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Footprint Mapping and Line Loss Analysis of a Mixed-Model Tractor Assembly Line: A Lean Manufacturing Study at Mahindra & Mahindra, Nagpur Plant

Vedant Avinash Dodke
MBA, School of Business,
Indira University,
Pune, India 411033

Mr. Nisar Jamadar
General Manager (Material Logistics) and External Guide,
Mahindra & Mahindra Ltd., Farm Equipment Sector,
Nagpur, Maharashtra, India

Dr. Nitin Joshi
Associate Professor and Area Chair - MBA, School of Business,
Indira University,
Pune, India 411033
nitin.joshi@indirauniversity.edu.in

Dr. Sanjay Asati
Assistant Professor - MBA, School of Business,
Indira University,
Pune, India 411033
sanjay.asati@indirauniversity.edu.in

Abstract **- In the competitive agricultural equipment sector, assembly-line stability depends on synchronized sub-assembly supply, disciplined kitting, and rapid recovery from production interruptions. Contemporary literature positions Lean Manufacturing, Value Stream Mapping (VSM), and Kaizen as foundational approaches for exposing hidden losses and sustaining continuous improvement. This applied industrial study examined the mixed-model tractor assembly operations of Mahindra & Mahindra Ltd., Farm Equipment Sector (FES), Nagpur Plant, covering a Pre-Assembly Line (Stages 1–22) and a Post-Assembly Line (Stages 51–90). The primary objectives were to develop a complete footprint map of the production facility, quantify line losses by department and day, evaluate production performance and manpower availability, identify root causes through cause-and-effect analysis, and design a practical Lean-based aid for material identification. Conducted during an eight-week summer internship, the methodology combined shop-floor observation, discussions with logistics officers, supervisors, and quality managers, and a census analysis of the plant's Daily Loss Analysis Register, Daily Production Graph, and Absenteeism Register for April and May 2026.**

The plant recorded 909 loss incidents (2,898.5 minutes) in April and 728 incidents (4,352.0 minutes) in May 2026. Transmission sub-assembly supply was the largest source of April downtime (775.0 minutes; 26.7%), while Planned Stoppages, frequently triggered by transmission shortages and NOVO model sequencing, became the largest May category (1,889.0 minutes). Material Logistics generated the most incidents (363 and 248) yet averaged only 1.1 minutes each, and Sheet Metal losses rose by 79% between the two months. Schedule adherence fell from 91.6% to 80.0% and Overall Line Efficiency (OLE) from 92.05% to 70.98%, with the decline concentrated in the first and second shifts, even as manpower adequacy improved from 85.8% to 92.5%. In conclusion, plant performance is constrained by upstream sub-assembly supply and production synchronisation rather than by workforce availability. A standardised Plant Inventory Bin Sticker (BIN-0042) was designed and piloted. It is recommended that management establish a transmission buffer supermarket, institute daily Transmission–Assembly coordination, stabilise Sheet Metal supply, expand bin stickers and kitting checklists, correct NOVO sequencing, and maintain trained standby operators.

Keywords - Lean Manufacturing, Footprint Mapping, Line Loss Analysis, TIMWOOD Waste Analysis, Tractor Assembly, Overall Line Efficiency (OLE)

I. INTRODUCTION

The Indian tractor industry is one of the largest in the world, accounting for roughly one-third of global tractor production and serving as a critical enabler of agricultural mechanisation and rural income growth [1]. Within this market, Mahindra & Mahindra holds a leadership position with an approximate 40% domestic share, built on a broad portfolio that spans compact 15 HP tractors to 75 HP models [2]. Serving such diverse demand requires mixed-model assembly, in which several variants with different transmission, drive, and cabin configurations are sequenced on a single line. Because every station depends on the timely arrival of the correct sub-assemblies and kitted parts, a delay in one area quickly propagates to the entire line, making the elimination of production losses central to maintaining throughput, cost competitiveness, and delivery reliability.

