

Politecnico di Torino

Politecnico di Torino

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Defect Solution For Plastic Injection Molding In Light Guide (Air Bubble / Fountain Effect)

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Company

Valeo

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Preface

The following thesis was presented and performed based on an on-site activity in a production environment, to fulfill the requirements for the Master Degree program "Engineering and Management" at Politecnico di Torino. The review was done under the Management and Production Engineering department.

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The analysis, investigation and implementation was performed under the supervision of Professor Domenico Augusto Francesco Maisano



Angel Correa

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Acronyms

LED - Light-Emitting Diode

OEM - Original Equipment Manufacturer

PDCA - Plan - Do - Check - Act

QR - Quick Response

4M - Man, Method, Machine, Material

FTA - Factor Tree Analysis

DOE - Design Of Experiments

PPM - Parts Per Million

CPK - Process Capability Index

R&D - Research And Development

OES - Original Equipment Spare Parts

IAM - Independent Aftermarket

AI - Artificial Intelligence

HMI - Human Machine Interface

DMS - Driving Monitoring System

EV - Electric Vehicle

DC - Direct Current

HVAC - Heating, Ventilation and Air Conditioning

ADAS - Advanced Driving Assistance Systems

PET - Polyethylene Terephthalate

IATF - International Automotive Task Force

VDA - Verband der Automobilindustrie

APQP - Advanced Product Quality Planning

PPAP - Production Part Approval Process

OLED - Organic Light-Emitting Diode

AOI - Automatic Optical Inspection

PVD - Physical Vapor Deposition

KPI - Key Performance Indicators

TMUK - Toyota Motors United Kingdom

PMMA - Polymethyl Methacrylate

JIT - Just In Time

VIN - Vehicle Identification Number

ECU - Electric Control Units

SQA - Supplier Quality Assurance

PC - Polycarbonate

UV - Ultraviolet

PP - Polypropylene

PBT - Polybutylene Terephthalate

PVD - Physical Vapor Deposition

DRL - Daytime Running Lights

PCB - Printed Circuit Board

SQE - Supplier Quality Engineer

PG - Product Group

QRQC - Quick Response Quality Control

8D - 8 Disciplines

5W2H - What, Why, Who, When, Where, How, How Many

MSA - Measurement System Analysis

SPC - Statistic Process Control

R&R - Reproducibility and Repeatability

CIE - International Commission on Illumination

CMM - Coordinate Measurement Machine

ISO - International Organization for Standardization

PPE - Personal Protective Equipment

LLC - Lessons Learned Card

Chapter 1

Introduction

Manufacturing quality has a pivotal role and a critical importance in today's highly competitive marketplace. It shapes how reliable a product is, the indicator of satisfaction of the end users, and whether a company can keep going strong over time ensuring a long term business viability. When quality decreases, it leads to expensive recalls, brand reputation damage, and even safety problems that have a direct impact on the trust from customers. Quality standards are no longer an option in such a driven industry, and they have become essential for differentiation.

This is especially true in the automotive industry. Vehicles are growing increasingly with more complex technology than ever, from advanced electronics, sensors and integrated systems, minor quality defects have the potential to create significant safety and functional problems for the end user. Headlamps, in specific, are a good example as they serve a critical safety component, illuminating the road, signaling intentions to other drivers, and incorporating technologies like LED matrices and automatic control. Should some quality failure occur during the headlamp production, like inconsistencies in the materials, assembly errors, or design tolerances, it can lead to reduced visibility, premature failures or regulatory non compliances, directly affecting the vehicle performance and the end user safety.

The supply chain plays a strategic role that goes more in depth than logistics. Automotive supply chains include multiple tiers of suppliers spread across different countries where raw materials, components, and sub assemblies must meet exacting consistent quality standards under tight timelines and schedules. Effective supply chain management ensures traceability, quality consistency, and rapid response to deviations. However, it also introduces vulnerabilities like

delays, variants, or inadequate communication decisions in supplier processes potentially increase quality risks in the downstream process. In an era of just in time production and global sourcing, the supply chain has evolved into a key competitive advantage, where collaboration, risk mitigation, and continuous improvement determine whether a manufacturer can deliver vehicles that consistently meet both customer expectations and strict international standards.

This thesis looks at a particular quality problem that came up during headlamp production. It digs into what caused it in the factory and across the supply chain, then draws out wider lessons for handling quality in complex car parts. The goal is to suggest practical ways to build stronger processes and avoid similar issues in the future.

The activities performed during this thesis project were focused on the performance of Valeo (Lighting Division) quality management process in addressing a critical defect in automotive headlamp production; consequently, this investigation proposes further optimizations to improve process reliability and prevent quality issue recurrence.

The study focuses on a real quality issue (on-site) detected at Toyota UK (OEM) assembly line. Defect refers to bright light spots caused by light leakage due to air bubbles (fountain effect) on the light guide for project 160B - LOW Headlamp. This defect originated from the Tier 2 supplier's plastic injection molding process (Supplier located in Veneto, Italy) and was escalated to Valeo (Tier 1 supplier, Chrzanow, Poland)

The primary objective is to conduct a comprehensive quality assessment of the applied troubleshooting and improvement approach, following Valeo standards PDCA (Plan-Do-Check-Act), through a structured case study methodology, including QR (Quick Response), containment and root cause analysis via 4M (Man, Machine, Method, Material) factors, FTA (Factor Tree Analysis), 5-Why questioning, parameter matrix prioritization, defect reproduction, on-site validation, DOE (design of experiments) on injection parameters, and permanent corrective / systemic actions.

The research evaluates the effectiveness in containing the problem, eliminating occurrence and non-detection risks, and achieving sustained defect reduction.

Furthermore, the thesis explores optimization strategies to strengthen future defect prevention in plastic injection molding for light guides. This includes refining process parameter controls, enhancing supplier quality walls and detection mechanisms, standardizing LLC (lessons learned) deployment, to improve overall quality efficiency, reduce PPM levels, and ensure CPK capability targets are met.

The findings contribute to both academic understanding of quality management in automotive Tier 1 and Tier 2 supply chains and practical implementation at Valeo by highlighting the strengths and limitations of the PDCA approach in a customer (Toyota) context, as well as providing actionable recommendations for systemic improvements, this research aims to support continuous quality enhancement, cost reduction, and zero-defect goals in automotive lighting manufacturing and beyond.

The thesis contains seven fundamental chapters, the second discusses the context of Valeo, the Tier 1 company, their foundation, global presence, organization and key figures. The third chapter of the thesis focuses on the theoretical foundation of plastic injection molding, the different defects and how the supply chain interacts for the thesis problem application. The fourth chapter discusses the methodology for all quality tools used and implemented during this thesis work. Fifth chapter defines the Toyota 160B lightguide and the pertinent characteristics and requirements, as well as the problem definition of the quality incident. The sixth chapter contains all the full analysis done for the resolution of the quality problem, utilizing quality tools, statistics and lean management techniques. Afterwards, chapter seven contains the conclusion of the incident closure and evaluation methods for continuous monitoring to arrive at the conclusion and takeaways in the last chapter.

Chapter 2

Company and Supply Chain Context

2.1 Valeo Group

Valeo is in automotive and mobility technology, a global leader. Their foundation's roots go back to 1923 in France, in a small laboratory in the city of Saint-Ouen, close to Paris, initially named as Société Anonyme Française du Ferodo. From their beginnings as a small workshop producing friction materials, the company has evolved into a multinational entity with over 100,216 employees, €20.9 million in sales, a presence in 29 countries, 149 plant sites, 59 R&D centers and 19 distribution platforms, as of 2025 figures (see Fig. 2.1)

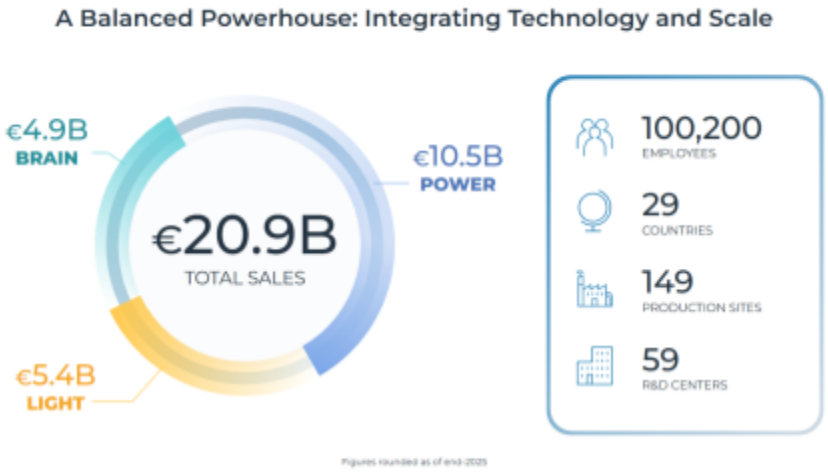


Figure 2.1: Valeo Key Figures 2025

2.1.1 Foundation

Valeo originated as the Société Anonyme Française du Ferodo (SAFF) in 1923, founded by Eugène Buisson in a workshop in the Paris region. It specialized in producing France's first friction materials for brake linings and clutches, capitalizing on the early 20th-century automotive revolution. By the end of World War II, SAFF had become a market leader in automotive braking and clutching. During the post war, the workforce grew to 2,500 employees, setting an opportunity for expansion.

2.1.2 International Expansion

During the post war economic boom, SAFF diversified their market; including sectors as electrical equipment, including plugs, alternators, starters, ignition, lighting, and wiper systems. This strategy grew with a rapid expansion.

With a monopolistic position in France's brake and clutch market, the company pursued international ventures starting in the 1960s, acquiring brands like Marchal and Cibié (famous in South America for headlamps). Brands under Valeo, such as Marchal and Cibié, supported motorsport, equipping winners at the 24 Hours of Le Mans. This era marked the shift from local supplier to a global competitor.

2.1.3 Unification

In 1980, SAFF rebranded as Valeo (Latin for "I am well"), uniting brands like Ferodo, Cibié, Marchal, and others under one single organization. During this period, Valeo was operating in 15 countries through over 70 sites and expanded into Spain and Asia. This globalization solidified its leadership in the already evolving automotive market.

2.1.4 Global Footprint

Valeo maintains a balanced global presence across all major automotive hubs, with its largest operations centered in Europe. As of the end of 2023, Europe accounts for 50% of total sales, supported by over 48,400 employees, 63 production sites, and 28 R&D centers. Asia (including China) follows with 29% of sales, boasting 59 production sites and 22 R&D centers,

while the Americas contribute 21% of sales through 27 production sites and 7 R&D centers (see Fig 2.2)

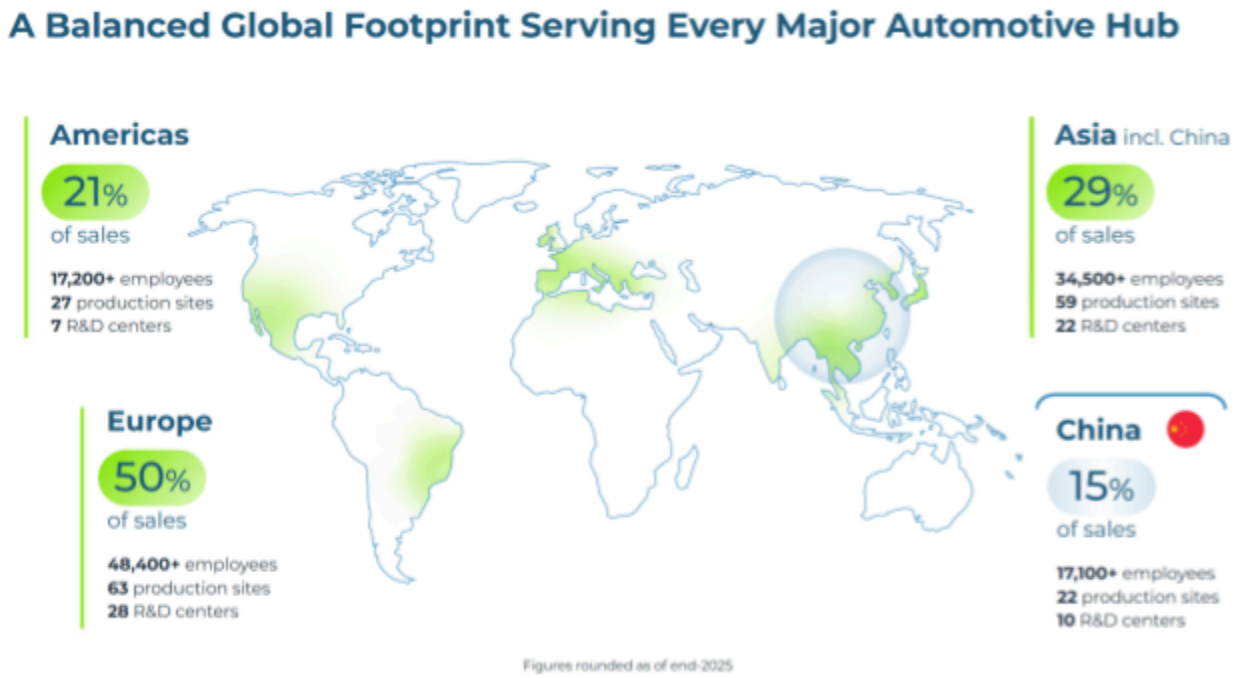


Figure 2.2: Valeo Global Presence

2.2 Valeo Divisions

Valeo is structured around three core divisions; Brain, Power, and Light, focused on technologies for electrification, software, autonomous driving, safety, and sustainable mobility. These divisions manage global growth, operating performance, product groups, and product lines, with Valeo maintaining strong market positions and a growing presence in different regions across the world.

The company also operates a separate Aftermarket activity through Valeo Service, which functions as a key fourth pillar, but not formally classified as one of the three core Divisions (see Fig. 2.3). It supplies original equipment manufacturer (OEM) spares to dealer networks and high quality replacement parts to the independent aftermarket worldwide, supporting vehicle maintenance, repair, and sustainability initiatives.



Figure 2.3: Valeo Divisions

2.2.1 Valeo Divisions: Brain

The Valeo Brain division acts as the main intelligence for the software center vehicle, integrating sensors, powerful computing units, and sophisticated software to enable advanced driver assistance systems. As a global leader in perception technology, this division produces ultrasonic sensors and cameras that allow the vehicle to visualize and interpret its surroundings with high precision. These components are linked to high performance controllers that process data in real-time to manage everything from automated parking to highway pilot functions. Beyond safety, the division focuses on the interior user experience, developing interfaces that adapt to passenger needs through software updates.

2.2.2 Valeo Divisions: Power

The Valeo Power Division focuses on electrification and electric mobility acceleration, merging thermal management systems and powertrain systems into a single structure (established in 2024). Power Division delivers technologies that improve vehicle range, performance,

comfort, efficiency, and CO2 reduction through electric motors, thermal solutions, high voltage systems, and full electrification, as well as supporting the transition to electrified vehicles with a competitive global footprint and strong growth potential.

2.2.3 Valeo Divisions: Light

The Valeo Lighting Division specializes in technologies to ensure optimal vehicle visibility for drivers and road users in different conditions such as day/night time and different weathers. It also designs and manufactures advanced lighting systems, wiper systems, sensor cleaning, and related products.

Lighting division emphasizes safety and performance, using software platforms that enable communication such as signaling to pedestrians, vehicles, and sensor reliability.

2.2.4 Valeo Divisions: Aftermarket (Valeo Service)

Valeo service operates as its dedicated aftermarket specialty, separated from the three core divisions but integrated to the group's system.

This division supplies original equipment spare parts to automaker dealer networks (OES) and a wide range of replacement parts and accessories to the independent aftermarket (IAM) for passenger cars, commercial vehicles, and other applications.

Aftermarket activity covers product categories like air conditioning, clutches, wiper systems, lighting, braking, engine management, filters, electrical accessories, and more.

This structure (three divisions + aftermarket as a distinct activity) has been consistent since the 2024 reorganization, with financial reporting segmented around Brain, Power, and Light. It positions Valeo to capitalize on major trends like electrification, software defined vehicles, and safer and sustainable mobility.

2.3 Products

Valeo is a pioneering force in 4 main domains: electrification, driving assistance, lighting and onboard life.

2.3.1 Driving Assistance Systems (Comfort & Driving Assistance)

Valeo's Driving Assistance Systems domain develops the sensors and software that function as the vehicle's brain and senses. It integrates ultrasonic sensors, radars to deliver real

time environmental perception. The domain also addresses the interior experience through AI based cabin monitoring that tracks driver alertness and enhances the Human-Machine Interface (HMI). These technologies enable a wide range of functions, from emergency braking to fully automated valet parking. The main objective is to advance toward zero accidents by combining hardware and software solutions for safer and more intuitive mobility.

Advanced Driver Assistance Systems (ADAS)

These technologies are designed to monitor the vehicle's environment to prevent accidents and assist in driving tasks, using detection of obstacles and map the environment in 3D for autonomous functions, also providing 360° visibility to help the driver see blind spots and stay in lanes, as well as automating steering and braking to guide the car into tight parking spaces.

