



FACULTY OF ENGINEERING
DEPARTMENT OF INDUSTRIAL ENGINEERING

**A SYSTEM DESIGN FOR PLASTIC BABY SHAMPOO BOTTLE
MANUFACTURING USING BLOW MOLDING TECHNOLOGY**

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ISE 402: System Design

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1. Product Determination and Scope

This project focuses on the system design of an automated plastic baby shampoo bottle manufacturing system. The selected product is a small plastic baby shampoo bottle with a capacity range of 100–400 mL. The bottle is planned to be produced from High Density Polyethylene (HDPE) which is commonly used for personal care packaging due to its durability, light weight and suitability for blow molding processes.

The selected manufacturing method is extrusion blow molding. This process is appropriate for producing hollow plastic containers such as shampoo bottles because it allows the plastic material to be heated, shaped inside a mold, cooled and removed as a finished bottle. Since the product has a standardized shape and stable demand, a continuous flow production system is considered suitable for this design.

The proposed production line includes the main stages of raw material feeding, heating and extrusion, blow molding, cooling, ejection, trimming, quality inspection, packaging and finished goods storage. These stages are arranged in a sequential layout so that the output of one stage becomes the input of the next stage. A basic control system is included to monitor production status, machine conditions, alarms and production records.

An important part of the proposed design is the recycling of production scrap. Trimming waste and defective HDPE bottles are directed to an inline granulator where they are reduced into reusable plastic particles. These particles can then be returned to the production process when technically suitable. This helps reduce material waste and supports a more sustainable production approach.

The main objectives of the system are to produce at least 1,500 accepted bottles per hour, keep the total defect rate below 5%, maintain traceability of production and inspection records, keep the total investment cost within USD 120,000 and fit the system within a factory area not exceeding 200 m².

The design also considers worker safety, environmental responsibility and sustainable production principles, especially; SDG 12: Responsible Consumption and Production, SDG 8: Decent Work and Economic Growth and SDG 9: Industry, Innovation and Infrastructure.

2. REQUIREMENTS

2.1 Functional Requirements

1. The system shall automatically transfer HDPE plastic granules from the raw material silo to the blow molding machine hopper via a pneumatic conveyor line during normal production without operator intervention.
2. The system shall keep the blow molding machine hopper fill level above 25% of its total capacity during production by automatically triggering a refill cycle when the level sensor detects a lower level.
3. The system shall heat the HDPE raw material to a processing temperature between 180°C and 220°C before the extrusion process starts.
4. The system shall maintain the extruder barrel temperature within $\pm 3^{\circ}\text{C}$ of the operator defined setpoint during continuous production.
5. The system shall extrude a continuous plastic parison with a uniform wall thickness of ± 0.15 mm before mold closing.
6. The system shall close the blow mold around the extruded parison and inflate it with compressed air between 6 and 10 bar to form the bottle body according to the approved mold geometry.
7. The system shall produce bottle bodies with external dimensions conforming to the approved mold specification with a ± 2 mm tolerance.
8. The system shall complete the cooling and solidification of each formed bottle within 30 seconds after mold closure while maintaining coolant supply temperature at $10^{\circ}\text{C} \pm 2^{\circ}\text{C}$.
9. The system shall automatically eject the cooled bottle from the mold cavity and transfer it to the trimming stage without manual handling.
10. The system shall remove neck flash and base flash from each bottle with at least 95% trimming completeness and shall direct bottles with residual flash above 5% to the scrap granulator feed.
11. The system shall collect trimming flash generated at the trimming station and transfer it to the inline granulator through a dedicated scrap conveyor preventing scrap accumulation in the production area during normal operation.
12. The system shall inspect each trimmed bottle at the vision inspection station using at least four cameras and LED lighting to detect defects such as wall cracks, surface fractures, deformation, incomplete blow, neck damage and leakage risk.
13. The system shall classify each inspected bottle as Accepted, Reworkable-Defective or Non-Reworkable-Defective within 2 seconds after image capture.
14. The system shall automatically divert accepted bottles to the packaging conveyor, reworkable defective bottles to the rework holding lane and non-reworkable defective bottles to the scrap granulator feed lane.
15. The system shall transfer bottles between consecutive production stages, including molding, trimming, inspection, packaging and storage with a maximum inter-stage waiting time of 2 minutes under normal operating conditions.

16. The system shall package accepted bottles into corrugated cardboard cartons and apply labels including production batch ID, production date, shift number, bottle count and responsible operator ID.
17. The system shall display current line status, shift production count, defect rate, active alarms, barrel temperature information and preventive maintenance status on the operator HMI panel with updates at intervals not exceeding 5 seconds.
18. The system shall initiate an emergency stop of the entire production line, including the blow molding machine, conveyors, trimming station, inspection station, packaging station and granulator within 3 seconds after any emergency stop button is pressed.
19. The system shall store production records for each shift, including total bottles produced, total accepted bottles, rejected bottles by defect category, reworked bottles, raw material consumed, scrap granulated, unplanned downtime duration and downtime cause codes.
20. The system shall retain all production, inspection and alarm records for a minimum of 30 days with records retrievable by shift ID, production date or batch ID.
21. The system shall activate visual and audible alarms within 10 seconds when a major fault is detected, including barrel temperature deviation of $\pm 5^{\circ}\text{C}$ or more, vision system failure, conveyor jam, hopper level below 25%, air pressure below 5 bar or granulator overload.
22. The system shall allow authorized operators to adjust the production speed between 1,000 and 2,000 bottles per hour via the HMI without needing to restart the machine or change equipment and the updated speed shall take effect within 60 seconds after approval.
23. The system shall monitor the stock level in the raw material silo in real time and issue a low stock alert when it falls below the amount required for 8 hours of continuous production at the current production rate.
24. The system shall process all collected HDPE scrap, including trimming flash and non-reworkable defective bottles into reusable granules with a maximum particle size of 6 mm through the inline granulator.
25. The system shall prevent mold closure when the parison presence sensor does not detect a properly extruded parison in the mold area, preventing dry-cycle damage to the mold tooling.