The Nagpur plant of Mahindra & Mahindra's Farm Equipment Sector assembles the Arjun, Yuvostar, NOVO, NST, Garuda, H1, and JIVO series on a common line comprising a

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Pre-Assembly Line (Stages 1–22, from skid loading to pre-paint masking) and a Post-Assembly Line (Stages 51–90, from propeller shaft fitment to Vehicle Testing Unit inspection and roll-out). These lines are supported by kitting zones, storage areas, docking stations, sub-assembly sections, quality offices, and a paint testing line. Despite this structure, the plant's Daily Loss Analysis Register shows that disruptions are spread across several departments rather than a single cause: during April 2026 the plant produced 9,841 tractors against a plan of 10,743, and during May 2026 (to 25 May) it produced 7,257 against a plan of 9,072, leaving shortfalls of 902 and 1,815 tractors.

To address these challenges, this study presents an empirical investigation of line losses at the Nagpur plant using a three-stage approach. First, a footprint map of the entire facility was developed to understand layout, material flow, and the interaction between production areas. Second, the April and May 2026 loss registers, production records, and manpower records were analysed to identify the dominant contributors to loss and their root causes. Third, a Lean-based improvement, a standardised Plant Inventory Bin Sticker, was designed and piloted to reduce kitting-related interruptions. Together, these steps provide a data-driven diagnostic framework and practical, low-cost recommendations to stabilise production and improve Overall Line Efficiency.

II. LITERATURE REVIEW AND THEORETICAL BACKGROUND

A. Literature Review

Womack et al. [3] introduced Lean Production by examining the Toyota Production System, arguing that productivity improves when activities that add no value are systematically removed, while Ohno [4] described the seven wastes and the logic of just-in-time flow on which that system rests. Imai [5] established Kaizen as a philosophy of small, sustained improvements involving employees at every level. Rother and Shook [6] presented Value Stream Mapping as a method for visualising the movement of material and information, and Liker [7] distilled the management principles of Toyota, notably continuous process flow to expose problems and pull systems to limit unnecessary inventory. Baudin [8] adapted Lean principles to mixed-model assembly, emphasising organised workstations, point-of-use storage, standardised labelling, and efficient kitting, whereas Monden [9] detailed just-in-time and Kanban-based control, including line-side supermarkets and controlled buffer stocks. Shingo [10] contributed the poka-yoke concept of mistake-proofing, and Ishikawa [11] introduced the cause-and-effect diagram used for structured root-cause analysis. These sources are largely foundational and conceptual; this study applies them jointly, through footprint mapping, register-level loss analysis, and a kitting aid, in a live mixed-model tractor assembly environment.

B. Theoretical Background

This study is grounded in Lean Manufacturing, a production philosophy derived from the Toyota Production System (TPS) that prioritises customer value by eliminating operational waste. Only a small fraction of activities on an assembly line add value in the customer's eyes, such as engine mounting, axle fitment, hydraulic integration, tyre fitment, and testing; all other activities, including waiting for sub-assemblies, searching for missing parts, and unplanned stoppages, are non-value-adding. These are classified using the TIMWOOD framework: Transport, Inventory, Motion, Waiting, Overproduction, Overprocessing, and Defects [4].

Footprint mapping complements Value Stream Mapping by focusing on the physical space of the facility, namely the location of stations, storage areas, aisles, and the routes travelled by materials and people. It exposes long travel distances, poorly located storage, and zone conflicts that are invisible in tabular data. Root causes are examined using the Ishikawa (fishbone) diagram organised around the 4M framework (Man, Machine, Material, Method), and continuous improvement follows the Kaizen principle of targeted, low-cost changes implemented at the shop floor.

Finally, the study draws on material-flow concepts for mixed-model assembly. Kitting delivers every part required for an operation to the station in a single, pre-organised set, and a bin sticker system provides standardised visual identification at each bin or rack. Line-side supermarkets and buffer stocks decouple the main line from fluctuations in upstream sub-assembly supply, and poka-yoke devices and checklists prevent errors at source. Line performance is expressed through Overall Line Efficiency (OLE), computed shift-wise as Actual Production divided by Revised Target.

III. MATERIALS AND METHODS

A. Research Objectives

This study evaluates line losses at the Mahindra & Mahindra Nagpur tractor assembly plant to achieve six core objectives: (1) develop a comprehensive footprint map of the Pre-Assembly (Stages 1–22) and Post-Assembly (Stages 51–90) lines and their supporting zones; (2) conduct an incident-level analysis of the Daily Loss Analysis Register for April and May 2026 by department, category, and day; (3) analyse production performance and manpower availability to corroborate the loss findings; (4) identify root causes of recurring losses through structured cause-and-effect analysis; (5) design and pilot a standardised Plant Inventory Bin Sticker for the kitting process; and (6) formulate practical, Lean-based recommendations to reduce the frequency and severity of line losses.