- **Sensors**
  - SCALA LiDAR (Gen 1, 2, and 3)
  - Ultrasonic sensors (see Fig 2.4)
  - Radar (Short and Long range).



Figure 2.4: Ultrasonic Sensors

- **Vision Systems**
  - Front cameras
  - Surround view 360° (see Fig 2.5)
  - Rear view cameras

- **Parking Systems**
  - Park4U (Automated parking)
  - Automated valet parking



Figure 2.5: Surround view (360°)

Interior Experience

This technology focuses on the interface between the vehicle and its occupants to improve comfort and safety, enabling the driver to control vehicle features through intuitive touch, voice, or gesture, and also detects driver fatigue or distraction and ensures no children or pets are left behind.

- **HMI (Human Machine Interface)**
  - Smart surfaces
  - Head-up displays (HUD)
  - Steering wheel switches
- **Interior Monitoring**
  - Driver Monitoring Systems (see Fig 2,6)
  - Life presence detection (see Fig 2.7)



Figure 2.6: Driver Monitoring System (DMS)



Figure 2.7: Life Presence Detection

2.3.2 Powertrain Systems

The products concerned Powetrain Systems correspond to complete electrical systems for vehicles, including electric motors, inverters, and on board chargers for high voltage battery electric vehicles. Valeo also leads in cost effective 48V hybrid systems used both for conventional engine hybridization and small mobility solutions such as ebikes and urban quads. In addition, the domain optimizes transmission and air management systems to maximize energy efficiency. This ensures minimal energy waste whether the power source is a battery or traditional fuel.

Electrification

Products concerning this technology provide the electrical power needed to move the vehicle, ranging from mild hybrids to full EV. They act as the primary power source for high performance electric propulsion providing a cost effective way to hybridize traditional engines for better fuel economy.

- **High Voltage (EV/PHEV)**
  - eAxle (Integrated motor/inverter/gearbox)
  - Inverters
  - On-board chargers
  - DC/DC converters
- **48V Systems (Mild Hybrid)**
  - 48V eMotor (see Fig. 2.8)
  - 48V Belt Starter Generator (iBSG)
  - 48V eBike systems
  -



Figure 2.8: 48V eMotor

Transmission & Clean Engines

These components optimize the mechanical transfer of power and air intake efficiency. They manage gear shifts and torque delivery to the wheels smoothly as well as improving engine performance and reducing emissions by optimizing airflow. Starters and alternators provide reliable engine ignition and generate electrical power for the vehicle's electronics.

- **Transmission**
  - Dual Wet Clutch (DWC)
  - Torque Converters
  - Dual Dry Clutch (see Fig 2.9)
- **Air Management**
  - Electric Superchargers
  - Water cooled charge air coolers



Figure 2.9: Dual Dry Clutch

- **Starters and Alternators**
  - i-StARS (Starter-Alternator)
  - Reinforces starters

2.3.3 Thermal Systems

Valeo's Thermal Systems products manage heat exchange throughout the vehicle, a critical element in the electric vehicle transition. They provide battery thermal management solutions that maintain optimal temperatures, supporting fast charging, safety, and extended driving range. The domain also develops high efficiency heat pumps and HVAC systems that minimize battery consumption while ensuring cabin comfort. Furthermore, advanced air filtration and purification technologies protect passengers from pollutants, allergens, and viruses. These products improve both vehicle performance and interior air quality.

Climate Control

These components are dedicated to regulating the environment inside the vehicle cabin maintaining the desired temperature and humidity for passengers regardless of outside weather. Other applications include the filters for pollutants, viruses, and allergens to provide clean air to end users.

- **Cabin Comfort**
  - HVAC modules
  - Electric Compressors (see Fig 2.10)
  - Fragrance diffusers



Figure 2.10: Electric Compressor

- **Air Quality**
  - Cabin air filters (PM2.5/Anti-allergen)
  - Air purifiers

Thermal Management (Battery and Motor)

Components concerning this technology regulate the temperature of the battery, electric motor, and electronics. They prevent battery overheating during fast charging and driving to extend battery life, eradicating heat from internal combustion engines to prevent mechanical failure.

- **Electric Vehicle Cooling**
  - Battery cooling plates
  - Chiller Units
  - Heat Pump systems (see Fig. 2.11)
- **Engine Cooling**
  - Radiators
  - Fan systems
  - Condensers

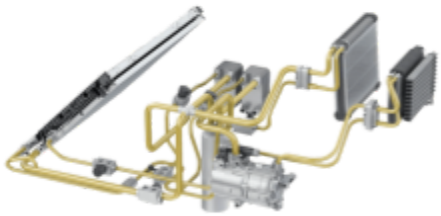


Figure 2.11: Heat Pump System

2.3.4 Visibility Systems

The Visibility Systems products are based on the principle of “seeing and being seen” in all conditions. It includes advanced lighting technologies such as adaptive Matrix LED headlamps that project symbols and selectively mask high beams, along with kinetic rear lights for communication with other road users. The domain also encompasses intelligent wiper systems, notably the AquaBlade, which distributes washer fluid directly along the blade to maintain clear visibility for the driver and ADAS sensors. These solutions enhance safety and aerodynamic efficiency.

Lighting Systems

Advanced exterior and interior light solutions for safety and communication. Front lighting illuminates the road with adaptive beams that don't blind oncoming traffic as rear lighting signals the driver's intentions (braking/turning) to other road users using high definition light. Other applications from lighting technologies include interior lighting creating a personalized cabin atmosphere and providing functional light for passengers.

- **Front Lighting**
  - Matrix LED headlamps
  - Adaptive Front-lighting Systems (AFS)
  - Laser high beams
- **Rear Lighting**
  - OLED rear lamps
  - 3D effect lighting
  - Kinetic rear lamps (communication via light)
- **Interior Lighting**
  - Ambient lighting (see Fig. 2.12)
  - Projection lighting

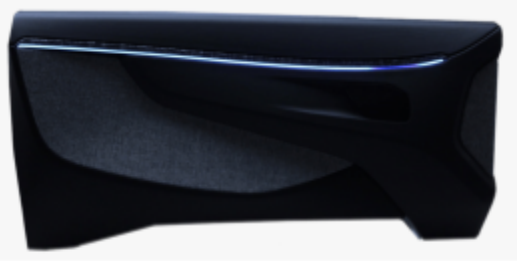


Figure 2.12: Ambient Lighting

Wiper Systems

Products including these technologies are mechanical and fluid systems designed to keep the windshield and sensors clear. Wiper blades remove rain, snow, and debris from the windshield for a clear line of sight as for wiper hardware, providing the mechanical power and cleaning fluid distribution to the glass and camera lenses.

- **Wiper Blades**
  - AquaBlade (see Fig. 2.13)
  - Silencio
  - Everguard (Silicone)
- **Wiper Hardware**
  - Wiper motors (front/rear)
  - Washer pumps
  - Reservoirs



Figure 2.13: AquaBlade (Integrated Fluid Distribution)

Chapter 3

Background Context and Supply Chain Framework

3.1 Plastic Injection Molding (Global Background)

Critical for automotive manufacturing, plastic injection molding, has allowed since its adoption, the optimization of production of lightweight, complex and cost effective plastic components. The current competitive market has faced different challenges and pressure to produce lighter, to meet emission standards, and to keep innovative designs with a competitive cost. Plastic injection molding is a convincing alternative by forcing molten polymers into precision molds under high pressure, allowing the achievement of these characteristics, rather than other injection technologies like die casting, which as a metal fabrication, results in heavier, production time consuming and high cost impact, especially for complex shapes.

According to Grand View Research (GVW, 2026) reports, the global injection molded plastic market was valued at USD 362.5 billion in 2025 (see Fig 3.1) with a projection to reach USD 481.42 billion by 2033. The automotive industry represents approximately one fifth of the market size. This is the reflection of a deep integration of this technology in the automotive volumes, due to the demand at high scale, which is expected to grow due to the new emphasis in OEM of substitution of metal parts due to a sustainable adaptation for new standards and goals, with a special focus on fuel economy and the increasingly production demand in the market of electric vehicles, which represent a high growth factor for the use of this technology abilities in sectors that are in need for lightweight components. This represents an important area of opportunity for plastic injection molding, which will continue playing a pivotal role during the next years at the automotive level

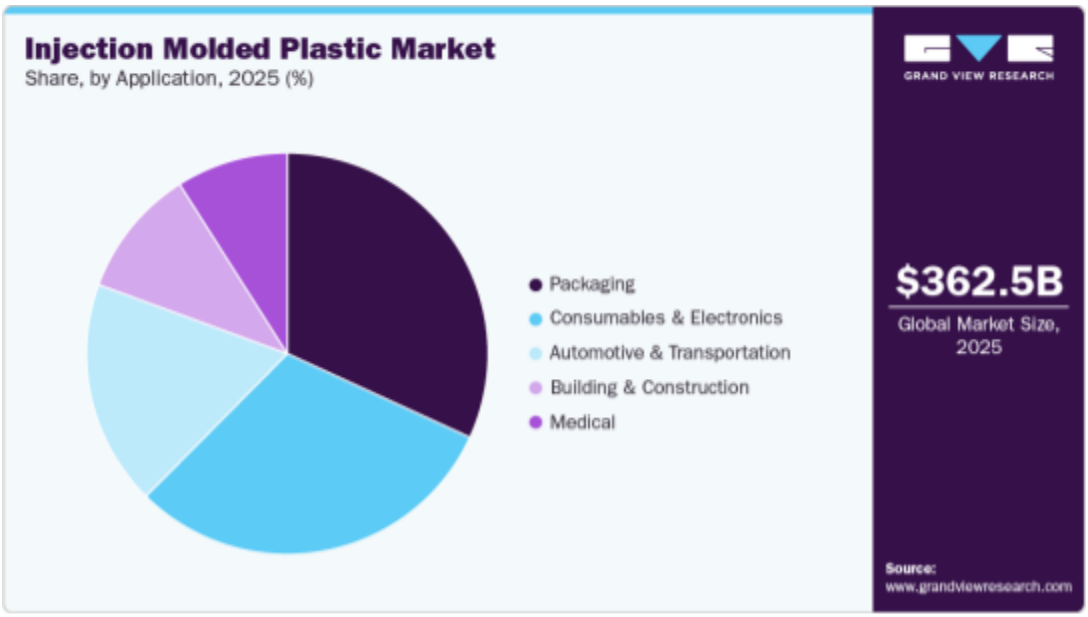


Figure 3.1: Global Injection Plastic Market 2025

Scalability is key in the economic optimization of injection molding, due to being one of the few processes that can be cost effective in terms of matching a profitable scenario in high volume production. The initial mold tooling usually requires a significant investment, therefore as Golebski & Stoic (2023) explain, an initial stage to map the desired plastic injected part, understanding the shape of every single component with a virtual simulation approach, is critical in the mold design phase to optimize the cost. Additionally in the case of a high volume production, the investment can be amortized in the part unit cost, dropping it by around 30% to 40% compared to technologies like machining and metal stamping. As different with other technologies, plastic injection molding, represents a higher flexibility and efficiency in terms of cycle times, measured in running seconds and not in minutes, assisting in the thousands of vehicle daily production lines, and also in cost savings due to repeatability factor, rather than a custom production, effecting in the automotive supply chain economic output.

The flexibility that plastic injection molding provides is one of the strongest benefits due to the ability to adapt it to complex shapes, different geometries and multi material injected parts, with overmolding technologies. The process allows R&D engineers to create elaborated parts in a single cycle, by incorporating during a design phase, different additions in the drawing as, thin walls for efficiency in material saving and part weight, ribs to support material stabilization and avoid bendings or breakage of the part (see Fig 3.2), thick sections to increase rigidity or undercuts to allow a safer ejection of the part out of the mold, avoiding additional assembly steps. As different to other technologies, tight tolerances are more feasible in plastic injection molding for the characteristic repeatability of this process, also having a positive effect in the internal waste of material, due to the precise similarity to the shape design.



Figure 3.2: Reinforcement Ribs On Injection Moulded Part

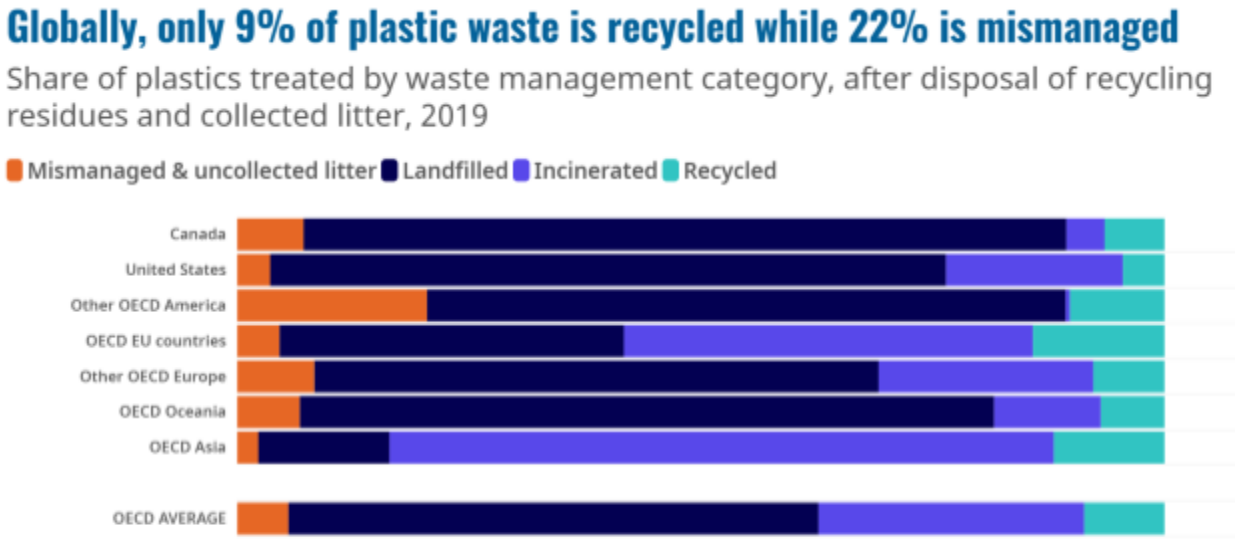


Figure 3.3: Global Treatment of Plastic (2019)

Weight reduction in plastic parts has a direct impact on performance and sustainability. One of the main benefits of achieving this is the decrease of plastic waste. According to the Organisation for Economic Co-operation and Development (OECD 2022), production of plastic around the world reached 400 million tons in 2019 with only 9% recycled and a large portion of the rest, has been incinerated or disposed of (see Fig. 3.3). Reducing weight indicates a result in better fuel efficiency, acceleration, driving range, and low energy consumption.

The decrease of weight in parts in plastic injection molding is achievable by different methods and techniques such as the one described previously, the feasible adaptation of the part design by the addition of extra characteristics such as ribs, to produce an efficient structure of the component in the areas that the injection of the material is only needed. Maintaining the performance with plastic injection technology is more practical due to the possibility of advanced simulation tools that aids the designers to optimize the part shape before running a production.

As Amran et al., (2016) contribute, another technique that allows to develop and control the decrease of weight in the plastic injection molding, refers to the definition of an injection optimum parameter combination, being usually the most critical with a direct impact on part weight, mould temperature, melt temperature, injection time and cooling time, which with the

help of simulation tools and on field experimental activities, a significant weight loss can be achieved, additionally of the maintenance of the original part shape, without the necessity of creating a deformation in it, or to go out of the design stipulated tolerances, allowing to keep the expected performance of the end product.

Material versatility has an important role in plastic injection molding, having an effect in the precision of part production. This factor has been crucial to mitigate risks on durability, heat resistance, weight reduction, among other ones. The automotive market has a wide variety of plastic components, increasing constantly, and every of them have different specifications and functionalities that allow the engineering of the design with the suitable type of resin.

3.2 Plastic Injection Molding (The Process)

The plastic injection process starts from molten plastic material which is injected under high pressure into a mold cavity, where it cools and solidifies to form the desired part geometry. This advanced manufacturing technique is essential for mass producing identical plastic components. The process is a transformation of thermoplastic polymers from a solid granular state into a viscous melt, which is then forced into a temperature controlled mold. The process is defined by its ability to replicate complex geometries with high precision, making it crucial and important in automotive component manufacturing where both structural integrity and aesthetic finish are performed. The cycle is a sequence of mechanical and thermal processes impacting the physical properties of the final product. The material, in the form of granules or pellets, is fed into a heated barrel, homogenized by a rotating screw through a combination of friction and compression, and then forced into the mold. Upon cooling, the part hardens to the precise configuration of the cavity before ejection.

A typical injection molding machine comprises three primary units (see Fig 3.4), the injection unit, the mold, and the clamping unit. The injection unit is composed of a hydraulic screw drive, the material hopper, the screw, and the barrel with its respective heater bands to keep the temperature of the material while injected. As for the mold, the unit is composed by the cavity, which gives the form of the final piece, as well as a fixed platen and a moving platen to support the clamping and release of the part. Finally, the clamping unit consists of a rear platen during the ejection phase.