2.2 Non-Functional Requirements

1. The system shall produce at least 1,500 accepted plastic baby shampoo bottles per hour under normal operating conditions, measured as the average output during a continuous 4 hour production period within one shift.
2. The system shall keep the total defect rate below 5% of total daily production output calculated as rejected bottles divided by total bottles produced and recorded automatically at the end of each 8 hour shift.
3. The system shall maintain machine availability above 90% per shift calculated as scheduled production time minus unplanned downtime divided by scheduled production time.
4. The system shall limit total unplanned downtime, including machine faults, conveyor jams, sensor failures and material blockages to a maximum of 30 minutes during a single 8 hour production shift.
5. The system shall keep material waste below 5% of total raw material consumption per shift including trimming flash and non-reworkable defective bottles before granulation.
6. The system shall maintain all finished bottle dimensions, including height, outer diameter, neck diameter and base width within a ± 2 mm tolerance for all produced bottles.
7. The system shall keep waiting time between any two consecutive production stages below 2 minutes under normal operating conditions.
8. The system shall maintain a minimum HDPE inventory level sufficient for at least 3 days of uninterrupted production at the nominal production rate.
9. The system shall keep work in process (WIP) inventory between production stages below the output capacity of one full 8 hour production shift.
10. The system shall keep backorders caused by production shortages, downtime or supply delays below 2% of total monthly customer demand under normal operating conditions.
11. The system shall allow routine cleaning and scheduled preventive maintenance activities including barrel cleaning, trimming blade inspection, vision system recalibration and conveyor lubrication to be completed within 1 hour per shift without requiring disassembly of any major machine module.
12. The system shall provide clearly marked emergency stop devices at the raw material feed area, blow molding machine operator panel, trimming station, vision inspection station, packaging station and inline granulator with each device accessible within 1 meter of the operator's normal working position.
13. The system shall maintain all external machine surfaces accessible to operators below 45°C during normal operation, excluding guarded hot zones with visible hazard signs.
14. The system shall reduce unnecessary machine idle time by at least 15% compared to manual scrap removal through the integration of the closed-loop inline granulator and pneumatic scrap return system.

15. The system shall inspect 100% of produced bottles through the vision inspection system and automatically log every detected defective bottle with defect category, timestamp, shift ID and sequential bottle number.
16. The system shall achieve an Overall Equipment Effectiveness (OEE) of at least 80% over a complete production week, calculated using availability, performance rate and quality rate.
17. The system shall classify at least 95% of defective bottles as defective and at least 98% of non-defective bottles as accepted during commissioning tests using a predefined reference set of bottles.
18. The system shall process all scrap generated during a shift through the inline granulator within the same shift, leaving no unprocessed scrap in the scrap lane at shift end.
19. The system shall complete each pneumatic hopper refill cycle within 5 minutes after the low level sensor triggers the refill process.
20. The system shall improve OEE by at least 5 percentage points compared to a manual handling baseline after 4 weeks of automated operation with OEE data recorded continuously by the PLC.

3. Assumptions and Constraints

3.1 Assumptions

- Demand for plastic baby shampoo bottles is assumed to remain stable during the project period without major seasonal changes requiring machine speed or mold reconfiguration.
- HDPE granules that meet the selected material specifications are assumed to be continuously available from qualified suppliers with a maximum replenishment lead time of 5 working days.
- The selected extrusion blow molding machine is assumed to operate under normal manufacturer recommended conditions with major unplanned mechanical repairs not occurring more than once per calendar quarter.
- At least one trained blow molding machine operator and one qualified maintenance technician are assumed to be available per shift for machine monitoring, basic fault diagnosis, consumable replacement and production data review.
- The production facility floor is assumed to have sufficient load bearing capacity for all installed equipment. The usable production area is assumed to be at least 200 m² with enough ceiling height for the blow molding machine and pneumatic conveying pipes.
- A stable three-phase 380 V/50 Hz electrical supply is assumed to be available during all production shifts, with interruptions not exceeding 5 minutes per shift.
- A UPS is assumed to protect the PLC, HMI and vision inspection controllers against momentary power fluctuations.
- The bottle design, mold cavity dimensions, target bottle weight and mold specifications are assumed to remain unchanged during the project period.
- Required packaging materials such as corrugated cartons, hot-melt adhesive and batch ID labels are assumed to be available on site with at least a 3 day supply buffer.
- Trimming flash and non-reworkable defective bottles are assumed to be compatible with direct granulation and re-extrusion since a single HDPE grade is used throughout production.
- It is assumed that the production facility provides an ambient temperature between 18°C and 30°C and adequate ventilation for safe production conditions.
- All production quality and alarm data generated by the PLC, HMI and vision inspection system are assumed to be storable on a local industrial PC or plant server for at least 30 days.
- The facility compressed air system is assumed to maintain a supply pressure of at least 8 bar at the blow molding machine inlet under normal operating conditions.
- The vision inspection system cameras and LED illumination are assumed to remain calibrated for at least one production shift without operator intervention.