B. Research Design and Data Collection

A mixed-method, observational, plant-based case study was carried out during an eight-week summer internship. Quantitative data were drawn in full (census sampling) from the plant records [12]: the Daily Loss Analysis Register (909 incidents over 24 working days in April 2026 and 728 incidents over 20 reported working days in May 2026), the Daily Production Graph (planned versus actual tractors), the OLE tracking sheet, and the Absenteeism Register (shift-wise availability against basic requirement; 25 days in April and 22 days in May). Qualitative data came from structured shop-floor observation, discussions with Material Logistics officers, assembly supervisors, and quality managers, and from the hands-on development of the footprint map covering all 57 assembly stages. The bin sticker assessment used purposive sampling of 15 active bin records in the Post-Paint Kitting Area.

C. Analytical Framework and Limitations

The footprint map was built in Microsoft Excel as a colour-coded, approximately scaled layout. Loss data were analysed using descriptive statistics, frequency analysis, and department-wise and daily trend analysis, after normalising inconsistent department labels in the manually maintained register (for

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example, 'MAINT' and 'MAINTENANCE'). Wastes were classified with the TIMWOOD framework and root causes were analysed with an Ishikawa diagram on the 4M basis. The study has limitations: May data extend only to 25 May; planned stoppages are included in total loss on the plant's own reporting convention; the map reflects the layout observed during the internship; and the bin sticker pilot covered a single part number (BIN-0042), so validation across all active SKUs remains for the plant team.

IV. DATA ANALYSIS AND DISCUSSION

Document the Production Line Through Footprint Mapping

TABLE I.
ONE-WISE FOOTPRINT SUMMARY OF THE NAGPUR TRACTOR ASSEMBLY PLANT

Zone / Segment	Footprint Attributes		
	Stages	***Primary Material / Sub-assembly Source***	***Loss Risk***
Pre-Assembly Line	1–22 (S1–S19)	Pre-Paint Kitting Area, HD Racks, Sub-Assembly Areas	Medium
Post-Assembly Zone A	51–69 (S51–S68)	Post-Paint Kitting Area, Transmission Shop, Battery and Tyre Storage	High
Post-Assembly Zone B	73–79 (S73–S78)	Post-Paint Skid Store, Radiator Sub-Assembly, Sheet Metal	High
Post-Assembly Zone C	80–90 (S79–S90)	Floor Storage, Direct Delivery, Post-Paint Kitting	Medium
Transmission Supply Interface	51–56	Transmission Shop (upstream in-plant sub-assembly feed)	Critical
Post-Paint Kitting Area	—	HD Racks, Dock 1, Dock 2, Store	Critical
Sheet Metal Supply Interface	59, 74–76	Fender, Hood, and Bonnet Sub-Assembly Areas	High
Storage and Docking Areas	—	HD Racks, Dock 1, Dock 2, Floor Storage, Battery and Tyre Storage	Medium
Quality Offices and Paint Testing Line	—	Part QA office, Paint Testing Line, Vehicle Testing Unit	Low

Table 1 summarises the footprint map developed for the Nagpur plant. Built in Microsoft Excel through repeated shop-floor walkthroughs, it covers all 22 Pre-Assembly stages, the 35 manually staffed Post-Assembly stages, and supporting areas including kitting zones, HD Racks, docks, sub-assembly areas, storage zones, and offices. Conveyor-transfer sections were mapped but not treated as manually staffed assembly stages. Overlaying the loss data on the map showed that the interface between the Transmission shop and Stages 51–56 is the most loss-prone material path in the plant. The Post-Paint Kitting Area, located at some physical distance from several high-loss stations, is the second critical zone, which is consistent with Material Logistics being the most frequent source of incidents.