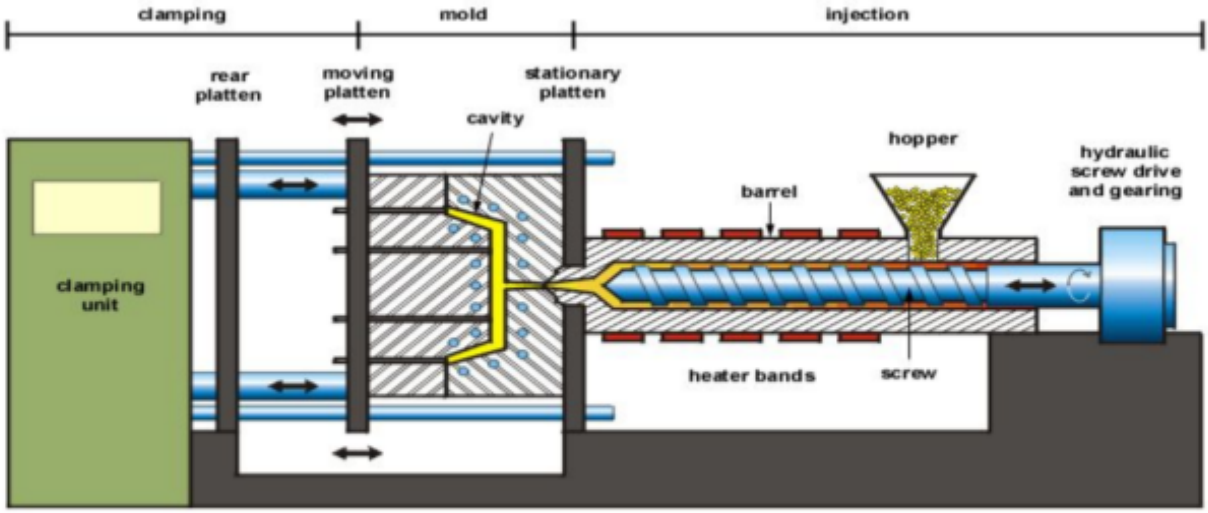


Figure 3.4: Injection Moulding Machine Scheme

3.2.1 Injection unit

The injection unit (see Fig 3.5) is the main system for material preparation and high pressure feeding within the molding process. It starts at the hopper, where plastic pellets drop into a cooled feed throat to prevent clogging before entering the barrel. Inside, a reciprocating screw rotates to move material forward, utilizing a varying depth to compress and melt the plastic. This mechanical move provides the majority of the thermal energy, while external heater bands maintain the specific melt temperature. As the screw rotates, it moves backward to create a shot of molten plastic. Once the shot is ready, the screw is driven forward linearly, acting like a piston to force material into the mold. A valve at the screw tip prevents backflow, ensuring that the full injection pressure is directed toward the cavity. The molten plastic passes through the nozzle, which must be perfectly aligned with the mold's sprue to prevent leakage. Some sensors and controllers monitor the screw's position and velocity to maintain consistent part weight and density. Ultimately, this unit's ability to homogenize the melt and control flow is what determines the structural integrity of the final part.

The injection unit is responsible for receiving, melting, homogenizing, and injecting the thermoplastic material into the mold. It includes the hopper, barrel with heater bands, reciprocating screw, and the hydraulic screw drive with gearing. This unit operates in a reciprocating manner, rotating to plasticate material and then advancing linearly to inject

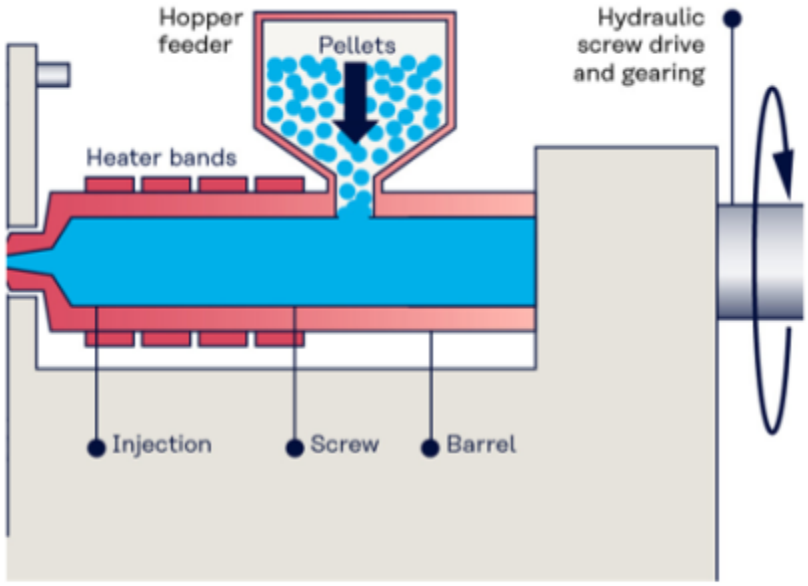


Figure 3.5: Injection Unit

- **Hopper**

The hopper is the container at the top of the injection unit where raw polymer pellets or granules are loaded. It feeds material by gravity into the feed throat of the barrel. Many hoppers include dryers (especially for absorbent materials like nylon or PET) or loaders for automated material handling. Proper hopper design prevents inconsistent feed, which could cause shot to shot variations. In continuous production, material level sensors help maintain a steady supply.

- **Barrel**

The barrel is a thick walled, heated cylinder housing the screw. It is essential in the monitor and control for temperatures precisely, as deviations can lead to degradation or incomplete melting.

External heater bands provide zoned temperature control, increasing from the feed to gradually melt the polymer. These band heaters encircle the barrel, divided into multiple independent zones for specific temperature controls. An accurate thermal management is crucial, too low and the melt is viscous with poor flow; too high and molecular weight drops or burning occurs.

- **Screw**

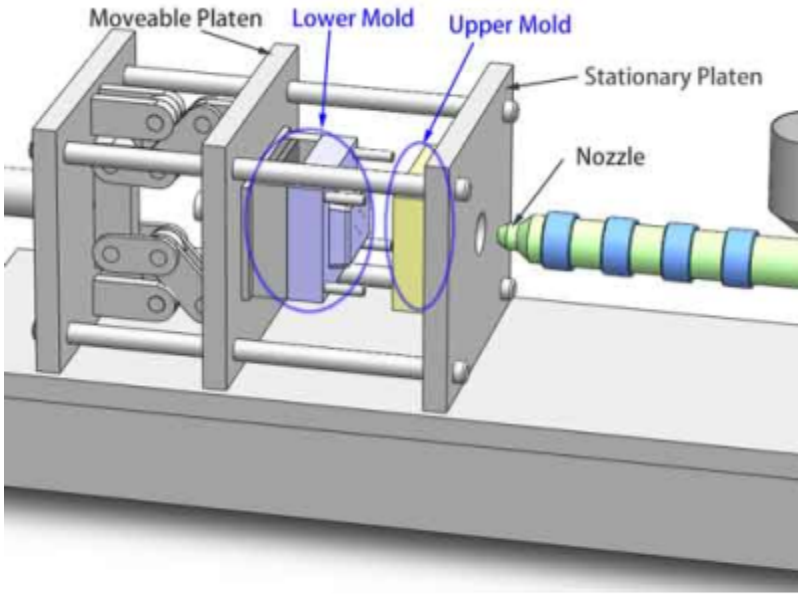
The reciprocating screw is the main system of the injection unit. It includes 3 main activities; the feed (transportation for conveying solids), compression (tapering to melt and compact), and metering (homogenization and pressure generation). Rotation plasticates material by friction and conduction from the barrel, while axial movement injects the melt. Screw design is material specific, general screws handle a range of resins, while specialized ones suit high viscosity or filled polymers. To prevent backflow during injection, a ring at the tip of the screw is installed as a valve.

- **Hydraulic Screw Drive and Gearing**

This provides the torque for screw rotation and the force for forward injection. Hydraulic motors controls allow precise speed, pressure, and profile position(control of velocity of the filling followed by pressure controlled packing).

3.2.2 Mold

The mold is the cavity that defines the part shape, including complex internal geometries such as cooling channels, ejector pins, and gating systems. The mold is the core of the process, where the actual shaping of the thermoplastic part occurs. In the scheme (see Fig 3.6), the cavity (lower mold and upper mold) is highlighted within the mold area between the platens. While the machine provides the force and motion, the mold defines the geometry, surface finish, and often critical features.



Figures 3.6: Injection Mold

- **Cavity**

The cavity conforms to the space into which molten plastic is injected. In the diagram (see Fig 3.6), the yellow highlighted cavity shows where the part solidifies. It is important to consider during the design, the angles for demolding, the wall thickness uniformity to avoid quality defects like sink marks, and to consider adding some gates and vents. There are also multi cavity molds which increase productivity since more parts can be injected at the same time,

but they require a balanced filling to ensure all parts are identical. Cooling channels are usually drilled or milled into the mold plates surrounding the cavity to control heat extraction rates, directly influencing cycle time and part quality.

- **Stationary Platen**

The stationary platen is fixed in the system and mounted firmly to the machine frame to hold the other mold half. It possesses a central hole interface where the injection nozzle meets the mold. Its design is crucial to achieve a high rigidity. The stationary platen applies and distributes the clamping force across the mold surface in an even manner. In the diagram (see Fig 3.6), it is positioned between the mold area and the injection unit.

- **Moving Platen**

The moving plate has a back and forth motion of the ejector side part of the mold to open and close it. It is guided by tie bars to ensure a proper alignment with the stationary platen. The movement of the plate is done by hydraulic cylinders and switch mechanisms to allow an efficient time during the opening and closure of the mold. The design of the plate generally has to be heavy and rigid enough to handle mold weight and clamping pressure without tensing, yet move smoothly to support high speed production. Proper lubrication and maintenance of guide elements are vital to prevent wear that could lead to misalignment over time.

3.2.3 Clamping Unit

The clamping unit (see Fig 3.7) is the last system of a thermoplastic injection molding machine.The main activity is to hold, in a secure manner, the two halves of the mold together under immense force during the injection and packing phases, preventing the molten plastic from forcing the mold open and causing defects such as excess material escaping at the parting line. When the component has cooled, the unit opens the mold to allow the ejection of the part.

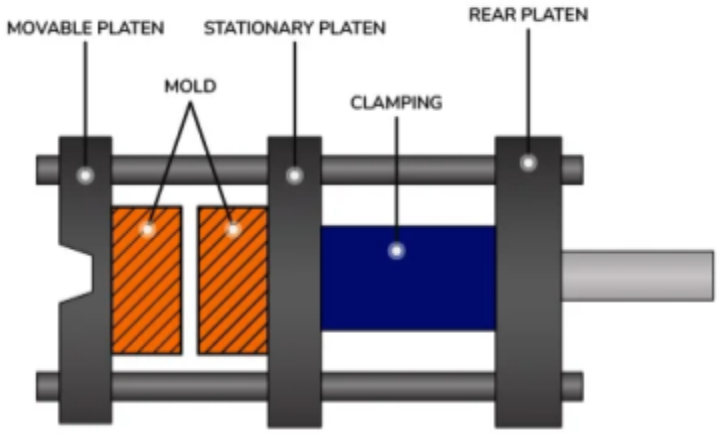


Figure 3.7: Clamping Unit

- **Rear Platen**

The rear platen function is to be the unmoving fixture for the clamping unit, providing a fixed base for the machine's hydraulic or mechanical systems. It is securely anchored to the machine bed to provide the necessary reactive force required to counteract the high pressures generated during the clamping and injection phases. Furthermore, the rear platen facilitates the precise alignment of the tie bars, which serve as the guiding framework for the platen's aligned movement. By maintaining extreme structural integrity, this component prevents mechanical deflection, ensuring that the mold halves remain sealed under intense hydraulic tonnage. Consequently, the rear platen is indispensable for achieving dimensional accuracy and preventing flash formation in the final molded product.

3.3 Automotive Supply Chain in Lighting Sector

This automotive supply chain is structured by levels, with the OEM (Original Equipment Supplier) at the top, followed by Tier 1 suppliers who deliver complete components directly to the vehicle assembly plants, and Tier 2 suppliers who provide sub components and special parts to the Tier 1 level. In this hierarchical model, the OEM focuses on vehicle design, final assembly, and brand management, while getting support from their Tier 1 suppliers. Tier 2 suppliers, on the

other hand, manufacture individual components or sub assemblies that are critical to the performance of these systems. This structure enables cost efficiency and technological innovation, but it also increases productivity in quality management and traceability across the chain, as well as product specialization.

Within the automotive lighting sector, this supply chain has gained significant importance in recent years. Modern vehicle lighting has evolved from simple illumination to advanced systems. These developments enhance vehicle safety, aesthetics, and energy efficiency, while imposing very strict requirements on optical performance, durability, and uniformity of light distribution. Lighting systems are now considered critical in safety, subject to international regulations and quality standards such as IATF 16949 and VDA 6.3. The sector demands close collaboration between OEM and suppliers throughout the product lifecycle, from design (APQP) and prototype validation (PPAP) to serial production.

In the specific case analyzed in this thesis, the supply chain involves Toyota UK as the OEM (end customer), Valeo as the Tier 1 supplier responsible for the complete lighting module, and a Tier 2 supplier plant located in Veneto, Italy, which manufactures the light guide component. This configuration is typical of the lighting industry, where Tier 1 suppliers integrate optical, electronic, and mechanical elements into a final module delivered directly to the vehicle manufacturer. Any deviation in quality at the Tier 2 level can cause a problem through the chain, affecting final vehicle performance and customer satisfaction. Understanding this is essential to analyze the root causes and effects of the quality incident described in the following chapter.

3.4 Valeo Chrzanow (Tier 1)

Valeo Chrzanow is located in Lesser Poland Voivodeship, and stands as a cornerstone of Valeo’s Visibility Systems division. It is recognized as one of the largest and most modern lighting factories in the world, acting as a benchmark for industrial excellence within the group.

3.4.1 Core Production Focus

Valeo Chrzanow plant is dedicated to the manufacturing of advanced lighting systems that are increasingly treated as electronic modules rather than simple mechanical parts. The facility produces Matrix LED headlamps, which use dozens of individual light emitting diodes controlled by a camera to separate shadows around oncoming cars while keeping the rest of the road bright. The plant also manufactures Kinetic Rear Lamps that use OLED or high definition LED clusters to display animations or warnings to trailing drivers. These products are essential for the transition toward autonomous driving, where lighting serves as a communication tool between the vehicle and its environment.

3.4.2 Technological Capabilities

The manufacturing floor at Chrzanow utilizes multi component injection molding, allowing different types of plastics (such as clear polycarbonate and black housing materials) to be molded into a single piece. The metallization process is particularly advanced, using high vacuum chambers to deposit microscopic layers of aluminum onto reflectors to achieve mirror like precision. Assembly occurs in a clean room environment due to the potential contamination able to decrease the aesthetic and functional high end lens. Furthermore, the plant employs sophisticated Automated Optical Inspection (AOI) systems, where high speed cameras and AI algorithms verify the alignment and light intensity of every LED to ensure they meet strict international safety regulations.

3.4.3 Strategic Importance in the European Supply Chain

Strategically positioned in Central Europe, Valeo Chrzanow is a vital hub in the European automotive market. Its location allows for efficient on time deliveries to major car assembly plants across Poland, Germany, Czech Republic, and Slovakia. The site supplies for premium OEMs like Audi, .BMW, and Volvo, as well as volume manufacturers like Stellantis and Renault. Beyond manufacturing, the site plays a critical role in industrialization engineering, working closely in the process of prototype designing with Valeo R&D centers and developing mass production strategies.

3.4.4. Commitment to Sustainability

In alignment with Valeo's global CAP50 (see Fig. 3.8) roadmap toward carbon neutrality by 2050, the Chrzanow plant has implemented rigorous energy saving measures. This includes the installation of heat recovery systems from the injection molding machines to heat the facility and the optimization of the energy intensive vacuum metallization cycles. The plant also focuses on circular economy principles, with a strict segregation of plastic scrap for regrinding and reuse where it is permissible. Quality management is standardized by the IATF 16949, ensuring that the facility maintains the highest levels of operational reliability required by the global automotive industry.



Figure 3.8: Valeo Chrzanow CAP

During the context of this research, Valeo Chrzanow plays the role of a Tier 1, supplying directly the assembled head lamp to the OEM customer, Toyota UK.

3.3 Supplier (Tier 2) and Relationship with Valeo

Supplier group is an established industrial leader founded in the 1970s, specializing in the design and manufacturing of high precision molds and plastic components. While the company originally served the electromechanical and household appliance sectors, it has evolved over 50 years to become a primary reference for the automotive market. Headquarter is in Colceresa, Italy and the group offers a model from initial feasibility studies and co design using CATIA and

Moldflow analysis to complex injection molding, PVD metallization, and final assembly. The company maintains a robust production infrastructure, including 26 injection molding machines at its main site.. Their technical expertise is particularly evident in their work with lightguide systems and multi material (2K, 3K, and 4K) injection processes for prestigious automotive brands such as Ferrari, Audi, BMW, Porsche, and Mercedes Benz. To support these operations, the supplier uses their own software solutions like I-KNOW for document management, HIPLAN for toolshop monitoring, and TEMI for live production KPI tracking.

