process and fund released by finance.
	The rolling schedule made by the planning department is not available with the sales department before rolling. The rolling details are circulated to the sales department after rolling or then the next day.	Casting & rolling plan should be available with the sales department also. Proper coordination between the planning team, sales team and production team is required—implementation of MES system to coordinate the functioning of the associated departments.

CAUSES: LETTER OF CREDIT	CURRENT PRACTICE	RECOMMENDED PRACTICE
Production delay for Plate dispatch within LC period	Plates are produced if the rolling plan is given to the production team. There is no cross-check with the marketing department for the LC date.	The production should be held till the LC amendment/extension if it is expected that production will not be completed within the LC period.
	LC period is fixed with the customer without considering any process constraints for any specific grades. LC period is randomly fixed with the customers. So, the production of critical grades may exceed the LC period.	A proper negotiation by the marketing team is required to fix the LC period by analyzing the order's history.
Unavailability of vehicles or any other logistics issues within the LC period	Sometimes the plates cannot be dispatched within the LC period due to logistics issues like unavailability of vehicles for road transport or some other reason related to logistics.	Production planning should add some buffer time to total production time, considering the uncertainty of logistics.
		Proper coordination between the production and logistics team is required, and the logistics team should plan for dispatch from the day of the rolling plan.

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