Evaluate Production Performance and Overall Line Efficiency

TABLE II.
RODUCTION PERFORMANCE AND SHIFT-WISE OLE, APRIL AND MAY 2026

Parameter	April 2026	May 2026 (to 25th)
Working days recorded	24	20
Planned production (tractors)	10,743	9,072
Actual production (tractors)	9,841	7,257
Shortfall against plan (tractors)	−902	−1,815
Schedule adherence	91.6%	80.0%
Average daily actual (tractors)	~410	~363
OLE – 1st shift	94.86%	69.28%
OLE – 2nd shift	92.45%	71.00%
OLE – 3rd shift	97.75%	96.57%
OLE – total (all shifts)	**92.05%**	**70.98%**

Table 2 shows a clear deterioration in plant performance. Planned daily output was similar in the two months (about 448–454 tractors per day), yet actual output fell from roughly 410 to 363 tractors per day, reducing schedule adherence from 91.6% to 80.0%. As reported on the plant's OLE tracking sheet, total OLE fell by 21.1 percentage points, from 92.05% to 70.98%. The collapse was not evenly distributed: the first and second shifts fell by 25.6 and 21.4 points respectively, while the third shift fell by only 1.2 points. Since the first two shifts are most exposed to hand-offs from Transmission and Sheet Metal sub-assembly departments, this shift-wise pattern points to upstream supply, rather than kitting or staffing, as the main driver. Total logged incidents fell from 909 to 728 while loss minutes rose from 2,898.5 to 4,352.0, so the average severity per incident increased markedly.

Quantify Department-wise Line Losses

TABLE III.
EPARTMENT-WISE LINE LOSS, APRIL 2026 (909 INCIDENTS)

Department	Loss (min)	Incidents	Avg. min / incident	Share of loss
Transmission	775.0	112	6.9	26.7%
Planned Stoppage	619.5	8	77.4	21.4%
Material Logistics (ML)	415.0	363	1.1	14.3%
Sheet Metal (SM)	294.0	86	3.4	10.1%

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Department	Loss (min)	Incidents	Avg. min / incident	Share of loss
Production Planning (PPC)	242.0	4	60.5	8.3%
MFG-ABS (Absenteeism)	155.5	5	31.1	5.4%
MFG	101.5	24	4.2	3.5%
Part QA	61.0	134	0.5	2.1%
Total (incl. other departments*)	**2,898.5**	**909**	**3.2**	**100%**

[a] *Other departments (MES, Maintenance, Process, Engine, etc.) account for the balance of the register: 235.0 minutes across 173 incidents.

TABLE IV.
EPARTMENT-WISE LINE LOSS, MAY 2026 (728 INCIDENTS)

Department	Loss (min)	Incidents	Avg. min / incident	Share of loss
Planned Stoppage	1,889.0	19	99.4	43.4%
Transmission (combined)	1,284.5	105	12.2	29.5%
Sheet Metal (SM)	525.5	131	4.0	12.1%
Material Logistics (ML)	272.5	248	1.1	6.3%
Production Planning (PPC)	203.0	4	50.8	4.7%
Part QA	43.5	109	0.4	1.0%
MFG	40.5	10	4.1	0.9%
Maintenance (MAINT)	34.5	27	1.3	0.8%
Total (incl. other departments*)	**4,352.0**	**728**	**6.0**	**100%**

[b] *Other departments (MFG-ABS/IT, Engine, Admin, Maintenance, etc.) account for the balance of the register: 59.0 minutes.

Tables 3 and 4 reveal two distinct loss profiles. Transmission was the largest April contributor (775.0 minutes, 26.7%) despite only 112 incidents, because each stoppage was severe: representative entries include transmission shortages of 100 minutes on 24 April and 98 minutes on 18 April. Material Logistics, by contrast, logged the most incidents (363) but averaged just 1.1 minutes each, the classic 'many small cuts' pattern of missing kitted parts, wrong-model parts, and absenteeism-related trolley delays. In May, Planned Stoppage surged to 1,889.0 minutes across only 19 incidents (99.4 minutes on average), and several of its largest entries, such as 198 minutes on 12 May, were explicitly caused by transmission shortages. This suggests that the plant had begun scheduling downtime around known transmission shortfalls instead of absorbing them as unplanned loss. Sheet Metal losses rose from 294.0 to 525.5 minutes (+79%) and from 86 to 131 incidents (+52%), signalling a parallel deterioration in fender, hood, and bonnet supply.