3.2 Constraints

- The total initial capital expenditure for the complete production system, including machinery, conveyors, vision inspection system, inline granulator, closed-loop recycling system, installation, commissioning, operator training and auxiliary equipment, shall not exceed USD 120,000.
- The total installed footprint of the production system, including machinery, conveyors, storage areas, operator working zones and minimum 1 m operator aisles, shall not exceed 200 m².
- The selected blow molding machine shall have a manufacturer rated production capacity of at least 1,500 bottles per hour for 100–400 mL HDPE baby shampoo bottles.
- All selected machinery and system components must be commercially available in Türkiye, CE certified and serviceable or deliverable to Istanbul with a spare parts delivery time of no more than 10 business days.
- The system shall comply with applicable Turkish occupational health and safety legislation, EU Machinery Directive 2006/42/EC, EN ISO 12100 machine safety principles and CE marking requirements.
- The system shall comply with applicable Turkish and EU environmental regulations related to plastic manufacturing waste, recycling and industrial waste disposal.
- The production line shall be operable by a maximum team of four operators per shift, including one blow molding operator, one quality/inspection operator, one packaging operator and one general support/logistics operator.
- The complete system design shall be finalized and submitted within the ISE 402 academic project timeline defined by the course instructor.
- The system shall include a closed loop HDPE scrap recycling mechanism that returns recoverable production scrap to the raw material stream within the same production shift.
- The blow molding machine extruder barrel temperature shall not exceed 230°C at any zone during normal or transient operation.
- The compressed air demand of the blow molding machine at maximum production speed shall not exceed 80% of the facility compressor system's rated free air delivery capacity.
- The vision inspection system shall inspect bottles at the conveyor speed required for the maximum production rate of 2,000 bottles per hour without stopping or slowing the conveyor.

4. Process Model

4.1 Selected Process Model

The most appropriate process model for the plastic baby shampoo bottle manufacturing system is the **Continuous Flow Process Model**. This model is suitable for high volume and standardized production, where the same product is produced repeatedly through a fixed sequence of operations.

In this system, the production line is designed to operate with minimum interruption. Each stage is directly connected to the next stage through material handling equipment and synchronized timing. This helps reduce work-in-process inventory, shorten waiting times between stages and keep the production flow stable.

The continuous flow model also supports the system requirements defined earlier, such as producing at least 1,500 accepted bottles per hour, keeping inter stage waiting time below 2 minutes and maintaining machine availability above 90%.

Justification for the Continuous Flow Model

- **Fixed Sequence of Operations:** The blow molding process follows a fixed order:
Raw Material Feed → Plasticizing and Extrusion → Blow Molding → Cooling → Ejection → Trimming → Inspection → Packaging → Storage. These stages cannot be skipped or rearranged without interrupting production.
- **High Volume and Standardization:** The system targets at least 1,500 HDPE baby shampoo bottles per hour with fixed mold geometry. Since the product design remains stable during the project period, continuous flow production is appropriate.
- **Inter-Stage Synchronization:** The blow molding machine acts as the main pacing unit of the line. Conveyors, trimming, inspection and packaging stations are arranged according to this production rate to prevent bottlenecks and excessive WIP accumulation.
- **Closed-Loop Recycling Compatibility:** The inline granulator operates as a parallel sub - process to the main line. Trimming flash and rejected HDPE bottles are collected continuously and returned to the raw material stream without stopping the production line. This supports both production efficiency and waste reduction.

Improved Process Model with Inline Recycling Integration

The proposed system improves the standard continuous flow model by adding a closed loop material recovery path. In this path, trimming flash and rejected HDPE bottles are collected directly from the trimming and inspection stages, sent to the inline granulator and converted into reusable plastic granules.

The recovered granules are then returned to the raw material stream without stopping the main production line. This allows the system to reduce material waste while maintaining continuous production.

This integration provides three main benefits: it reduces manual handling of plastic scrap, improves workplace safety, minimizes recoverable plastic waste and supports sustainable production. It also strengthens the project's alignment with SDG 12: Responsible Consumption and Production, SDG 8: Decent Work and Economic Growth and SDG 9: Industry, Innovation and Infrastructure.

4.2 Machinery Types and Quantities

4.2.1 Raw Material Feed System

- **HDPE Bulk Storage Silo (1 unit):** Stores at least 3 days of HDPE granules and supplies material to the production line through a pneumatic conveying pickup point.
- **Pneumatic Conveying Line (1 system):** Transfers HDPE granules from the storage silo to the blow molding machine hopper. The system is equipped with a hopper level sensor and triggers automatic refill when the hopper level falls below the required level.

4.2.2 Extrusion Blow Molding Machine

- **Extrusion Blow Molding Machine (1 unit):** Produces 100–400 mL HDPE baby shampoo bottles with a rated capacity of at least 1,500 bottles per hour. The machine includes controlled heating zones, mold clamping, automatic ejection and a take out mechanism.
- **Screw and Barrel System (included with machine):** Melts and prepares the HDPE material for extrusion according to the selected processing temperature range.
- **Blow Mold Tooling (1 active set + 1 spare set):** Forms the approved baby shampoo bottle geometry and supports dimensional tolerance of ± 2 mm. The mold also includes cooling channels connected to the chiller system.

4.2.3 Cooling System

- **Closed-Loop Water Chiller Unit (1 unit):** Maintains coolant supply at approximately $10^{\circ}\text{C} \pm 2^{\circ}\text{C}$ to support bottle cooling and solidification within 30 seconds.
- **Coolant Circulation Pump and Manifold (1 system):** Circulates chilled water through the mold cooling channels at the required flow rate.

4.2.4 Trimming Station

- **Rotary Trimming Station (1 unit):** Removes neck and base flash from molded bottles at line speed. The station is selected to achieve at least 95% trimming completeness and trimming flash is transferred to the scrap recycling system.

4.2.5 Vision Inspection Station

- **Multi-Camera Vision Inspection System (1 unit):** Inspects each bottle using four cameras and LED illumination. The system detects defects such as cracks, deformation, incomplete blow, neck damage and leakage risk. It also classifies bottles as accepted, reworkable defective or non-reworkable defective within 2 seconds.
- **Pneumatic Diverter Gates (1 set):** Direct accepted bottles to packaging, reworkable bottles to the rework lane and non-reworkable defective bottles to the scrap granulator feed.

4.2.6 Packaging Station

- **Automated Carton Packaging Station (1 unit):** Counts accepted bottles, places them into corrugated cardboard cartons, seals the cartons with hot-melt adhesive and applies labels containing production batch ID, production date, shift number, bottle count and operator ID.

4.2.7 Closed-Loop Scrap Recycling Sub-System

- **Inline HDPE Scrap Granulator (1 unit):** Processes trimming flash and rejected HDPE bottles into reusable granules with a maximum particle size of 6 mm.