The vision of the supplier includes the relocation of its Italian headquarters to a larger 22,000 square meter facility and the establishment of a new plant in Morocco, which is expected to open in 2026. These investments in new locations, advanced machinery, and digital tools underscore the group's commitment to maintaining its status as a specialist in aesthetic and technical components for both automotive and non-automotive industrial sectors.

During the context of this research, the supplier plays the role of a Tier 2, supplying directly the injected lightguide to Valeo Chrzanow (Tier 1).

3.4 Toyota UK (OEM) Customer Requirements and Quality Standards

Toyota Motor Manufacturing UK (TMUK) operates as a major European production hub for Toyota, with the primary vehicle manufacturing plant in Burnaston, Derbyshire, and an engine plant in Deeside, North Wales. As an Original Equipment Manufacturer (OEM), TMUK is central to Toyota’s regional strategy, focusing heavily on the production of hybrid electric vehicles like the Corolla. Valeo Chrzanow, located in Poland, serves as a critical Tier 1 supplier within this chain, specializing in advanced automotive lighting systems. As part of Toyota's supply chain, Valeo Chrzanow provides essential components such as headlamps and rear signaling lamps. The relationship is characterized by high technical standards, as Valeo Chrzanow site is one of the largest and most advanced lighting factories in the world, capable of producing the complex LED and matrix lighting technologies required for Toyota’s modern vehicle platforms. Valeo’s role involves not only the physical delivery of parts but also collaborative engineering to ensure that lighting components meet Toyota’s rigorous and strict quality and safety specifications.

During the context of this research, Toyota UK plays the role of the OEM, assembling directly the complete car supplied to the final user (see Fig. 3.9)

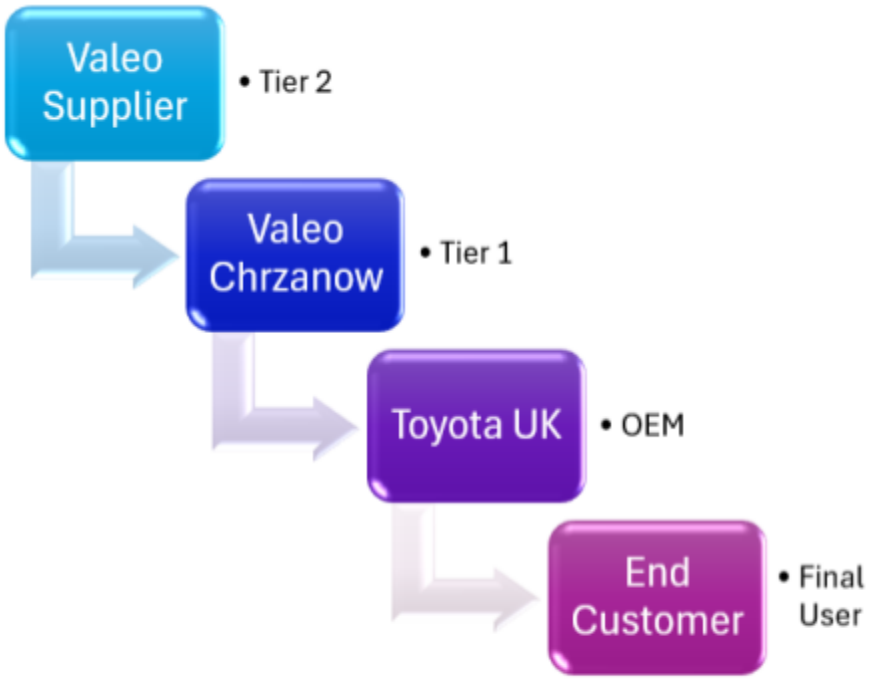


Figure 3.9: Tier Supply Chain

This graph illustrates the linear flow of the supply chain for the automotive relationship between these entities:

- Tier 2 (Supplier): mainly responsible for specialized injection-molded components, such as the PMMA lightguides which will be the point of discussion in this research. They supply these critical sub-components to the Tier 1 (Valeo Chrzanow) To Valeo, tier 2 is also responsible for data submission such as capability studies, dimensional reports, quality controls.

- Tier 1 (Valeo Chrzanów): This plant in Poland specializes in lighting systems (Wiper systems and Lighting). They assemble the supplier components into complete headlamps or rear lighting clusters. To Toyota, Valeo must guarantee the photometric performance, fit and finish of the entire lamp assembly.

- OEM (Toyota): The Original Equipment Manufacturer (Vehicle Producer). They receive the just in time (JIT) assemblies from Valeo and integrate them into the vehicle on the assembly line.
- Final Customer: Should a failure be experienced, Toyota uses the traceability VIN (Vehicle Identification Number) to trace the lamp back to Valeo Chrzanów, who then uses batch tracking to trace the specific lightguide back to tier supplier.

3.5 Headlamp

Rather than a single illumination component, a headlamp is a complex high tech assembly that integrates mechanical housings, electronic control units (ECUs), LED modules, and sophisticated optics such as lightguides and reflectors, as the ones used in the context of Toyota 160B project (see Fig. 3.10). For Valeo, the headlamp is a key driver of the Visibility Systems business group, serving both a functional safety purpose, providing optimal road illumination and signaling and an aesthetic purpose through light patterns. Within the supply chain, the headlamp represents the final Tier 1 (Valeo) output that results from a multi tier integration process. In upstream, Valeo manages Tier 2 suppliers which provide precision molded components and optical lenses that must meet strict photometric standards. In midstream, at sites like Valeo Chrzanow, these sub components are assembled using advanced techniques such as ultrasonic welding and automated robotic sealing. Downstream, the completed headlamp assemblies are delivered to the OEM (Toyota), where they are installed directly onto the vehicle. This position in the supply chain makes Valeo responsible for the total quality of the system, requiring SQA oversight to ensure that every sub component from upstream partners fits perfectly into the final assembly requirements.



Figure 3.10: Toyota 160B Headlamp

3.5.1 Core Components

- **Lens**

The Lens is the primary protective barrier of the headlamp (see Fig. 3.11), typically manufactured from optical grade Polycarbonate (PC) due to its high impact resistance and transparency. Because polycarbonate is susceptible to environmental degradation, it is treated with a hard coat to provide UV protection and chemical resistance against cleaning agents. Technically it must maintain its geometric profile to ensure that light passing through it is not refracted incorrectly, which would distort the beam pattern.

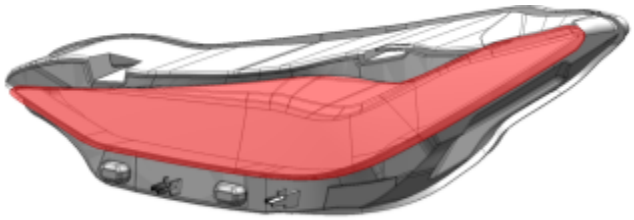


Figure 3.11: Lens

- **Housing**

The Housing (see Fig. 3.12) serves as the structural foundation for the entire assembly, usually injection molded from glass fiber reinforced polymers like Polypropylene (PP-GF) or Polybutylene Terephthalate (PBT-GF). These materials are selected for their high dimensional stability and low thermal expansion, ensuring that the internal optical components remain perfectly aligned even when exposed to extreme engine temperatures. The housing features complex mounting points for vehicle integration and integrated channels for wiring harnesses, acting as a hermetic shell that protects sensitive electronics from moisture.

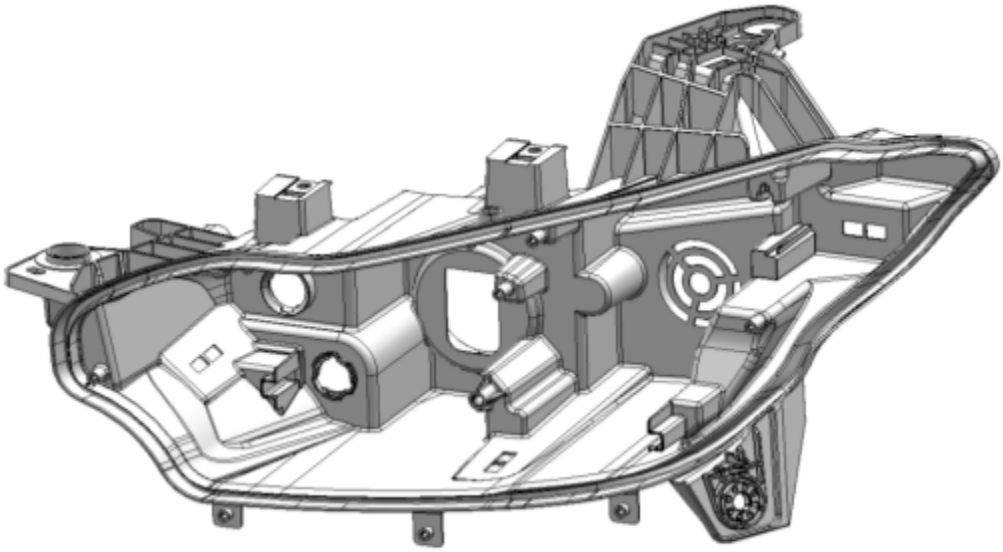


Figure 3.12: Housing

- **Bezel**

The Bezel is an optical component that serves both aesthetic and technical roles by covering the internal structural elements (see Fig 3.13). It is often made from heat resistant plastics like PBT or PC and finished using Physical Vapor Deposition (PVD) to create a metallic, chrome like appearance. This component is designed to manage stray light, by absorbing or redirecting unwanted reflections from the light source, which prevents glare and ensures the headlamp meets legal photometric requirements regarding light distribution.

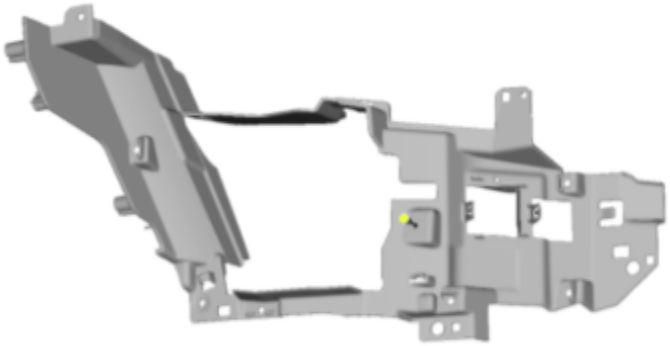


Figure 3.13: Bezel

- **Lightguide**

Lightguides are precision engineered optical tubes (see Fig. 3.14) that transport light from a LED source over a distance. Usually they are made from high purity PMMA or Polycarbonate, they feature microscopic light guiding elements such as prisms or textures along their length that disrupt the internal reflection to leak light out in a controlled, uniform manner. This technology is applied to create homogeneous light signatures for Daytime Running Lights (DRL) and position lamps, allowing designers to create thin, curved, or complex 3D lighting shapes.



Figure 3.14: Lightguide

- **LED Modules and PCBAs**

These components are circuit board assemblies (see Fig 3.15) that represent the light engine of the headlamp. The modules consist of high intensity semiconductor chips mounted on insulated metal substrates or aluminum core PCBs to facilitate rapid heat dissipation. Because LED efficiency and lifespan decrease as temperature rises, these modules are paired with passive or active heatsinks. The application involves electronic drivers that use pulse width modulations to control brightness levels for different functions, such as dimming a DRL to serve as a position lamp.



Figure 3.15: LED Modules And PCBAs

- **Reflection Systems**

Reflectors are responsible for shaping the raw light into a legal beam pattern. Reflector systems (see Fig 3.16) use metallized surfaces to bounce light onto the road. These systems are technically designed to create a sharp cut off line which is a distinct boundary between light and shadow that prevents high intensity light from reaching the eyes of oncoming drivers while maximizing the range of the beam.



Figure 3.16: Reflection System

- **Actuators and Leveling Motors**

Leveling actuators are electromechanical devices integrated into the housing to provide dynamic adjustment of the beam's aim. Using motors controlled by the vehicle's electronic control unit, these actuators can adjust the vertical pitch of the optical unit in response to vehicle load changes or braking. (see Fig 3.17)



Figure 3.17: Actuators and Leveling Motors

- **Sealing and Venting Systems**

These components are critical for maintaining the internal environment of the headlamp. The interface between the lens and housing is typically sealed with high performance polyurethane or hot melt adhesives to prevent water ingress. However, because air expands and contracts with temperature changes, headlamps utilize semi permeable membranes (see Fig 3.18). These vents allow for pressure equalization and the escape of moisture vapor to prevent internal condensation, while simultaneously blocking the entry of liquid water and dust particles.

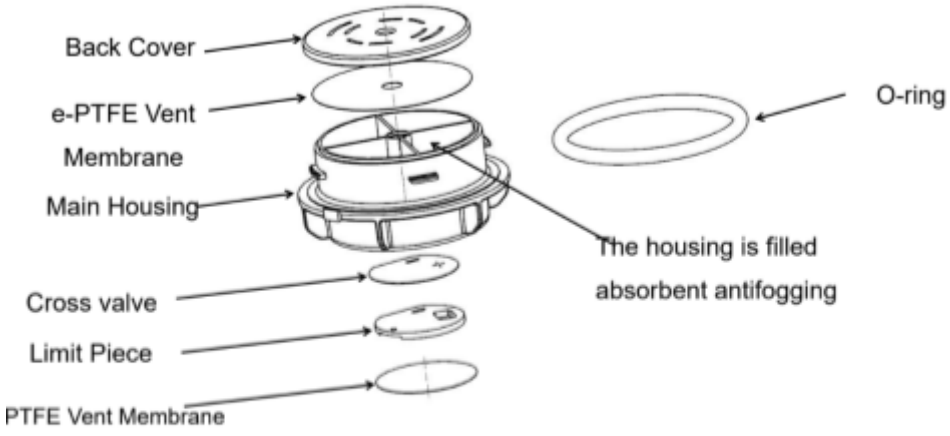


Figure 3.18: Sealing and Venting System

3.6 Plastic Injection Commodity in Valeo

Plastic injection molding within Valeo's framework, is segmented into distinct categories under a broader "Plastic and Transformation" commodity (see Fig 3.19). Segment CC focuses on Technical Plastic Parts, emphasizing functional components defined primarily by press tonnage and structural performance. Segment CD addresses Aspect Parts, which prioritizes visible, aesthetic, or decorated elements that meet strict surface quality and appearance standards. Valeo's approach to plastic commodities is based on two main goals, maintaining strong technical performance while staying cost competitive. This is especially important given the automotive industry's move toward electrification and vehicle lightweighting.

BASICS of the TECHNOLOGIES of the COMMODITY

Segment Code	Segment Name
CA	**Raw Material (Resins)**
CB	Chemicals
CC	Technical Plastic Parts
CD	Aspect Plastic Parts
CE	Overmolding & Specific Technologies
CG	Rubber Parts
CH	Foams

Figure 3.19: Valeo Plastic Commodities

As reviewed before, Commodity CC represents the foundational engineering core of the "Plastic and Transformation" sector, focusing exclusively on Technical Plastic Parts where structural integrity and functional reliability are priority. These components, characterized by their production via high tonnage injection molding presses, are engineered to withstand rigorous mechanical stresses and environmental volatility, with the need of deep focus on the rheological properties of high performance polymers such as glass fiber reinforced polyamides.

The quality assurance for CC parts prioritizes dimensional stability and process capability (Cpk), ensuring that internal components such as housings or structural brackets maintain their geometric precision under extreme thermal and mechanical loads. As the automotive industry transitions toward electrification, the CC segment becomes increasingly critical, as these parts must facilitate significant vehicle lightweighting without compromising the safety or durability of the vehicle's internal architecture.

On the other hand, Commodity CD is defined by its focus on Aspect Parts, where the primary objective is the management of surface aesthetics and perceived quality. This segment includes components that are directly visible to the end user, requiring a more strict SQA

methodology that evaluates surface topography, colorimetric consistency, and the integration of secondary transformation processes such as chrome plating, painting, or laser etching. Consequently, the CD commodity demands rigorous boundary sampling and UV resistance validation to ensure that the aesthetic homogeneity of the vehicle is preserved throughout its lifecycle, balancing the requirements of automotive design with the industrial rigorosity of mass production.

3.7 Main Plastic Injection Defects

The quality of automotive injection molding components is defined by their strict adherence to dimensional, aesthetic, and structural specifications. Despite advanced manufacturing protocols, the process remains susceptible to various deviations that may affect the integrity of the final assembly. As explained by Chaciński & Sutowski (2021) for these quality failures, it is essential to categorize them by measurable, such as dimensional deviations with a unit and a tolerance consideration, and as non measurable, meaning a qualitative approach. The following sections provide the most common defects encountered in the production of plastic automotive components.

- **Inclusions**

They are identified as the localization of contaminants embedded within the plastic body (see Fig 3.20). These impurities come into sight as visible black or brown dots that disrupt the material's purity and visual clarity. In high quality production, these dots represent a failure in material cleanliness, resulting in a product that appears stained or internally flawed, and can affect the light dispersion of the component.