Identify the Highest-Impact Loss Incidents

TABLE V.
EN HIGHEST-IMPACT SINGLE INCIDENTS, APRIL AND MAY 2026

Date (Shift)	Department	Min.	Incident description
01-Apr (S3)	Planned Stoppage	340	Planned loss
12-May (S2)	Planned Stoppage	198	Transmission shortage
11-May (S3)	Planned Stoppage	178	Planned loss
09-May (S3)	Planned Stoppage	162.5	Planned loss
22-May (S1)	Transmission	150	Transmission shortage
13-May (S3)	Planned Stoppage	137	Plan completed
15-Apr (S3)	MFG-ABS	105	Absenteeism; line speed reduced to 80 vehicles per shift
24-Apr (S3)	Transmission	100	Line stopped due to transmission shortage
18-Apr (S3)	Transmission	98	Line stopped due to transmission shortage
30-Apr (S3)	PPC	98	Line stopped as NOVO came early at post-painting

Table 5 confirms that the most damaging events are large, infrequent stoppages tied to Planned Stoppage and Transmission shortage, not the high-frequency kitting incidents that dominate the Material Logistics count. The 340-minute planned loss on 1 April, covering nearly a full shift, is the single largest event in either month. Daily totals reinforce the pattern: from 7 to 13 May, daily losses ranged from 326.0 to 458.5 minutes, more than double the typical April level, and this sustained multi-day severity is consistent with a systemic transmission and sheet-metal supply problem rather than isolated disturbances.

Classify Wastes Using the TIMWOOD Framework

TABLE VI.
IMWOOD OPERATIONAL WASTE CLASSIFICATION AND SHOP-FLOOR EVIDENCE

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Vol. 14, Issue 12, UCBO - 2026

TIMWOOD Waste	Waste Classification		
	Observed Manifestation	***Plant Evidence (April–May 2026)***	***Process Location Affected***
Transport	Transmission sub-assemblies and kitted parts travel from the Transmission shop and HD Racks to line-side	775.0 min Transmission loss in April	Transmission shop to Stages 51–56; HD Racks
Inventory	Fender and hood sub-assembly WIP imbalance	Sheet Metal loss rose from 294.0 to 525.5 min	Fender, hood and bonnet sub-assembly areas
Motion	Kitters and operators travel to fetch missing parts	363 ML incidents (April); 248 (May)	Post-Paint Kitting Area; line-side stations
Waiting	Line idle awaiting transmission and other sub-assemblies	Single stoppages of 100 min (24 Apr) and 198 min (12 May)	Stages 51–90 (Post-Assembly Line)
Over-production	NOVO units arriving early at the paint shop disrupt sequencing	PPC loss of 242.0 min (April) and 203.0 min (May)	Paint shop to post-painting hand-off
Over-processing	Re-verification and rework cycles for fitment and dimensional issues	Documented in Part QA incident logs	Fitment and dimensional re-verification
Defects	Errors and rejections requiring correction at incoming checks	Part QA: 134 incidents (April); 109 (May)	Incoming and in-process checks

Table 6 shows that all seven wastes are observable at the plant, but Waiting and Transport dominate in minutes, while Motion dominates in frequency. Waiting for transmission sub-assemblies is the most costly form of non-value-adding time, because the entire line stops. Motion waste appears as many short interruptions in which kitters leave their tasks to search for parts. The NOVO sequencing issue illustrates how flow imbalance in one area, the paint shop, transfers waste to downstream assembly.

Assess Manpower Availability and Absenteeism

TABLE VII.
ANPOWER AVAILABILITY AGAINST REQUIREMENT, APRIL AND MAY 2026

Parameter	April 2026	May 2026
Days recorded	25	22
Basic requirement (man-shifts)	18,167	14,872
Total available (man-shifts)	15,592	13,755
Total shortfall (man-shifts)	−2,575	−1,117
Average daily shortfall	−103.0	−50.8
Staffing adequacy ratio	85.8%	92.5%
Worst single day	28-Apr (−739)	26-May (−662)

Table 7 yields a counter-intuitive result: staffing adequacy improved from 85.8% to 92.5% while line losses and the production shortfall worsened. Absenteeism is a real problem and was the proximate cause of the 155.5-minute MFG-ABS loss in April, and the worst gap days (28 April and 26 May) warrant management attention, particularly since 27 and 30 April were among the highest-loss days of the month (324.0 and 356.0 minutes). However, absenteeism is a secondary contributor; the April-to-May decline is explained mainly by Transmission, Planned Stoppage, and Sheet Metal losses, which are largely independent of line-side manpower.