- **Scrap Conveyor (1 system):** Collects trimming flash and rejected bottles from the trimming and inspection areas and transports them to the granulator.
- **Granule Return Line (1 system):** Returns reusable HDPE granules from the granulator back to the raw material stream, supporting closed-loop material recovery.

4.2.8 Material Handling and Control

- **Conveyor Belt Segments (4 segments):** Transfer bottles between molding, trimming, inspection, packaging and storage stages at synchronized speed, keeping inter-stage waiting time below 2 minutes.
- **PLC Control System (1 unit):** Coordinates machine timing, station communication, alarms, emergency stop logic and data logging.
- **HMI Touchscreen Panel (1 unit):** Displays line status, production counts, defect rate, alarms, temperature information and maintenance status, with updates at intervals not exceeding 5 seconds.
- **Emergency Stop Buttons (6 units):** Installed at major stations including raw material feed, blow molding machine, trimming station, inspection station, packaging station and inline granulator.

4.3 Facility Layout

The production system is arranged as a **linear product layout** which supports the fixed and sequential structure of the continuous flow process. Each workstation is placed according to the order of production, starting from raw material input and ending with finished goods storage.

The main layout sequence is:

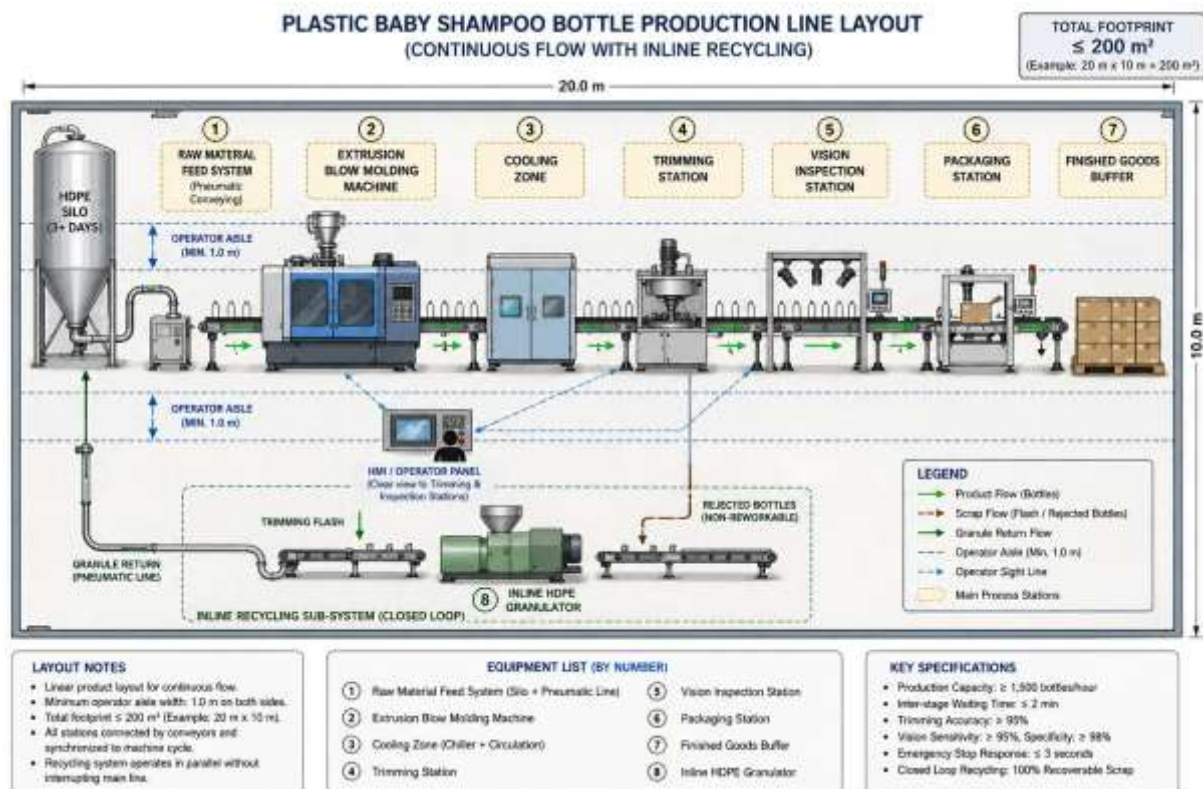
Raw Material Silo → Pneumatic Feed System → Blow Molding Machine → Cooling Zone → Trimming Station → Vision Inspection Station → Packaging Station → Finished Goods Buffer

The total installed footprint of the system is planned to remain within 200 m² in line with the space constraint defined in the project.

The inline granulator and scrap return system are positioned parallel to the main production line close to the trimming station and inspection diverter gate. This placement allows trimming flash and rejected bottles to be transferred to the granulator through the shortest possible path. The granule return line carries reusable HDPE granules back to the raw material feed area without interrupting the main production flow.

Operator aisles with a minimum width of 1 meter are maintained around the line to support safe movement, maintenance access and supervision. The HMI panel is located near the blow molding machine operator area so that the operator can monitor the main machine, trimming station and inspection station from a central position.

This layout is selected because the product is standardized, produced in high volume and follows a fixed sequence of operations. The linear arrangement reduces material handling distance, limits unnecessary WIP accumulation, improves operator visibility and supports the closed-loop recycling system without creating cross traffic or process interruption.



4.4 Inventory Levels

Table 4.1 presents the minimum and maximum inventory levels planned for the critical and non-critical components of the system. The minimum stock level represents the safety stock required to continue production during supplier delays, short term disruptions or minor maintenance activities without stopping the line.

The maximum stock level represents the highest practical inventory level that can be stored within the available facility area. These limits are determined by the 200 m² factory space constraint, material handling capacity and safe storage requirements for HDPE granules, packaging materials, spare parts and consumables.