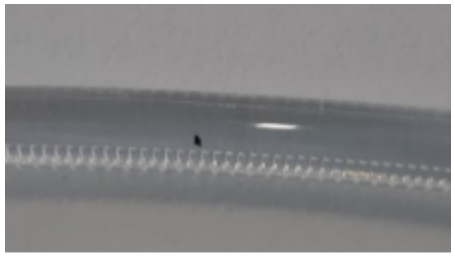


Figure 3.20: Inclusions

- **Weld Marks**

This defect is characterized by a lack of structural toughness, causing the part to crack or crumble under minimal force. Weld marks appear as thin lines on the surface where separate flows of material meet but fail to bond perfectly (see Fig 3.21). These lines are not just visual flaws but represent structural flaws where the part is most likely to break.

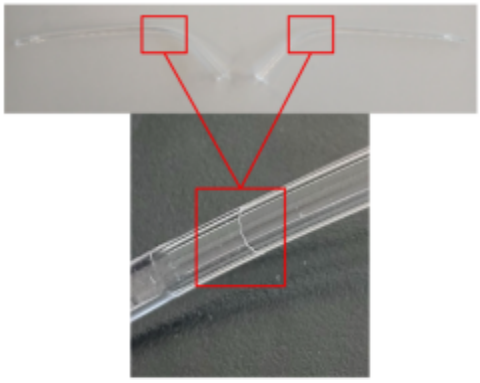


Figure 3.21: Weld Marks

- **Air Bubbles**

Gassing defects appear as trapped air bubbles, inside the clear plastic (see Fig 3.22). Because PMMA has a high transparency, these bubbles can be spotted. They can be perfectly round or stretched out into long, thin shapes. Unlike scratches on the surface, these are actual empty holes inside the solid material. They are usually found in the thickest parts of the plastic or at the very end of where the liquid plastic flowed into the mold.



Figure 3.22: Gassings

- **Discoloration**

The presence of inconsistent color, appears as streaks, shades, or shifts in transparency. This defect is a lack of chromatic uniformity, and specifically in PMMA, a dark or yellow tone (see Fig 3.23). It is a primary aesthetic failure that prevents the product from meeting specific visual standards.

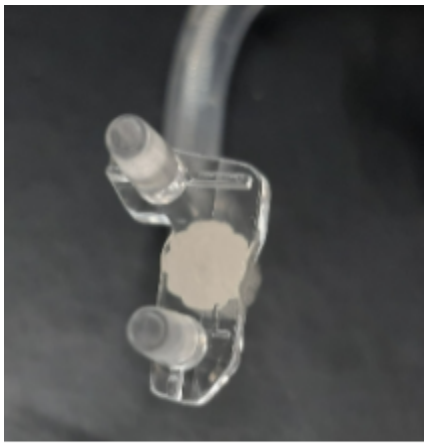


Figure 3.23: Discoloration

- **Ejector Pin Marks**

Ejector pin marks are small circular indentations on the surface of the part (see Fig 3.24). These marks are physically left behind by the mechanical components used to push the part out of the mold, the pins. They represent a disruption in the surface finish, often appearing as localized deformations that stand out against the surrounding texture in the component.



Figure 3.24: Ejector Pin Marks

- **Flash**

Flashes or burrs, refers to the plastic that extends beyond the intended edges of the part (see Fig 3.25). It appears as an excess of material that leaks out of the main injection flow and component, creating sharp borders. This defect indicates that the material did not stay contained within the designated boundaries of the mold and often may require additional processes after injection, as a deburring, to trim the extra material.

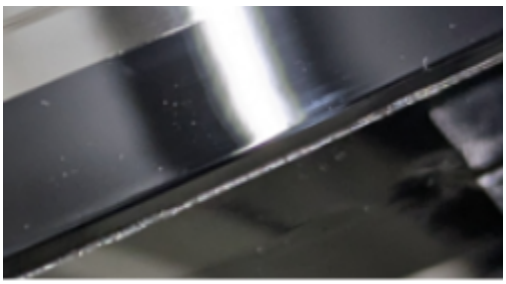


Figure 3.25: Flash

- **Graining Texture Degradation**

This defect involves localized variations in the part's finish, such as variation in a textured graining (see Fig 3.26), usually on a shiny surface. It is characterized by the material's failure to accurately replicate the pattern of the mold surface. This results in a product that looks uneven, lacking the uniform tactile quality required for high end components.

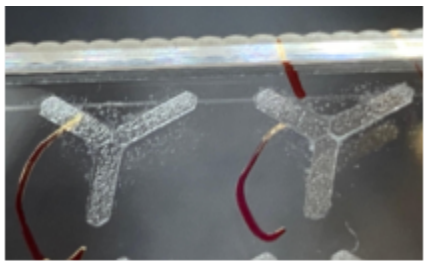


Figure 3.26: Surface Texture Inconsistencies

- **Short Cut**

Short cuts, or missing material, is characterized by a physically incomplete part where a certain section, typically the edges are missing, due to the injection flow (see Fig 3.27). The defect is a total failure of the material to fill the entire volume of the mold, resulting in a product that is not functional because it lacks its intended geometric form.



Figure 3.27: Short cut

- **Sink Marks**

This defect is a surface depression that typically occurs in thicker sections of a part, such as areas where ribs, or internal walls meet the main surface (see Fig 3.28). Usually it is caused by the uneven cooling and volumetric shrinkage during the polymer melt. While often considered an aesthetic defect, significant sinking can also indicate internal voids or structural inconsistencies within the molded component.



Figure 3.28: Sink Mark

- **Mass Deviation**

Mass deviation refers to part weighing significantly more or less than its design specification. A part with insufficient mass may have hidden voids or thin sections, while a part with excessive mass may be overly dense or thick. The weight inconsistency serves as a primary indicator that the internal structure of the part is not uniform, potentially affecting its long term durability.

3.8 Researcher's Involvement in the Case (The Role of Valeo SQE)

The PG SQA (Product Group Supplier Quality Assurance) acts as the critical technical and quality link between a Tier 1 manufacturer, such as Valeo, and its external supply base. The primary responsibility begins during the development phase through the APQP (Advanced Product Quality Planning) process. In this stage, evaluation of the supplier's manufacturing capabilities and oversee the validation of tooling and processes. For precision parts like the Toyota 160B lightguide, the PG SQA ensures the supplier's production environment is capable of meeting strict optical and dimensional standards before granting PPAP (Production Part Approval Process) approval for mass production. Once the parts are in serial production, the PG SQA shifts to a monitoring and corrective role, tracking key performance indicators such as PPM (Parts Per Million) defect rates. If a quality deviation occurs, the PG SQA leads the Quick Response Quality Control (QRQC) process, holding the supplier accountable for root cause analysis and the implementation of permanent corrective actions through 8D or PDCA reports. By conducting regular process audits and performance reviews, the PG SQA ensures that the supplier maintains a stable, high quality output, effectively protecting the final OEM assembly line from defects and costly production stops.

Chapter 4

Quality Tools Methodology

4.1 Quality Tools Introduction

During the oversight of this incident, numerous quality management tools and methodologies were integrated into Valeo's incident management. To ensure the problem solving and continuous improvement, the organization employs a structured approach rooted in the Plan, Do. Check, Act (PDCA) cycle. Within this main foundation, various analytical techniques are utilized to identify root causes and prevent recurrence, including the 5 Why analysis, Factor Tree Analysis (FTA), and the 4M (Man, Machine, Material, Method) categorization. Furthermore, the 5W2H method provides a descriptive foundation for incident characterization, while advanced statistical tools such as Measurement Systems Analysis (MSA), Statistical Process Control (SPC), and Design of Experiments (DOE) are leveraged to validate measurement integrity and optimize process performance. This chapter establishes the technical basis and introduction of these tools for the systematic resolution of quality incidents within the automotive manufacturing environment.

4.2 Quick Response Quality Control (QRQC)

QRQC is Valeo's primary methodology for handling quality issues directly on the production floor. It is built on the San Gen Shugi mindset, which emphasizes the importance of the real place (Gemba), the real object (Gembutsu), and the real facts (Genjitsu). This approach requires a fast, disciplined reaction to any deviation, involving management immediately to ensure the problem is contained. As Aoudia & Testa (2012), Valeo Group developed the tool

with the purpose of achieving daily and continuous improvement to reach a Total Quality Management.

4.3 Plan, Do, Check, Act (PDCA)

The PDCA cycle (see Fig 4.1) is the standard logic used at Valeo for continuous improvement. It breaks down problem solving into four steps, planning the change by defining the problem and identifying the potential factors, implementing the solutions and countermeasures in a reduced scale, checking the results against the original goals to evaluate and ensure that the standards are followed, and acting to standardize the solution by updating procedures and processes if it is successful. PDCA process helps the organization maintain operational stability and ensures that improvements are sustained over time.



Figure 4.1: PDCA Cycle

4.4 Factor Tree Analysis (FTA)

The FTA is a symptomatic tool used to investigate the two main branches of a quality failure, the occurrence root cause of the defect and why it was not caught by the existing control system, non detection. By breaking the incident down into these two distinct paths, the analysis identifies the specific technical and systemic factors that allowed the part to be produced and

subsequently released. This duality approach ensures that corrective actions address both the manufacturing process and the detection barriers, providing more robust quality controls to mitigate future recurrences.

4.5 4M (Method, Man, Machine, Material)

The 4M methodology categorizes brainstormed potential causes of a quality problem into four defined areas, Man, Machine, Material, and Method (see Fig 4.2). While the tool itself is limited to these four categories, the variables examined within each area are open. For instance, the brainstorm of Valeo quality incidents may include, but are not limited to, the following factors:

- **Man:** Operator training, certifications, and human error
- **Machine:** Equipment settings, maintenance, and tool wear
- **Material:** Component batches and raw material quality
- **Method:** Work instructions, process parameters, and missing standards.

During this structured approach, it is ensured that the supplier, with the support of the Valeo SQA engineer, evaluates all components of the production process.

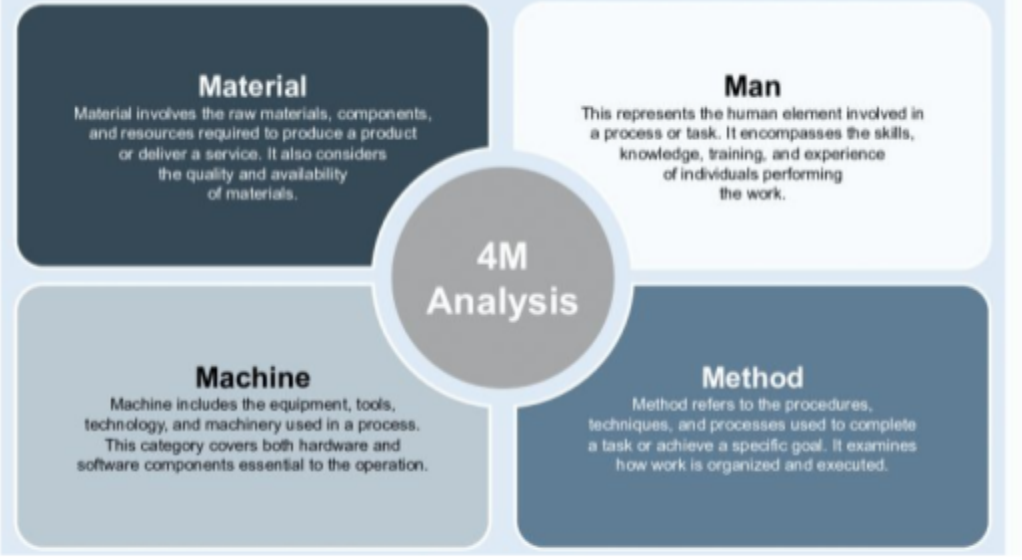


Figure 4.2: 4M Methodology

4.6 Five Whys

The 5 Why technique is a tool for finding the root cause of a quality issue. By asking “why” repeatedly, usually five times, but not limited to it, Valeo suppliers can look past the immediate failure to find the fundamental process or management weakness. This method is critical for ensuring that the final solution addresses the source of the problem rather than just the symptoms (see Fig 4.3). As Serrat (2017) explains, the method relies on three essential pillars for success, providing precise and thorough descriptions of the issue, maintaining total transparency when answering each "why," and committing to identifying and fixing the root cause of the problem.

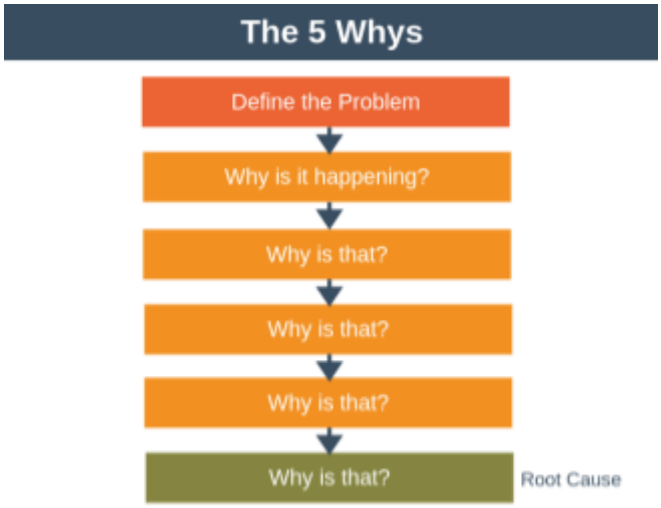


Figure 4.3: 5 WHYs Methodology

4.7 Reproduction & Repetitibility (R&R) by Attributes

Before analyzing any production data, Valeo uses Measurement System Analysis (MSA) to ensure the data is reliable. For the specific case of this quality incident, the Attribute R&R was the study performed. It is applied to measurement systems where the result is a discrete classification, such as "pass or fail" and for visual inspections for surface defects. Since these measurements are subjective or based on fixed limits, the study focuses on the level of agreement between different inspectors and their consistency when checking the same part multiple times.

The goal is to ensure that all inspectors align with Toyota standard reference, minimizing the risk of either rejecting good parts or, more critically, accepting defective ones.

4.8 Design of Experiments (DOE)

In cases involving plastic injection suppliers, Valeo SQA often utilizes qualitative DOE to resolve visual and surface level quality incidents, such as the gassings. Unlike quantitative experiments that measure physical dimensions, a qualitative DOE focuses on the presence or severity of a defect. The DOE consists of varying process parameters, such as holding pressure or mold temperature, and then categorizing the resulting parts based on the visual standard.

The evaluation of a qualitative DOE is based on the following factors:

- **Attribute Agreement**

The results are evaluated by checking if the observed improvements are consistent across different trials. Since the data is not numerical, the goal is to find a process window where the defect is visually eliminated across all test samples.

- **Comparison Against Limit Samples**

Each trial result is compared against a physical master sample, consisting of the maximum allowed deviation from the standard. The DOE is considered successful if the chosen parameters result in parts that are clearly better than the limit sample.

- **Visual Confirmation Run**

The final evaluation involves a production run using the optimized settings. Success is confirmed when a significant batch of parts is produced with zero occurrences of the qualitative defect, proving that the process adjustment has effectively removed the visual defect.

4.9 Statistical Process Control (SPC)

SPC uses statistical methods to monitor production processes in real time. By using control charts, Valeo can track process performance and distinguish between normal variations

and signs of a real problem. This allows the production team to step in and fix a process before it produces defective parts, making quality management proactive rather than reactive.

For an Special Process and Product Characteristic (SPPC), Valeo typically requires a minimum Process Capability Index (Cpk) of 1.67. This index measures how well a process can produce parts within the customer's specification limits and specifically explains for the centering of the process by comparing the process variability to the distance between the process average and the nearest specification limit. A high Cpk indicates that the process is both stable and centered, meaning there is a very low risk of producing defective parts due to minor fluctuations Valeo sampling requirement size to validate this capability during the initial process qualification is a minimum of 100 parts. These parts are usually collected from a continuous production run, over a period of several hours or shifts, to ensure the sampling will have some natural variability in the process.

Chapter 5

Toyota 160B Lightguide and Problem Definition

5.1 Toyota Lightguide 160B (Low Grade)

Toyota standard provides a clear structure for designing and using lightguides, which are components specifically made to carry and distribute light. The low grade category focus is on the material balance manufacturing costs with the ability to spread light evenly across a specific area. This thesis examines how the 160B low grade lightguide maintains its physical structure and visual quality after a defect component is claimed. This research aims to explain how this specific standard ensures reliable lighting performance in its technical applications.

5.1.1 Toyota Lightguide 160B (Material PMMA Clear 8N)

The polymer used in Toyota 160B lightguide primarily involves the Polymethyl Methacrylate (PMMA) 8N (see Fig 5.1) which is specifically acknowledged for its clarity and natural resistance to UV light, which prevents the material from turning yellow over time. In the low grade 160B specification, this base polymer is often modified with specific chemical additives known as diffusing agents. These additives create internal reflections that help the light spread out evenly rather than traveling in a straight line. Furthermore, the molecular weight is managed to ensure the material remains easy to mold into complex shapes while still maintaining enough durability to resist cracking under environmental stress. The grade 8N of this PMMA polymer indicates the material's specific melt flow rate and viscosity, while determining a normal heat resistance and standard molecular weight.