Diagnose Root Causes Using Cause-and-Effect Analysis

TABLE VIII.
AUSE-AND-EFFECT MATRIX (4M FRAMEWORK) FOR RECURRING LINE LOSSES PART-1

4M	Root-Cause Analysis	
	Root Cause Identified	***Supporting Evidence***
Man	Kitting trolleys not fully loaded before shift start	363 ML incidents (April); 248 (May)
Man	Absenteeism reduces line speed and delays trolley feeding	15-Apr: 105 min; gaps of −739 (28-Apr) and −662 (26-May)
Machine	Transmission sub-assembly line cannot match main-line takt time	112 incidents / 775.0 min (April); 105 / 1,284.5 min (May)
Machine	MES and process equipment delays	MES 41.0 min; Process 20.5 min (April)
Material	Sheet Metal sub-assembly supply shortfall, worsening month on month	294.0 to 525.5 min (+79%)
Material	Transmission components not available in sequence	24-Apr: 100 min; 22-May: 150 min
Material	No standard bin label for most SKUs	Observed during mapping and kitting assessment

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Vol. 14, Issue 12, UCBO - 2026

4M	Root-Cause Analysis	
	Root Cause Identified	***Supporting Evidence***
Method	NOVO early arrival disrupts downstream sequencing	PPC loss 242.0 min (April); 203.0 min (May)
Method	No formal kitting-trolley checklist or standard work sheet	ML incident descriptions recur across both months
Method	Transmission shortages handled as Planned Stoppage, not resolved at source	12-May: 198 min planned stoppage

TABLE IX.
AUSE-AND-EFFECT MATRIX (4M FRAMEWORK) FOR RECURRING LINE LOSSES PART-2

4M	Root-Cause Analysis	
	Operational Impact	***Recommended Countermeasure***
Man	Kitting delays; missing parts at station	Pre-shift trolley loading check and sign-off
Man	Reduced line speed; trolley feeding gaps	Trained standby operator pool
Machine	Repeated line stoppages awaiting transmissions	Transmission buffer supermarket (one shift)
Machine	Short stoppages awaiting system or process input	Preventive maintenance and MES response review
Material	Fender, hood and bonnet shortages at stations	Sheet Metal root-cause study and small buffer
Material	Stoppages of 100–198 min; planned loss	Daily Transmission–Assembly coordination
Material	Search time and wrong-part picking	Plant Inventory Bin Sticker for all SKUs
Method	Early arrival forces re-sequencing downstream	Align Paint Shop and PPC sequencing
Method	Inconsistent kitting quality across shifts	Standard kitting checklist per trolley type
Method	Shortage hidden inside planned loss figures	Log shortages as loss at source, not as planned stoppage

Table 8 (Parts 1 and 2) points to three interconnected root causes. First, the in-plant Transmission sub-assembly supply cannot consistently match the takt time of the main line. Second, Sheet Metal supply is deteriorating. Third, Material Logistics and kitting remain a chronic source of small losses that erode efficiency. A supplementary plant log reinforces the picture: scanning delay at the newly introduced LH/RH scuttle sticker poka-yoke station recurred at least ten times with the same stated cause and was resolved each time by operator counselling. This is a symptom-level response to a system-level problem, which a Kaizen-based standard work review is designed to correct.

Design and Pilot a Lean Improvement: The Plant Inventory Bin Sticker

TABLE X.
ESIGN FIELDS OF THE PLANT INVENTORY BIN STICKER (PILOT: BIN-0042)

Field	Purpose for Kitters and Operators
Bin Number (BIN-0042)	Unique identifier for tracking and audit; easy reference in loss reports
Feeding Frequency (2× per shift)	Tells the kitter how often to replenish; shown prominently on the left panel
Part Number (007543855C91)	SAP part number for procurement reference and barcode scanning
Description (Knob Hand Accelerator)	Human-readable name for instant identification at line-side
Model Number	Links the part to a tractor variant; critical for mixed-model management
Store Location (RACK-A / ROW-3)	Exact source location for fast, accurate picking
Daily Requirement (48 pcs)	Total daily quantity across shifts to support the production plan

Table 9 lists the fields of the bin sticker, which was designed in direct response to the high frequency of Material Logistics incidents. The existing kitting area relied on informal labels and on kitter experience, a weakness whenever replacement kitters are deployed during absenteeism. The template was developed in four steps: identifying required fields with ML officers and kitters, placing the most referenced fields prominently, adopting the gold and yellow colour convention of plant visual management, and piloting with BIN-0042. During the pilot, kitters and operators identified the correct part and its replenishment requirement without supervisor help, and the store location was judged the most time-saving field. Even a modest reduction in per-incident occurrence would yield a meaningful cumulative gain in line continuity.