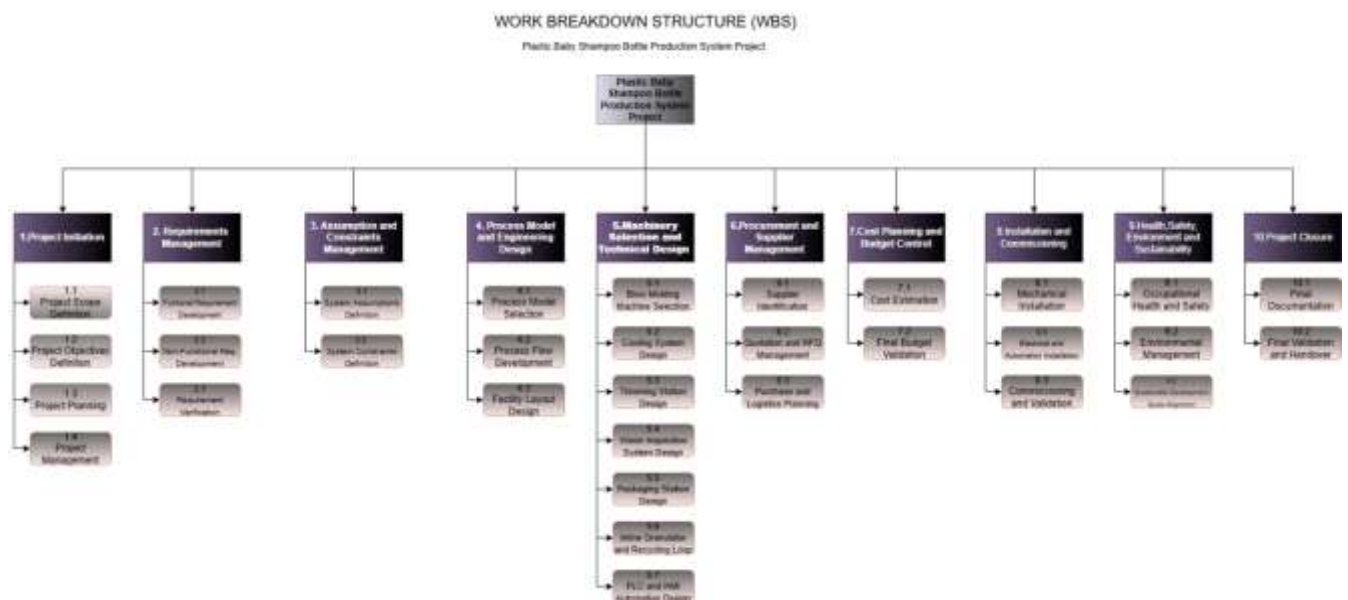
Component	Category	Role	UoM	Min Stock	Max Stock	Basis / Note
HDPE granules	Raw Material – Critical	Main feed material	t	2	8	Supports approximately 3–12 days of production
Colorant / masterbatch	Raw Material – Critical	Color pigment	kg	50	200	Around 0.5% of HDPE material weight

Component	Category	Role	UoM	Min Stock	Max Stock	Basis / Note
Compressed air pressure requirement	Utility – Critical	Blow air supply	bar	6	10	Required for blow molding operation
Chilled water	Utility – Critical	Mold cooling circuit	m ³ /h	2	6	Supplied by closed-loop chiller at 10°C ±2°C
Mold cavity set	Tooling – Critical	Bottle forming	sets	1	2	One active mold set and one spare mold set
Blow-pin / die head needles	Consumable – Critical	Parison formation	pcs	4	12	Spare parts for periodic replacement
Extruder screw and barrel liner	Spare Part – Critical	Plasticizing element	pcs	1	1	Kept for annual inspection or replacement need
Rotary trimming blades	Consumable – Critical	Flash removal	pcs	6	18	Supports regular blade replacement
Vision-system lamps / LEDs	Consumable – Critical	Inspection lighting	pcs	8	24	Spare lighting components for inspection system
Corrugated cartons	Packaging – Critical	Finished goods packaging	pcs	500	2000	Supports short-term shipment buffer
Hot-melt adhesive sticks	Packaging – Critical	Carton sealing	kg	20	80	Based on approximate shift consumption
Batch ID label rolls	Packaging – Critical	Traceability labels	rolls	5	20	One roll supports approximately 1000 labels
Granulator screen mesh	Consumable – Not Critical	Scrap granulator filter	pcs	2	6	Spare mesh for monthly inspection or replacement
Pneumatic conveyor hoses	Spare Part – Not Critical	Raw material conveying	m	10	30	Spare hose length for maintenance
PPE kits	Safety – Critical	Operator protection	kits	4	12	One kit per operator team with spare kits
Finished-goods pallets	Logistics – Not Critical	Warehouse stacking	pcs	20	60	Reusable pallets for storage and shipment

Table 4.1 Inventory Levels

5. Work Breakdown Structure and Cost Analysis

5.1 Work Breakdown Structure (WBS)



5.2 Cost Estimation and Budget Analysis

The Cost Breakdown Structure (CBS) converts the work packages defined in the WBS into estimated monetary values. All cost figures are presented in USD and are based on approximate 2025–2026 market rates.

The costs are grouped under major categories such as equipment, field construction, engineering and management, indirect costs and contingency. This structure helps show which parts of the system create the highest investment need and makes the proposed budget easier to evaluate.

The total estimated cost of the system is **USD 97,435** which is below the **USD 120,000** capital expenditure limit defined in the system constraints. This leaves an approximate budget margin of **USD 22,565** or about 18.8 % for possible exchange rate changes, supplier price differences, transportation costs or small scope adjustments.