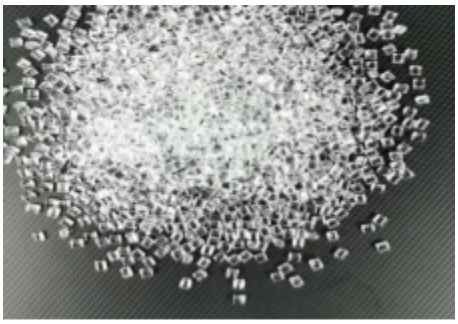


Figure 5.1: PMMA Clear 8N

5.1.2 Toyota 160B Lightguide (Manufacturing Process)

The manufacturing process of Toyota 160B lightguides in the Tier 2 supplier consists solely of injection molding where the polymer resin is heated to a molten state and injected into a highly polished mold under extreme pressure. An Engel 300 (see Fig 5.2) ton (approx. 3,000 kN) injection molding press is used and runs a precise cyclic process. It plasticizes polymer pellets via a reciprocating screw, clamps the mold under 300 tons of force, injects melt at high pressure, and applies holding pressure, cools the part, and ejects it.

To meet the 160B standard, the process must be strictly controlled to prevent internal bubbles, which are microscopic defects that can disrupt the path of light. The cooling phase is particularly critical; if the material cools too quickly or unevenly, internal stresses can develop, leading to light leakage. By maintaining precise temperature and pressure settings the assurance that the low-grade 160B component achieves a consistent performance.



Figure 5.2: Engel 300 Press

5.1.3 Toyota 160B Lightguide (Quality Controls)

Quality control for Toyota 160B lightguides involves strict optical testing to ensure that the light output remains consistent and meets the required luminosity standards. The primary method used is photometric tests, where devices like, specialized optical systems such as the one used by Valeo Tier Supplier, FEASA, and Ulbricht Sphere measure the brightness at multiple points along the length of the part to identify any dark spots or uneven transparency. Another critical test is the measurement of the color to evaluate the component's yellowing which is usually linked to the chemical composition for successfully resisting discoloration after exposure to heat and UV light. Furthermore, other quality testing includes the performing spectrophotometer tests to verify that the color coordinates of the light remain within a specific range, included in the 2D design, ensuring that the material does not shift the intended nominal of the light source.

- **Colorimetry and Optical Control (Tier 2 Supplier Control)**

This process focuses on the material's light transmitting properties during the injection molding phase. Using specialized equipment like FEASA sensors, spectrometers (see Fig 5.3), and Ulbricht spheres, technicians measure the chromatic coordinates (X and Y values) and the total luminous flux of the PMMA material. The Ulbricht sphere can capture all light transmitted by the lightguide, while the spectrometer breaks that light down into its chromatic variables to ensure the color remains within the specified tolerance. This ensures that the light guide does not shift its standard transparency and maintains the required transmission level.



Figure 5.3: Spectrometer

Toyota 160B Lightguide chromatic coordinates are based on the CIE 1931 color space standard, which searches for an achievement on a white defined point by (x,y) coordinates (see Fig. 5.4)

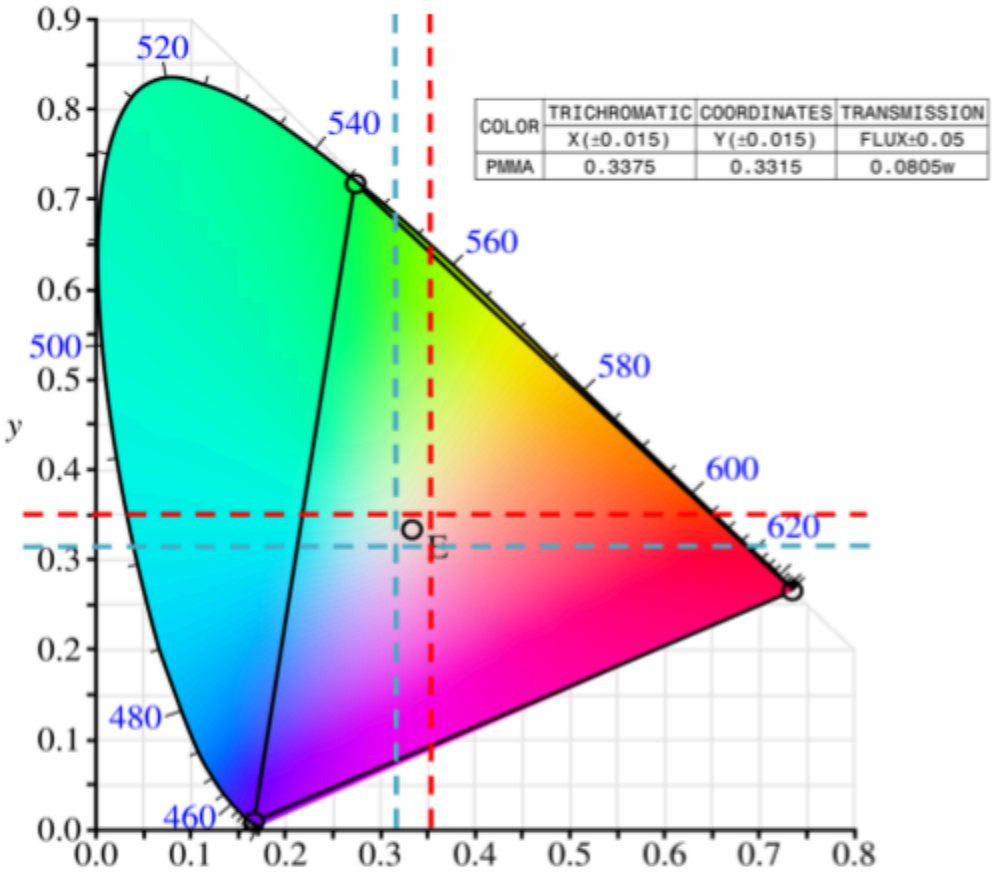


Figure 5.4: CIE 1931 Chromaticity Diagram

- **Dimensional Control (Tier 2 Supplier Control)**

The dimensional control for Toyota 160B lightguide is performed by a 3D control machine, Coordinate Measuring Machine (see Fig 5.5). The process focuses specifically on the critical interface between the light guide and the PCB. A Coordinate Measuring Machine establishes a primary datum on the lightguide's seating surface and then measures the offset to the PCB contact point. The machine verifies that this functional gap is maintained at the nominal value established in the 2D design with its respective tight tolerance tolerance. This precise measurement is essential to ensure that the lightguide sits at the correct focal distance from the LEDs on the PCB, preventing assembly interference or loss of optical efficiency.



Figure 5.5: Coordinate Measurement Machine

- **Qualitative features (Tier 2 Supplier Control)**

The qualitative control consists of the Tier 2 operator performing the visual inspection under the defined lighting conditions and from the specified viewing position, ensuring that the part is correctly oriented and that the inspection area is free from disturbing reflections. The operator visually checks the component for qualitative defects such as scratches, cracks, bubbles, contamination, surface damage, or other defects according to the applicable defect acceptance by Valeo (see Table 5.1). The inspection should be performed at the specified illumination level, 1,500 ± 250 lux, aligned with ISO 8995-1 / EN 12464-1 as is commonly used as an appropriate target.. The operator should maintain the prescribed viewing distance and posture to obtain a consistent inspection while avoiding unnecessary visual or ergonomic constraint. Appropriate Personal Protective Equipment (PPE), particularly protective gloves, should be worn when handling the component to prevent contamination, fingerprints, and damage, while also protecting the operator's hands. Only defects that meet or exceed the defined acceptance criteria are classified as nonconforming, otherwise, the part is accepted.

Description of area & color	Red	Orange	Green	White
Same color of point on same surface color (ex : black point on black surface, dots)	Diam 1mm	Diam 1,5mm	Diam 2mm	All aspect defects acceptable except : break, lack of material, cracks, burrs
Color of point differente of surface color (ex : black point on metal surface)	Diam 0,5mm	Diam 0,7mm	Diam 1mm	
Lenght line maximum acceptable (soft scratches, soft fiber)	1mm	5mm	10mm	
Weathered surface /Damaged (lack of varnish,porosity,bubble, shrink holes, blister, freezing,...)	None	3*3	10*10	
Distance between multiple defects	15mm	10mm	5mm	
Quantity of defects per area	To be defined with customer or NA			

Table 5.1: Quality Defect Acceptance

5.2 Problem Definition

The Quick Response (QR) activity is the mandatory first phase of the Valeo PDCA (Plan, Do, Check, Act) FTA (Factor Tree Analysis) process, requiring completion within the first 24 hours from the incident notification to ensure immediate customer protection. It begins with a specific problem definition using the 5W2H tool; What, Why, When, Who, Where, How, and How Many (see Fig 5.6) to provide a structured, fact based description of the issue. This is supported by a detailed characterization where Valeo and suppliers must provide photographic comparisons and precise data measurements of good versus bad parts to clearly identify the technical gap in the standard.

WHAT IS THE PROBLEM ? > Use 5W + 2H to know what is the Current Situation ?			
5W2H		**CHARACTERIZATION**	
WHAT happened? [4]		What is the difference between good and bad parts? [11]	
WHY is it a problem? [5]		Was part produced in the standard process? [12]	
WHEN detected [6]		When was it manufactured at Supplier? [13]	
WHO detected? [7] (name of operator)		Who manufactured? [14]	
WHERE detected? [8]		In which other application or processes product is used? [15]	
HOW detected? [9]		Are we capturing the defect when reinjecting product in normal process? [16]	
HOW MANY bad parts? [10]		Did a similar problem happen previously at customer or internally? [17]	

Figure 5.6: 5W2H Methodology

Simultaneously, suppliers must perform customer securitization through containment actions. This involves 100% sorting of all stock across the entire supply chain, including the supplier plant, transit, and Valeo locations, to prevent further non conforming parts from reaching the production line. These immediate countermeasures are recorded alongside the identification of the first certified shipment to signal that the perimeter is secure. This thesis formalizes the diagnostic characterization of a non conformity identified in the Toyota 160B

lightguide. The following 5W2H analysis serves as the foundation for the subsequent root cause analysis and the implementation of corrective actions to restore process capability.

1. What happened?

The non conformity is characterized by the presence of an internal air bubble found in the light guide Toyota 160B low grade (see Fig 5.7) This aesthetic defect results in an uncontrolled light leakage on the Daytime Running Light (DRL) function. This represents a significant deviation from the required optical homogeneity and aesthetic standards defined in the technical specifications.



Figure 5.7: Toyota Light Guide air bubble

2. Why is it a problem?

The defect constitutes a failure in functional requirements. The localized high intensity light points compromise the uniform light distribution expected by the OEM (Toyota), with the homogeneity needed potentially impacting regulatory compliance and expected quality.

3. Who detected it?

The defect was initially identified by a Toyota UK assembly line operator and subsequently validated by their resident quality technician. The manufacturing responsibility is traced back to the Tier 2 Supplier, while the analysis and incident management are coordinated by the Valeo SQA team.

4. Where was it detected?

The detection occurred at the Toyota UK assembly plant. However, the origin of the defect is localized to the injection molding process at the Tier 2 supplier production facility. The defect was specific to the DRL light guide and didn't affect other current similar applications nor products.

5. When was it detected?

The incident was officially notified on October 8, 2025. While the exact manufacturing shift could not be isolated due to a lack of granular traceability provided by the customer, the sorting activities and containment measures were initiated between October 9 and October 11, 2025.

6. How was it detected?

The non conformity was identified through visual inspection during the active light testing phase. The standard visual inspection protocols at the supplier level failed to capture the defect, indicating a gap in the current detection capability within the standard production flow.

7. How many bad parts?

A total of 7 non compliant parts were identified out of a population of 21,136 units sorted, resulting in a cumulative defect rate of 331 Parts Per Million (PPM). Initial findings at the Toyota UK site showed a higher concentration 1,500 PPM, emphasizing the urgency of the containment, while in Valeo Chrzanow the detection reached 2,130 PPM (see Table 5.2)

	Nb. NG Parts	Nb. Sorted		PPM	
-Results of sorting in Valeo's Customer plant	5	3333	=	1500	PPM
-Results of sorting in Valeo Plant	2	2130	=	939	PPM
-Results of sorting in Other Valeo Plants				'----'	PPM
-Results of sorting in Transport			=	'----'	PPM
-Results of sorting in Valeo's Logistics platform				'----'	PPM
-Results of sorting in Supplier's Logistics platform			=	'----'	PPM
-Results of sorting in Supplier plant	0	15673		0	PPM
-Results of sorting in after-sales stocks			=	'----'	PPM
TOTAL SORTING	7	21136	=	331	PPM

Table 5.2: Containment Sorting Results

5.3 Containment Actions

Upon identification of the non conformity, the supplier initiated a comprehensive containment strategy designed to mitigate immediate risk and secure the customer's production integrity. To address downstream stock, a third party inspection service was involved to perform 100% sorting of affected material directly at the customer's facility. Internally, the supplier facilitated the general notification to their multidisciplinary areas, quality, production and logistic departments, ensuring a synchronized organizational response. Concurrently, all existing inventory within the warehouse was placed under a formal quarantine to undergo a mandatory 100% re-inspection protocol. To enhance detection capabilities at the point of manufacture, visual management aids were deployed at operator workstations to ensure manual inspection accuracy. These immediate actions were formalized through the issuance of an internal quality alert, establishing a documented framework for the containment phase and preventing the further escape of defected final goods.

Chapter 6

Analysis of the Incident

6.1 Factor Tree Analysis (Occurrence)

When a quality incident is reported to a supplier, reproducing the defect is a critical first step in the resolution process in order to validate the root cause. This process can facilitate the implementation of the Factor Tree Analysis and root cause analysis to ensure its effectiveness, as well as identifying that the issue doesn't come from an isolated case or an anomaly in the process.

Hereunder, the factors studied in the Toyota 160B lightguide claim of the air bubble are explained in detail, as well as the process to reproduce the defect and identify properly the factors out of norm or the standards to be modified in order to achieve a zero defect production.

6.2 External factors

- **Material Moisture Content**

As reviewed previously, Toyota 160B lightguide utilizes polymethyl methacrylate (PMMA) 8N. The presence of internal moisture within PMMA significantly compromises the structural and optical integrity of the polymer during its process in injection. Polymers absorb atmospheric water that, as explained by Drozda & Wick (1996) during the heating process temperatures exceeding the boiling point within the injection barrel, undergoes a rapid phase transition into water vapor, these evolved gases are unable to migrate to the surface and instead become trapped, leading to voids or internal porosity. Consequently, achieving a moisture

content below typically 0.02% for PMMA is a fundamental requirement to prevent the formation of these disruptions during the plasticization phase.

Supplier drying process begins with the resin pellets placed in a controlled thermal energy and dry air within a specialized hopper, where specific parameters, temperature, is below 98°C and residence time of 2 to 3 hours, according to the material manufacturer technical data sheet, are maintained to extract internal moisture. Once the material reaches the required dryness level, it is transported through vacuum loaders directly into the injection machine's hopper.

During the verification of the moisture content factor, Valeo SQA and the supplier performed a test with thermo balance. A sample was retrieved from the previously mentioned drying hooper, after the drying time standard amount was completed (see Table 6.1). Consequently, the resins were weighted into the scale for a fifteen gram sample which was in the heating chamber to begin the test, the device heated the sample and monitored the weight loss, with a conclusion of 0,01% moisture content (see Fig 6.1), showing the potential initial factor within specification.



Figure 6.1: Moisture Content Thermobalance

Recommended Processing Conditions				
Predrying Temperature		°C		max. 98
Predrying Time in Desiccant-Type Drier		h		2 - 3
Melt Temperature		°C		220 - 260
Mold Temperature (Injection Molding)		°C		60 - 90

Table 6.1: TDS Drying Time

6.3 Process Parameters

- **Mold Temperature**

The temperature of the mold has an impact on the solidification of the part as it can become accelerated in the outer layers, due to a low temperature, causing it to freeze and become rigid. Meanwhile the inner plastic is still in a hot and liquid state, and during its cooling process it reaches a thermal contraction, the outer plastic already solidified resists deformation. Consequently, the internal stress pulls the material apart at its center, resulting in a void.

During the analysis in the supplier, the standard temperature was defined in the supplier process within a range of 274,8 ± 0,15°C.

The initial test performed, was done with a 10 shot sample, and consisted of increasing the temperature to its standard upper limit 275,1°C.

Maximum limit	Mold Temperature 275,1 °C	1	2	3	4	5	6	7	8	9	10	Result
	Air Bubble											70%

Table 6.2: Test 1 Mold Temperature

The result was very similar to the standard scrap rate of the production run, with 70% of lightguides with an air bubble found (see Table 6.2). Consequently, it was increased to 2°C the parameter to continue monitoring the effect of a higher mold temperature, resulting in a slower solidification. The result was present at 80% of the 10 shot sample. (see Table 6.3)

Maximum limit + 2°C	Mold Temperature 277,1 °C	1	2	3	4	5	6	7	8	9	10	Result
	Air Bubble											80%

Table 6.3: Test 2 Mold Temperature

The last test done solely for mold temperature consisted of increasing an extra 1°C to continue monitoring how the behavior of the solidification performed, but extra discoloration issues from the transparency of the PMMA were present (see Table 6.4)

Maximum limit + 3°C	Mold Temperature 278,1 °C	1	2	3								Result
	Air Bubble											67%
	Yellowing											33%

Table 6.4: Test 3 Mold Temperature

- **Injection Speed**

Injection speed can result in trapped air, if performed too fast, since the limited time for venting from the mold can be present. By slowing down the injection speed, the molten plastic has a higher possibility to push the air out of the vents smoothly, which can potentially solve the air bubble defect. Generally, increasing the injection time will decrease the injection speed, as they are 2 direct and correlated variables.