Recommend Feasible Lean Improvement Initiatives

TABLE XI.
RIORITISED LEAN INTERVENTIONS AND PROJECTED BUSINESS IMPACT PART-1

Priority Bottleneck (Lean Waste)	Proposed Improvement	
	Intervention	***Expected Effect***
Transmission-driven stoppages (Waiting / Transport)	Transmission buffer supermarket between the Transmission shop and Stages 51–56, sized for one full shift	Line keeps running during transmission-shop delays
Late detection of shortages (Waiting)	Daily Transmission–Assembly meeting reviewing the next 24–48 hours against availability	Early warning before a stoppage occurs

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Priority Bottleneck (Lean Waste)	Proposed Improvement	
	Intervention	***Expected Effect***
Rising Sheet Metal losses (Inventory / Waiting)	Root-cause study; better planning, tighter inventory control, small buffer	Stable fender, hood, and bonnet supply
Frequent ML incidents (Motion / Defects)	Extend bin stickers to all active parts, worst-affected first	Faster identification, less search time
Missing or wrong kitted parts (Defects)	Checklist per trolley type with sign-off and supervisor spot-checks	Fewer material-related stoppages
NOVO sequencing (Overproduction)	Align Paint Shop and PPC sequencing to the assembly plan	Fewer planned stoppages
Absenteeism spikes (Waiting)	Trained standby pool activated above an absenteeism threshold	Flexibility without permanent headcount

TABLE XII.
RIORITISED LEAN INTERVENTIONS AND PROJECTED BUSINESS IMPACT PART-2

Priority Bottleneck	Implementation Plan		
	Proposed Owner	***Timeline***	***KPI to Track***
Transmission -driven stoppages	Plant Head; Transmission Shop	Short term (4–8 weeks)	Transmission loss min / month
Late detection of shortages	Transmission and Assembly Managers	Immediate (1–2 weeks)	Shortage alerts raised vs. stoppages
Rising Sheet Metal losses	Sheet Metal Manager; Quality	Medium term (2–3 months)	Sheet Metal loss min / month
Frequent ML incidents	Material Logistics Officer	Short term (4–8 weeks)	ML incidents per day
Missing or wrong kitted parts	Production Supervisors	Immediate (1–2 weeks)	Kitting incidents per shift
NOVO sequencing	Paint Shop; PPC	Medium term (2–3 months)	PPC loss min / month
Absenteeism spikes	HR; Production Supervisors	Medium term (2–3 months)	Stoppage min due to absenteeism

Tables 10 and 11 outline a low-capital improvement roadmap arranged by expected impact. The transmission buffer and the daily coordination meeting address the largest source of lost minutes, and together convert shortages from surprises into planned events. Stabilising Sheet Metal supply addresses the fastest-growing loss category. Expanding the bin sticker system and introducing kitting checklists target the high-frequency Material Logistics incidents, in keeping with the Kaizen preference for small, practical shop-floor changes. Correcting NOVO sequencing and building a standby workforce protect the line against planning and staffing disturbances. Because these measures rely on organisation, signage, and coordination rather than major capital, they can be phased in quickly.