CBS Group	Item / Specification	Supplier / Reference	Unit Price	Quantity	Subtotal (USD)
Major Equipment	Extrusion blow molding machine, 1 cavity, HDPE, 100–400 mL, 1,500 bottles/hour	Bekum / Plastiblow EU list, 2025	\$48,000	1	\$48,000
Major Equipment	Closed-loop chilled water unit, 5 kW, for mold cooling	Frigosystem catalog, 2025	\$6,500	1	\$6,500
Major Equipment	Rotary trimming station with 6 blade head	Colines EU price list	\$3,500	1	\$3,500
Major Equipment	Multi-camera vision inspection system, 4 cameras + LED ring	Cognex IS-2000 EU distributor	\$3,200	1	\$3,200
Major Equipment	Automated carton packaging station with hot melt sealer	Cermex EU catalog, 2025	\$5,800	1	\$5,800
Major Equipment	Inline HDPE scrap granulator, 50 kg/hour capacity	NGR Recycling EU list	\$7,500	1	\$7,500
Major Equipment	Pneumatic HDPE granule conveying system, 200 kg/hour	Piab EU price list, 2025	\$2,800	1	\$2,800
Major Equipment	Conveyor belt system, 4 × 3 m segments	FlexLink EU catalog	\$1,200	4	\$4,800
Major Equipment	Operator HMI panel, 15-inch touchscreen + PLC	Siemens distributor Türkiye, 2025	\$2,400	1	\$2,400
Field Construction	Floor epoxy coating and anchor bolt installation	Local contractor, Istanbul	\$1,800	1	\$1,800
Field Construction	Compressed air piping reroute to blow molding station	Local pipefitter rate card	\$950	1	\$950
Field Construction	Electrical switchboard and cable installation	Electrician labor, Türkiye 2025	\$1,400	1	\$1,400
Field Construction	Chiller water circuit piping, copper, 20 m	Plumber labor, Türkiye 2025	\$600	1	\$600
Field Construction	Mechanical fitter labor, 160 hours	Türkiye labor survey, 2025, \$9.5/hour	\$9.50	160 h	\$1,520
Engineering & Management	Detailed engineering and process design, 120 hours	EFCA rate, approximately \$33/hour	\$33	120 h	\$3,960

CBS Group	Item / Specification	Supplier / Reference	Unit Price	Quantity	Subtotal (USD)
Engineering & Management	Project management, 80 hours	PMI Türkiye rate, \$28/hour	\$28	80 h	\$2,240
Engineering & Management	TÜV-SÜD / SGS commissioning inspection	TÜV fee schedule, \$400/visit	\$400	3	\$1,200
Engineering & Management	Operator and maintenance training, 3 day session	OEM training service	\$1,800	1	\$1,800
Indirect	Sea freight, 1 × 20 ft container, Hamburg to Istanbul	Agora Freight quote, 2025	\$900	1	\$900
Indirect	Customs duty, 5% of CIF machinery value, HS 8477	Turkish Ministry of Trade tariff	5%	—	\$3,720
Indirect	Marine cargo insurance, 0.6% of EXW value	Allianz Cargo Guide, 2025	0.6%	—	\$564
Indirect	Scaffolding and safety nets hire, 3 weeks	İsıpan scaffold catalog	\$320	3	\$960
Indirect	EHS permits and industrial zone licenses	Istanbul municipality tariff	\$700	1	\$700
Indirect	Small tools and consumables, 2% of field cost	AACE RP 19R-97 guideline	2%	—	\$126
Contingency	Design-development contingency, 10% of direct cost	AACE Class IV guidance	10%	—	\$7,797
Contingency	Contractor overhead and profit, 8% of direct cost	ENR benchmark	8%	—	\$6,238

Contingency was added to cover supplier price fluctuations, exchange rate risk, transportation uncertainty and minor engineering revisions during commissioning.

Cost Summary

Cost Account	Subtotal (USD)	Percentage of Direct Cost
Major Equipment	\$62,000	74.3 %
Field Construction	\$6,270	7.5 %
Engineering & Management	\$9,200	11.0 %
Indirect Costs	\$5,930	7.1 %
Direct Cost Total	\$83,400	100 %
Contingency and Overhead	\$14,035	16.8% of Direct Cost
Final Project Cost	\$97,435	Final Total

6. Process Flow

6.1 Process Flow Diagram

Table 6.1 presents the process flow diagram for the plastic baby shampoo bottle manufacturing system. The main production flow starts with receiving HDPE raw material and continues through material feeding, heating and extrusion, blow molding, cooling, ejection, trimming, inspection, packaging and finished goods storage.

The diagram also includes two supporting sub processes. The first is the Rework Lane, where reworkable defective bottles are corrected and sent back for inspection. The second is the Closed-Loop Scrap Granulator which processes trimming flash and non-reworkable defective bottles into reusable HDPE granules and returns them to the raw material stream.

Step	Activity	Decision / Gate	Output / Next Step
1	Receive raw HDPE granules from supplier	Material quality inspection for color, contamination and moisture	Pass → Storage silo / Fail → Return to supplier
2	Transfer HDPE granules to machine hopper	Hopper level sensor checks whether fill level is above 25%	Pass → Step 3 / Low level → Auto-refill cycle
3	Heat and extrude HDPE material at 180–220°C	Barrel temperature control confirms $\pm 3^{\circ}\text{C}$ setpoint tolerance	Parison formed → Step 4

Step	Activity	Decision / Gate	Output / Next Step
4	Extrude parison and close mold with 6–10 bar blow air	Parison presence sensor confirms material in mold area	Confirmed → Mold closes / Not confirmed → Dry-cycle prevention
5	Perform blow molding and cooling within 30 seconds	Cycle timer and coolant temperature sensor confirm cooling conditions	Solidified bottle → Step 6
6	Eject bottle and transfer with take-out gripper	Gripper sensor confirms bottle removal	Bottle transferred to trimming conveyor → Step 7
7	Trim neck and base flash with at least 95% flash removal	Post trimming vision sensor checks residual flash	Trimmed bottle → Step 8 / Residual flash → Scrap granulator
8	Inspect bottle with multi camera vision system	Defect classification for cracks, deformation, incomplete blow, neck damage and leakage risk	Accepted → Step 9 / Reworkable → Rework lane / Non-reworkable → Scrap granulator
9	Package and label accepted bottles	Carton seal and label verification	Packed carton → Step 10
10	Transfer finished goods to storage	Inventory level checked against shipment schedule	Stock → Dispatch / Overstock → HMI alert
R	Rework station for reworkable defective bottles	Re-inspection by vision system	Pass → Step 9 / Fail → Scrap granulator
G	Inline scrap granulator for trimming flash and non-reworkable defects	Granule size check ≤ 6 mm	Reusable granules → Raw material hopper