During the analysis in the supplier, the standard injection time was defined in the supplier process within a range of 1,77 ± 0,11 seconds.

All the tests performed for injection speed were done with a 10 shot sample. The first test consisted of increasing the injection time to its standard upper limit, 1,88 seconds.

Maximum limit	Injection Time 1,88 s	1	2	3	4	5	6	7	8	9	10	Result
	Air Bubble											80%
	Yellowing											60%

Table 6.5: Test 1 Injection Time

The result (see Table 6.5) showed a positive result of 80% related to the lightguides with an air bubble present. However, the yellowing defect could be seen in the first parts of the run, correlated to the previous test done with the mold temperature increase. Furthermore, the

injection time was increased to 2,5 seconds to monitor the effect of a lower injection speed, resulting in an easier gas venting. The result improved with 90% of the 10 shot sample, and one new defect, a short shot found in the last injection point of the lightguide (see Table 6.6)

Maximum limit + 0,62 s	Injection Time	1	2	3	4	5	6	7	8	9	10	Result
	2,5 s											
	Air Bubble											90%
	Short Shot											90%

Table 6.6: Test 2 Injection Time

The last test done uniquely for injection speed consisted of increasing an extra 0,5 second of the injection time with a very continuous result of 90% of components with the air bubble defect (see Table 6.7)

Maximum limit + 1,12 s	Injection Time	1	2	3	4	5	6	7	8	9	10	Result
	3 s											
	Air Bubble											90%

Table 6.7: Test 3 Injection Time

- **Holding Pressure**

The lightguide volume shrinkage during the cooling phase is one of the most known causes to form a vacuum void and as Annicchiarico & Alcock (2013) explain the higher the pressure, the lower is the shrinkage. To mitigate these defects, the application of holding pressure is employed to facilitate the part compaction.

By increasing the pressure throughout the holding stage, additional molten polymer is forced into the mold cavity to compensate for the material's contraction as it solidifies. The compaction ensures that the density remains uniform and prevents the material from shifting from the center of the lightguide, which would otherwise result in an air bubble.

During the analysis in the supplier, the standard compaction was not defined by the supplier and there were no records of the previous production run parameter regarding holding pressure. During the beginning of this Gemba production run, the supplier was using a nominal of 105 bar / second to 70 bar / 6 seconds, consequently the first test was performed with these parameters. All the tests performed for injection speed were done with a 10 shot sample.

Maximum limit	Holding Pressure 105 bar/1s to 70 bar/6s	1	2	3	4	5	6	7	8	9	10	Result
	Air Bubble											70%

Table 6.8: Test 1 Holding Pressure

The result showed a result of 70% related to the lightguides with an air bubble present. (see Table 6.8) The decision was to increase by 10 bars the holding pressure to start a compaction of the injected part and see if the results improved, which they did to 90% of the 10 shot sample. (see Table 6.9)

Maximum limit + 10 bar	Holding Pressure 115 bar/1s to 80 bar/6s	1	2	3	4	5	6	7	8	9	10	Result
	Air Bubble											90%

Table 6.9: Test 2 Holding pressure

During the last test, it was decided to increase by 15 bars from the original test in the first phase of the packing pressure and to increase less, up to 10 bars in the last phase, at 6 seconds of holding, due to a higher cooling and solidification in the latter. The result was 100% positive in the first 10 shot samples, and by continuing to repeat to 20 shot samples, a small air bubble was found again, resulting in an efficiency rate of 95%. (see Table 6.10)

Maximum limit + 15 bar to 10 bar	Holding Pressure	1	2	3	4	5	6	7	8	9	10	Result
	120 bar/1s to 80 bar/6s											
	Air Bubble											
	Holding Pressure	11	12	13	14	15	16	17	18	19	20	95%
	120 bar/1s to 80 bar/6s											
	Air Bubble											

Table 6.10: Test 3 Holding Pressure

6.4 Design of Experiments

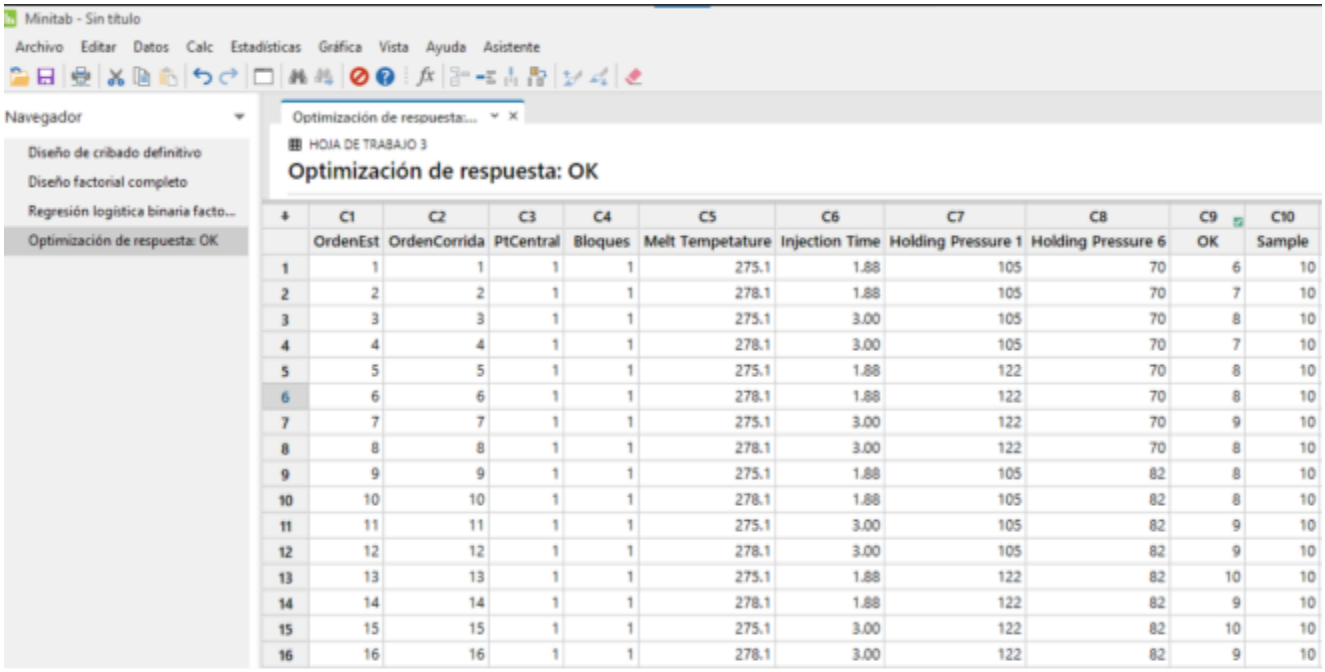
Once the defect was reproduced by altering the previous process factors by starting individual parameter testing from the standard limit to a graduate increase or decrease, based on each case, a new run was performed as a Design of Experiments, in this case altering the 4 parameters, mold temperature, injection time, holding pressure (1s) and holding pressure (6s) in each sample cycle.

The DOE was performed in Minitab 19 software, by using 4 factors with a binary response, lower and maximum values, constituting a run of 16 experiments, each of them with 10 samples, ending in a total of a 160 part run.

The following were the minimum and maximum values taken per factor based on the previous singular study for each:

- Mold Temperature [275.1 , 278.1]
- Injection Time [1.88 , 3.0]
- Holding Pressure at 1 second [105 , 122]
- Holding Pressure at 6 seconds [70 , 82]

The results were detailed as a number of OK parts out of 10 samples, considering all the quality visual defects. (see Table 6.11)



	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
	OrdenEst	OrdenCorrida	PtCentral	Bloques	Melt Tempetature	Injection Time	Holding Pressure 1	Holding Pressure 6	OK	Sample
1	1	1	1	1	275.1	1.88	105	70	6	10
2	2	2	1	1	278.1	1.88	105	70	7	10
3	3	3	1	1	275.1	3.00	105	70	8	10
4	4	4	1	1	278.1	3.00	105	70	7	10
5	5	5	1	1	275.1	1.88	122	70	8	10
6	6	6	1	1	278.1	1.88	122	70	8	10
7	7	7	1	1	275.1	3.00	122	70	9	10
8	8	8	1	1	278.1	3.00	122	70	8	10
9	9	9	1	1	275.1	1.88	105	82	8	10
10	10	10	1	1	278.1	1.88	105	82	8	10
11	11	11	1	1	275.1	3.00	105	82	9	10
12	12	12	1	1	278.1	3.00	105	82	9	10
13	13	13	1	1	275.1	1.88	122	82	10	10
14	14	14	1	1	278.1	1.88	122	82	9	10
15	15	15	1	1	275.1	3.00	122	82	10	10
16	16	16	1	1	278.1	3.00	122	82	9	10

Table 6.11: Design of Experiment Data

The factorial binary response analysis was run in Minitab and the optimized model with the highest percentage during all the experiments of OK parts was 93.70% with the optimum parameters being related solely to the holding pressure, with the increase to 122 bars at 1 second and 82 at 6 seconds.(see Fig 6.2)

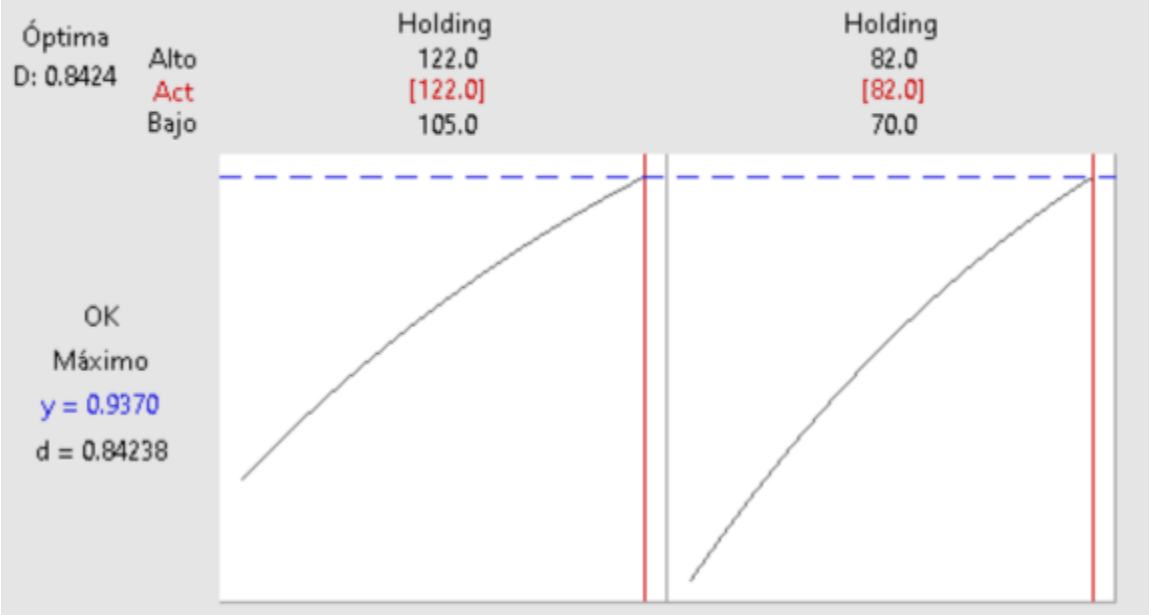


Figure 6.2: Optimized Model

6.5 Run at Rate Validation on Gemba

After establishing the modified parameters for the holding pressure, a 180 minute new run was performed by the supplier in order to determine in considerable production, the effects of the modification and the positive reduction of the internal scrap to reach the zero defect goal for the incident. The data collected is done by the SQA Engineer from Valeo. The study showed a production of 324 lightguides in 3 hours. A cycle time of 33.3 seconds per part with no quality defect found, meaning a zero rate internal part per million. (see Table 6.12)

Sample Production Run Data:		Yes
Total Changeover time as physically measured as at the beginning of the FDPR Run	Input by SQA during FDPR	0
Total Workstation Running Time in minutes	Input by SQA during FDPR	180
Total Breakdown time + Minor stoppages, Setups and Adjustments (minutes)	Input by SQA during FDPR	0
Total number of parts Produced (Good + Bad)	Input by SQA during FDPR	324
Total good parts (First time Right Parts only → ***Do not include Re-processed or Reworked parts***	Input by SQA during FDPR	324
Total bad parts	=K - L	*0*
Actual Takt time (seconds / part)	=((I - J)*60) / K	*33,3*

Calculations - I	
Change Over time in Minutes	*0*
Internal PPM	*0*
Good Parts Produced per Hour	*108*
Avg. Nbr of Parts Can be Produced Per Hour with Changeover + Minor Stoppages + Breakdown + Projected Downtime	*108*
Operation Number for Reference	*0*

Table 6.12: Run At Rate On Gemba

6.6 Dimensional Capacity Analysis

After validation of the run at rate with zero defects, a capability study was performed with 100 samples of the latter production run for the dimensional special product characteristic in the design, which as explained in chapter 4, consist of a distance between the PCB contact point to the primary datum of the lightguide. The samples were measured by the CMM in the supplier site and performing a normal distribution study, the CPK index was above the 1,67 value requested by Valeo (see Fig 6.3), confirming the holding pressure modification in the process didn't affect in a negative way to the dimensional capability of the lightguide.

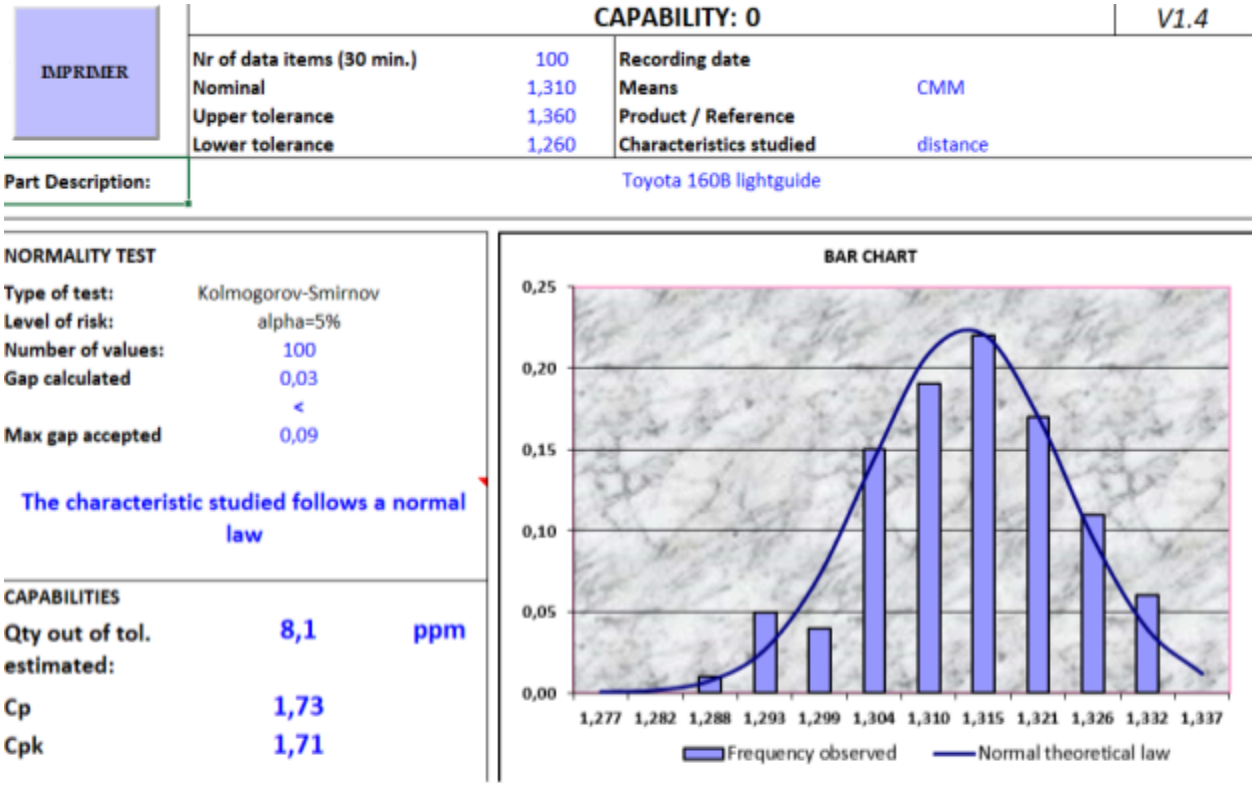


Figure 6.3: Dimensional Capability

6.7 Action Plan Countermeasures (Occurrence)

Following the successful analysis for the occurrence of the air bubble in the lightguide, in the pursuit of continuous improvement, the application of corrective and systemic actions are crucial. While corrective actions focus on rectifying immediate issues, systemic actions target the root causes to prevent recurrence across the supplier system ensuring a permanent structural enhancement.