V. FINDINGS, CONCLUSIONS AND SUGGESTIONS

A. Findings

The empirical investigation at the Mahindra & Mahindra Nagpur plant produced the following findings. A complete footprint map covering 22 Pre-Assembly and 35 Post-Assembly stages and all supporting zones was developed, the first structured visual layout of the plant. Transmission sub-assembly supply was the largest source of production loss: 775.0 minutes across 112 incidents in April (26.7% of total loss) and 1,284.5 minutes across 105 incidents in May, with severe single events of 100, 150, and 198 minutes. Schedule adherence fell from 91.6% to 80.0%, with shortfalls of 902 and 1,815 tractors, and OLE fell from 92.05% to 70.98%, concentrated in the first shift (94.86% to 69.28%) and second shift (92.45% to 71.00%), while the third shift remained stable. Material Logistics recorded the most incidents (363 and 248) but averaged only 1.1 minutes each, indicating repeated small disruptions from missing parts, incorrect kitting, and poor material identification. Sheet Metal losses rose 79% in minutes and 52% in incidents, and Planned Stoppages grew from 619.5 minutes across 8 incidents to 1,889.0 minutes across 19, often to manage known transmission shortages. Manpower adequacy improved from 85.8% to 92.5% while performance declined, so absenteeism was not the principal cause. Finally, the pilot Plant Inventory Bin Sticker (BIN-0042) allowed kitters to identify parts and replenishment needs without supervisor assistance.

B. Conclusions

This study achieved all of its stated objectives. A footprint map, a department-wise analysis of 909 April and 728 May 2026 incidents, a production and manpower assessment, a 4M root-cause analysis, and a piloted bin sticker together give a coherent picture of line losses at the Nagpur plant. The analysis confirms that overall performance is constrained by upstream sub-assembly supply and production synchronisation rather than by line-side manpower or machine capability. Material Logistics creates the most frequent interruptions, but Transmission produces the longest, and, together with the Planned Stoppages it triggers, the most consequential ones. Sheet Metal is an emerging concern. By deploying low-cost Lean interventions, namely a transmission buffer, daily coordination, standardised bin stickers, kitting checklists, corrected NOVO sequencing, and standby operators, the plant can reduce the frequency and severity of losses, improve schedule adherence and OLE, and build a foundation for continuous improvement.

C. Suggestions

To achieve tangible improvement across all stakeholders, the plant should execute a phased, collaborative roadmap:

For Plant Management & Planning: Establish a transmission buffer supermarket sized for at least one full shift between the Transmission shop and Stages 51–56, and correct NOVO sequencing between the Paint Shop and Production Planning and Control so that vehicles arrive in the order required by the assembly plan.

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For Transmission and Sheet Metal Departments: Hold a daily meeting with the assembly line scheduling team to compare the next 24–48 hours of the plan with sub-assembly availability, and conduct a root-cause study of Sheet Metal interruptions to stabilise fender, hood, and bonnet supply.

For Material Logistics & Kitting Teams: Expand the bin sticker system to all active parts, starting with the most problematic, and introduce a standard checklist for each kitting-trolley type, signed by the kitter and spot-checked by supervisors at the start of each shift.

For HR & Production Supervisors: Train a small standby group of operators who can be deployed whenever absenteeism crosses a defined limit, avoiding any permanent increase in headcount.

D. Implications of the study

The implications of this study provide strategic and operational benefits across all primary stakeholders:

- Plant Management: Stabilising sub-assembly supply and reducing planned stoppages protects throughput, improves schedule adherence, and limits the loss of manufacturing capacity that cannot be recovered within the same production cycle.
- Shop-Floor Operators & Kitters: Standard bin stickers and checklists remove dependence on memory and experience, shorten search time, and make the work easier for new or replacement personnel.
- Planning & Quality Teams: Register-level data and the 4M matrix give a factual basis for sequencing decisions and for tracking whether corrective actions reduce recurring losses.
- Upstream Departments: Early visibility of demand against availability enables the Transmission and Sheet Metal departments to plan their output to the pace of the main line.

E. Future Scope of the study

The footprint map and loss baseline established in this research open several avenues for future inquiry:
Simulation of Buffer Sizing: Discrete-event simulation can evaluate transmission buffer size, line pacing, and recovery behaviour under varying upstream disruption before physical implementation.
Digital Loss Capture: Replacing the manually maintained register with MES-integrated, real-time loss logging and Andon alerts would remove naming inconsistencies and shorten response times.
Cost-Benefit Evaluation: A detailed financial model of lost tractors, buffer inventory cost, and improvement investment would quantify the return on the proposed interventions.
Wider Validation: Extending the footprint map with travel-distance (spaghetti) analysis, covering complete-month and multi-season data, and validating the bin sticker across all active SKUs would strengthen the generalisability of the findings.

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