Table 6.1 Process Flow Diagram

6.2 Flow Chart:

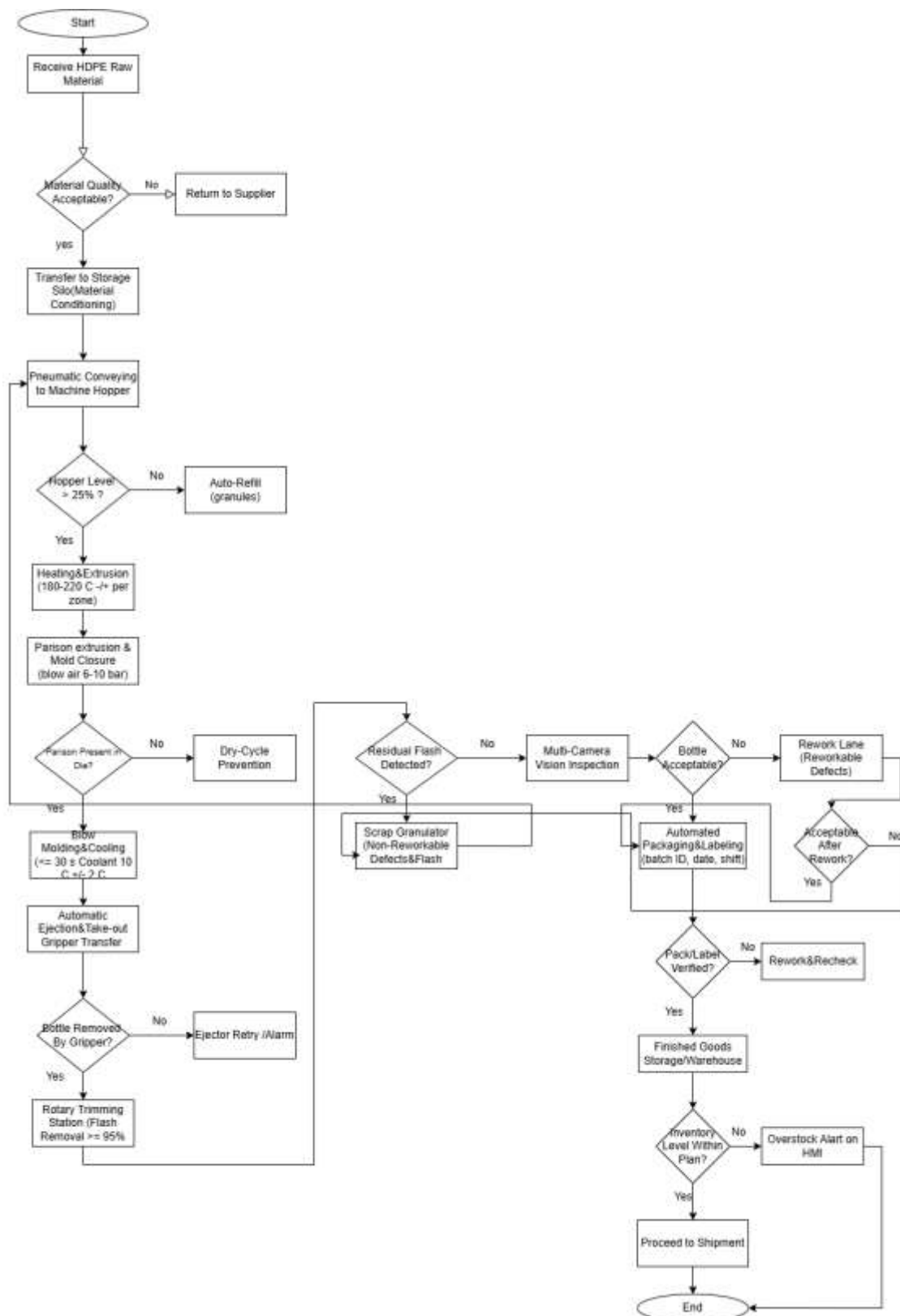


Figure 6.1 Process Flow Chart of the Plastic Baby Shampoo Bottle Manufacturing System

7. Impact on Health, Safety, Environment and Cost

7.1 Impact on Health and Safety

7.1.1 Reduction of Manual Scrap Handling Risks

The proposed system reduces manual handling of trimming flash and rejected bottles by using a dedicated scrap conveyor and inline granulator. In a manual system, operators would need to collect, carry and dispose of plastic scrap during the shift. These activities may create risks such as cuts, minor burns, repetitive bending and unnecessary physical strain.

By automating scrap collection and transfer, the system reduces direct operator contact with sharp or hot plastic waste. This improves workplace safety and decreases the possibility of scrap handling related injuries.

7.1.2 Emergency Stop and Safe Operation Control

Emergency stop devices are installed at all major production stations including the raw material feed area, blow molding machine, trimming station, vision inspection station, packaging station and inline granulator. When any emergency stop button is activated the system is designed to stop the entire production line within 3 seconds.

This prevents unsafe machine movement and reduces the possibility of secondary hazards during abnormal operating conditions. In addition, machine guards, sensor-based controls and safe working zones help prevent operator contact with moving machine parts during normal production.

7.1.3 Improved Ergonomics and Fatigue Reduction

The system reduces repetitive manual tasks such as scrap collection, bottle sorting and material transfer. As a result operators mainly focus on monitoring, adjustment, inspection follow up and basic maintenance activities.