6.7.1 Corrective Actions (Occurrence)

- Immediate shift of parameters, holding pressure increase to 122 bars during the first phase and 82 bars during the second phase for Toyota 160B Lightguide (low grade)
- Automatic machine scrap, for production start up and machine stoppages was increased to 10 initial scrapped parts due to the trend seen in the analysis of different runs, with higher percentage of defects being present after a machine stoppage for a parameter change.

6.7.1 Systemic Actions (Occurrence)

- The parameter sheet was updated based on the results obtained, to improve the standard across the next production runs of Toyota 160B. All users of this document were trained according to the new changes.
- In the start up production document, a new checkpoint was included for the quality operator to enforce that the critical parameters in real time production are aligned with the parameter sheet standard nominal values and within tolerances. The checkpoint was scheduled to be done every start of production and every shift change

6.8 Factor Tree Analysis (Detection)

The detection factor of the quality incident shifts the focus from why a failure occurred to why the existing control systems failed to identify it. FTA for Non-Detection isolates the gaps in the inspection and monitoring layers that give room to the non conformity to go through the next stage or the end user.

Below are the factors studied for the non detection of the air bubble explained in detail to identify properly the variabilities from the standards that have to be modified in order to achieve a zero defect shipment.

6.9 Inspection Station

- **Lighting Conditions at Inspection Station**

Good lighting is essential for quality inspection as it allows the control operator to detect visual defects. If a workspace is not illuminated sufficiently or has an excess of glare, an inspector might miss a defect. By using the right amount of light, the supplier ensures that every part is checked clearly and accurately, making sure only perfect items are sent to the customer.

Valeo standard for suppliers is to possess an inspection station with a standard of 1500 ± 250 lux. During the analysis a study was performed in Gemba with a luxometer and a 1584 lux result was thrown by the device (see Fig 6.4). Furthermore, supplier presented the periodical measurements report, being up to date



Figure 6.4: Luxometer Result

- **Toyota Lightguide Jig**

Besides the color control machine, the process flow (see Fig 6.5) of the supplier operator includes a second check in a jig provided by Toyota with a 1600 lux light to detect any visual defects. During the Gemba visit to the supplier, in the initial assessment of the operator, the latter was not utilizing Toyota's jig. There was not an existing standard in the layout for this control device, and the jig was placed at a far distance from the operator working space.

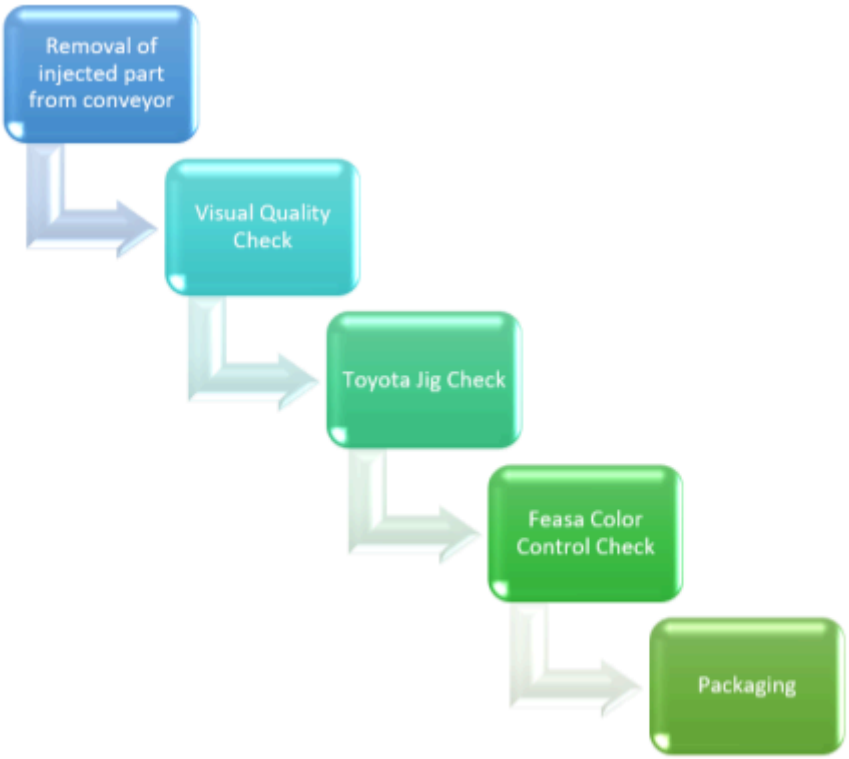


Figure 6.5: Operator Process Flow

As a result of the visual analysis of the work station, the decision was to reorder in real time, the physical layout of the station in an ergonomic manner for the operator, as well as enforcing that he will perform all check controls, following the correct flow (see Fig 6.6)

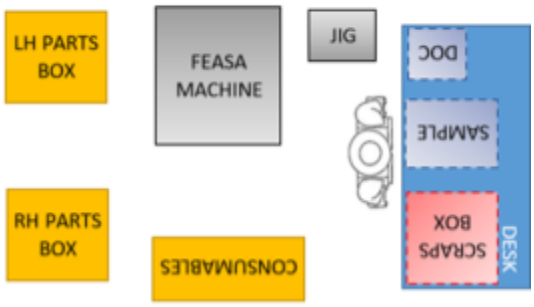


Figure 6.6: Optimized Layout

6.10 R&R for attributes

After all the station was correctly implemented with the corresponding three controls, visual, aesthetic Toyota jig, and color control machine, a Measurement System Analysis study was performed with 50 samples. The reproducibility and repeatability study was performed for attributes in a binary evaluation, pass or not pass.

The study was performed using 38 lightguides with no air bubble, and 12 lightguides with the issue. It was performed amongst three different operators, evaluating each piece three times. The result (see Fig 6.7) shows every operator vs the standard part, with operator B reaching a 98% of control effectiveness, while operator A and C were aligned 100% with the standard.

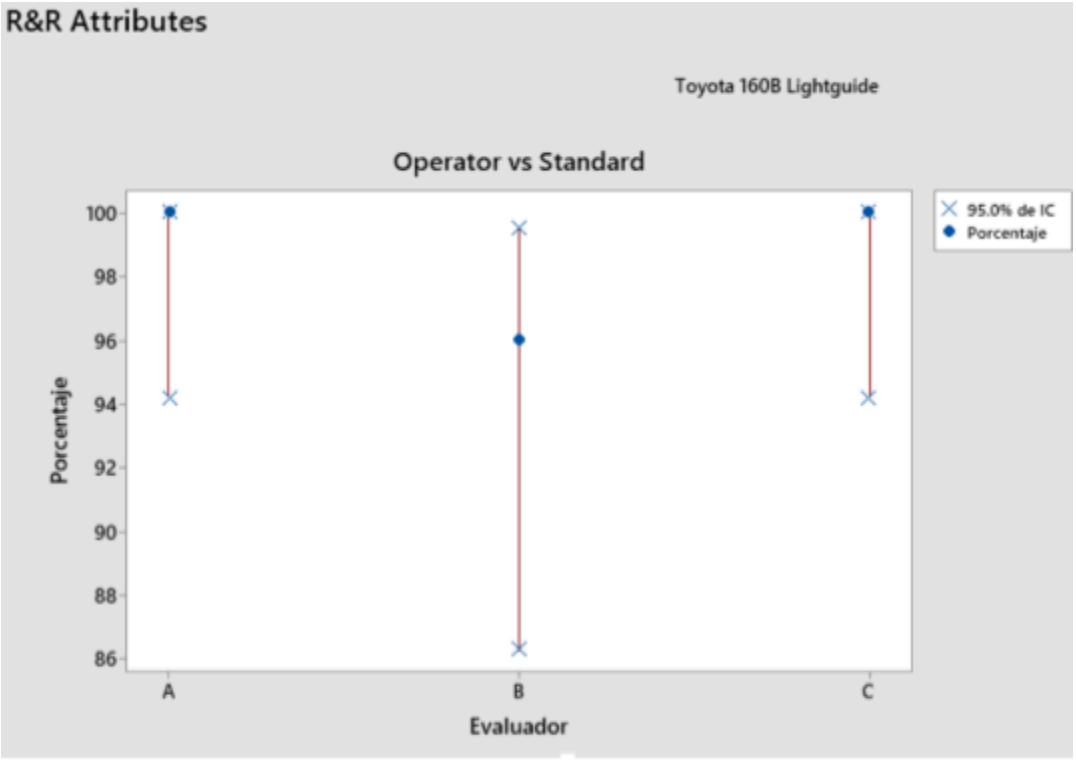


Figure 6.7: R&R Attributes

6.11 Action Plan Countermeasures (Occurrence)

6.11.1 Corrective Actions (Detection)

- Immediate layout modification during incident Gemba visit. The process flow must be followed, from visual inspection, light jig inspection and color control inspection. The change allows an ergonomic and efficient flow for the operator.
- Retraining to operators about the visual inspection standards with clear visual references, with a special focus on MSA results.

6.11.2 Systemic Actions (Detection)

- Implement a reinforcement periodic training program every six months by supplier quality team, including the performance of visual inspection MSA studies for requalification.
- Supplier created an updated standard of the layout for Toyota 160B line.
- New check point added in the start up production sheet where the quality technician verifies the correct physical layout vs the standard, to release production.

Chapter 7

Incident Control Validation

7.1 Gemba Check

A Gemba visit always provides a structured process for effective problem solving by emphasizing direct observation and systematic resolution. As Zvidzayi (2021) says, to avoid assumptions and understand the reality of the situation firsthand, Gemba relies on the importance of being at the place of the events. Once the problem is observed, temporary countermeasures are applied at real time to contain the issue, followed by an in depth root cause analysis. At last, the success of Gemba is dependent on standardization of found solutions to prevent a future recurrence of a claim.

At Valeo, the incident can reach its closure once the following runs after one month, or after a significant amount of production, demonstrating that the implemented actions were effectively solving the issue, in the process with zero defects in Valeo plants and zero supplier internal defects. In the case of Toyota 160B lightguide, the supplier showed the status after 5,000 parts with a 0% internal scrap rate.

7.2 Standard, Enforcement and Deployment

Standard, Enforcement and Deployment (StEDE) is an audit matrix tool used in Valeo to ensure operational excellence by focusing on the lifecycle of a process standard (see Fig 7.1). The first step is related to a clear existing standard, that formalizes the limit of what is acceptable and what is not. The enforcement of the standards consists of thoughtful monitoring and auditing to ensure the standard is strictly followed on the Gemba. Deployment ensures that the standard is shared and

implemented across all relevant users, lines or sites. The three processes assessed within this framework are, the set up of parameters, the work instructions, and the quality controls. In the case of Toyota 160B lightguide, the supplier demonstrated to fulfill all the points with a matrix, ensuring the standard exists and is clear for the users, deploying to the latter ones, and the direct managers from the users enforcing the standard periodically.

StEDE3 ASSESSMENT RESULT :			9 / 9		
Step 2 : StEDE3 Matrix			For supplier self assesment activity, column to be assessed by:		
			Direct Manager of the user		Manager from an other APU/Department
StEDE3 Matrix *Excellence Through Standards*			**EXISTING ?**	**DEPLOYED ?** *How were the users trained to apply this STANDARD ? (including their Direct Manager if not the trainer)*	**ENFORCED ?** *What is the Direct Manager of the users doing to ensure the strict and continuous EXECUTION of this STANDARD ?*
			Clear, Visible, Quantified, Doable.	Respected by users. Can be explained by users.	The Direct Manager checks on genba the respect of the standards and in case a gap is found an action is defined
For a given Process / Workstation : Are STANDARDS for...	... Set-up Parameters ...	*Parameters list, values and limits and necessary work instructions to set the machine/workstation up for production of the selected part number (to be compared with those used during the FDPR / IS)*	OK	ok	ok
	... Work Instructions ...	*Instructions defining how to operate the station safely, to produce parts, and how to maintain the equipment.*	OK	ok	ok
	... Quality Controls ...	*Activities to control the quality of the operation or of the product after transformation to ensure only good parts are transferred to the next station*	OK	ok	ok

Figure 7.1: StEDE3 Matrix

7.3 Lessons Learned Card

Valeo requirement to supplier includes a Lessons Learned Card (LLC) as a practical one page document used for the takeaways obtained from the actions performed of a quality incident, to deploy them in similar future projects as an opportunity of continuous improvement . The tool synthesises all the PDCA information analysis done during the incident management process comparing the previous status, with the defect, with the current one. The main goal is to perform horizontal deployment across different shifts, production lines, and plants to ensure the same error isn't repeated elsewhere.

For high thickness PMMA parts, standard injection parameters are insufficient. The holding pressure must be treated as a critical parameter. The study proved that a two stage holding pressure (122 bar to 82 bar) is essential to counteract the physics of thermal contraction. Future projects involving lightguides should mandate a specific holding pressure validation phase during the APQP stage to prevent vacuum voids before mass production begins. The Design of Experiments provided a vital lesson in process modification, attempting to solve the vacuum void by solely increasing mold temperature or slowing injection speed created new problems such as PMMA yellowing and short shots. An improved process window matrix will be implemented for suppliers. This document should define the boundaries where one defect is solved without triggering another one, ensuring that Tier 2 operators understand the side effects of parameter adjustments.

The work revealed that the defect reached the customer and was not detected, not because of a lack of tools, but because of their implementation, The Toyota jig was available but not used properly due to the incorrect flow standardization and ergonomics of the operator. A standardized master layout will be implemented for inspection stations. Continuous improvement audits will not only check if quality tools exist but also verify their ergonomic integration into the operator’s natural workflow.

Chapter 8

Conclusion

The activities carried during this thesis “Defect Solution For Plastic Injection Molding In Light Guide (Air Bubble / Fountain Effect)” encompassed the application of a series of quality management principles and tools to solve a critical quality crisis. The main objective was to resolve an aesthetic defect (air bubble) in a claimed Toyota 160B lightguide, which originated at Valeo supplier, impacting the Toyota UK assembly line. Throughout a series of steps and methodologies employed, the work performed in this paper successfully achieved the goal, providing both immediate technical solutions as well as long term systemic improvements.

As stated before, the objective of eliminating the quality claimed defect was reached by utilizing the full cycle of the PDCA (Plan - Do - Check - Act) and the QRQC (Quick Response Quality Control) methodology, allowing daily communication and on-site visits to the supplier. Both of these quality tools were the core for moving the project from 2,130 PPM to stabilize the process to a zero defect state. Throughout production runs using a Design Of Experiments, it was concluded that the holding pressure was the most critical variable. By increasing to the optimal values, on the initial phase and on the final phase, the material shrinkage was compensated, successfully eliminating the defect. During the Coordinate Measuring Machine capability study performance, the supplier reached a CPK that was exceeding Valeo’s requirement. Ensuring that the process, besides being free of defects, is also stable and centered.

The detection robustness was improved by re-engineering the inspection layout station to a logical and ergonomic flow that enforces the use of all quality controls, and mitigating the risk of failing to detect a defective part that will be sent to the customer. The optimization on Gemba of the layout demonstrated that human error can be approached in different ways and factors, not relying on the operator all responsibility, but to understand that the better the conditions, in this case, the physical workstation organization, the better quality indicators the company will have. This factor is as important as machine parameters to achieve a zero defect goal.

The testing done on different parameters, based on lessons learned from previous incidents and Valeo and supplier internal know-how, mold temperature, injection speed and holding pressure, provided a clear new lesson learned, demonstrating how an over correction of one variable could trigger a secondary defects like seen in the discoloration (yellowing) of the part, or as seen with the short cut. As trial and error can work in an immediate way, it does not guarantee quality stability in the long term, this is the importance of performing in depth studies with tools like the Design of Experiments and capability studies to ensure a potential recurrence will not take place.

Despite the successful outcome of the objective, some obstacles were encountered during the activity such as the traceability gaps that limited the supplier and PG SQA to encounter the real environmental conditions during the first initial failure, which potentially could have affected the PMMA moisture and thermal stability, due to its sensitiveness to minor ambient conditions. Traceability was also limited from part of the supplier, as the real machine parameters from the first initial failure were not able to be retrieved. Another limitation found was the time constraints, since the claim came from Toyota, the work of containment actions were done in parallel with the root cause analysis, to avoid the assembly line stoppage of Toyota.

After the work performed and lessons learned, two main activities are suggested for supplier management and training, specifically for plastic injection molding; the digitalization of the machine parameters with a monitoring system that detects a deviation from the optimized values settled by a DOE, with a respective access to the real time traceability; and a long term study for environmental humidity depending on the region of the supplier and how the seasonal fluctuations can drive the supplier to redefine the resin drying process and parameters.

In conclusion, this work demonstrated that the combination of punctual statistical tools like DOE and SPC combined with a lean management mindset is essential for maintaining the high quality standards required by the automotive industry. The project not only protected the relationship between Valeo and Toyota but also established a more resilient and transparent supply chain with the Tier 2.

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