This improves ergonomics by reducing bending, lifting and repetitive handling movements during the shift. Lower physical workload also helps reduce operator fatigue and supports safer more stable production.

7.1.4 Temperature and Noise Control

The system is designed so that machine surfaces accessible to operators remain below 45°C during normal operation. Hot areas such as barrel heating zones are guarded and marked with warning signs to prevent accidental contact.

Noise sources such as the granulator, conveyors and pneumatic conveying system are considered in the safety design. If workplace noise levels exceed safe limits, hearing protection zones and proper warning signs should be used. Therefore the system supports safer working conditions by controlling both heat exposure and noise related risks.

7.2 Impact on Environment

7.2.1 Closed-Loop HDPE Recycling

The system includes an inline granulator and pneumatic scrap return line that creates a closed-loop recycling process. All recoverable HDPE production waste, including trimming flash and non-reworkable defective bottles, is collected, granulated and returned to the main raw material feed during the same production shift.

Under normal operating conditions, the system targets a material waste rate below 5% of total raw material consumption. At a nominal production rate of 1,500 bottles per hour and an average bottle weight of approximately 40 g this allows the recovery of a significant amount of plastic waste that would otherwise require external disposal or landfill handling.

This reduces waste generation inside the facility and supports more sustainable material usage.

7.2.2 Energy Efficiency and Emission Reduction

Reusing HDPE scrap through inline granulation reduces the need for virgin raw material consumption. Producing recycled HDPE granules requires less energy compared to manufacturing new virgin HDPE from primary petrochemical sources.

As a result the system reduces overall embodied energy consumption and helps lower carbon emissions associated with raw material production and transportation. In addition, on-site recycling eliminates external scrap transportation, which further reduces fuel usage and environmental impact.

This directly supports sustainable production principles and improves resource efficiency.

7.2.3 Waste Minimization and Sustainable Production

The target material waste level is maintained below 5% of total raw material consumption per shift as defined in the non-functional requirements. Since recoverable HDPE waste is reprocessed internally, landfill waste from normal plastic production operations is minimized.

Only non-recyclable waste such as packaging waste, worn machine consumables and maintenance materials require external disposal. These waste streams are managed through standard industrial waste collection procedures.

This approach supports cleaner production and aligns with SDG 12 (Responsible Consumption and Production).

7.3 Impact on Cost

7.3.1 Initial Investment and Cost Recovery

The addition of the inline granulator, scrap conveyor and return line increases the initial capital investment of the system compared to a standard production line without recycling capability.

However, this investment creates long-term financial benefits by reducing virgin HDPE purchases, lowering scrap disposal costs and minimizing manual labor requirements for waste handling. Since recovered HDPE is directly reused in production, raw material purchasing costs decrease over time.

Therefore, the additional investment can be recovered within a relatively short operational period while improving sustainability performance.

7.3.2 Reduction in Operating Costs

Automation of trimming, inspection, packaging support and scrap handling reduces non value added manual work during production. Operators spend less time on repetitive physical tasks and more time on monitoring, preventive maintenance and quality control activities.

This improves labor efficiency and reduces hidden operational costs such as downtime caused by manual handling delays, injury-related interruptions and unnecessary process stoppages.

In addition, preventive maintenance supported by PLC monitoring helps reduce unexpected machine failures and associated repair costs.

7.3.3 Productivity and Throughput Improvement

The continuous flow production model, combined with automated inter-stage transfer and centralized PLC control, improves production stability and reduces unplanned downtime.

Compared to semi-manual production systems, the target Overall Equipment Effectiveness (OEE) of at least 80% represents a significant productivity improvement. Higher availability and faster defect handling increase the number of accepted bottles produced per shift.

This improves production throughput, increases operational efficiency and creates additional economic value without requiring major labor expansion.

8. Related Sustainable Development Principles

8.1 SDG 12 – Responsible Consumption and Production

The closed-loop inline granulator system directly supports **SDG 12: Responsible Consumption and Production** by reducing plastic waste and improving material reuse within the production facility.

Recoverable HDPE production waste, including trimming flash and non-reworkable defective bottles, is collected, granulated and returned to the raw material stream during the same production shift. This reduces the need for virgin HDPE material and supports a more circular production approach.

The system also targets a material waste rate below 5% of total raw material consumption, which is consistent with the aim of reducing waste through prevention, recycling and reuse.

8.2 SDG 8 – Decent Work and Economic Growth

The system supports **SDG 8: Decent Work and Economic Growth** by improving operator working conditions and reducing hazardous manual tasks.

Manual scrap collection, bottle sorting and repetitive material handling activities are reduced through automation. As a result, operators are exposed to fewer risks related to cuts, burns, repetitive bending and physical fatigue.

The system also shifts operator responsibilities from manual handling to monitoring, quality control, maintenance support and process supervision. This improves workplace safety while supporting higher productivity and more skilled work.

8.3 SDG 9 – Industry, Innovation and Infrastructure

The project supports **SDG 9: Industry, Innovation and Infrastructure** by integrating automation, inspection technology and closed-loop recycling into a small to medium scale plastic manufacturing system.

The use of PLC control, HMI monitoring, multi-camera vision inspection and inline scrap recycling improves process reliability, traceability and production efficiency. These technologies make the system more modern, data driven and scalable.

The modular layout also allows future improvements such as adding another blow molding machine, increasing mold capacity or adapting the system to similar bottle types with limited layout changes.

8.4 SDG 3 – Good Health and Well-Being

The system also relates to **SDG 3: Good Health and Well Being** because it reduces occupational health risks in the production environment.

Accessible machine surfaces are kept below 45°C, emergency stop buttons are located at major stations and scrap handling is automated through conveyors and the inline granulator. These design choices help reduce burn risks, laceration risks and repetitive handling injuries.

Noise and ventilation requirements are also considered in the system design. If noise levels exceed safe limits, hearing protection and warning zones are applied. Therefore the system contributes to a safer and healthier working environment for operators.

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