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Applying Quality Function Deployment (QFD) to Define a Robotic "Function Package" for Paint Applications

An ABB Robotics Case Study

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1. Introduction

This thesis project has started thanks to the internship I attended at ABB S.p.A. in Turin. I have been working within the ABB Robotics division, specifically in the paint and sealing department. I would like to thank ABB for this opportunity.

The team provides its customers with robots, plant layouts, and configurations designed for paint or sealing applications in the Auto Original Equipment Manufacturer (OEM) and General Industry (GI) Original Equipment Manufacturer sectors. The challenge with the product I've been assigned is to define a so-called “Function Package” that offers customers a more complete and integrated paint solution than the usual robot ABB provides, yet more standard compared to the systems configured by ABB engineers. The package must include every peripheral involved in the process, fully configured and integrated, giving customers a near "plug-and-play" station for paint.

The aim of this project is to build a simple configuration so that it can satisfy a market which is not the usual Auto OEM, but a wider field, the General Industry (GI) sector, enabling standardization. The objective of the thesis is to build a Quality Function Deployment (QFD) for the Function Package, going through the phase of understanding the market, identifying the characteristics, and defining a product that can be delivered to customers, satisfying their needs.

1.1 The Idea

The idea comes from a project initially started in Sweden and finalized at the ABB branch in Sesto San Giovanni: The Spindle Package (Figure 1). This product is characterized by many alternatives related to welding robots produced by ABB, spindles, everything about the Human Machine Interaction (HMI), cables, safety systems, documentation – everything necessary to have a completely working welding station made by ABB, configured with external suppliers' products where needed.[1]

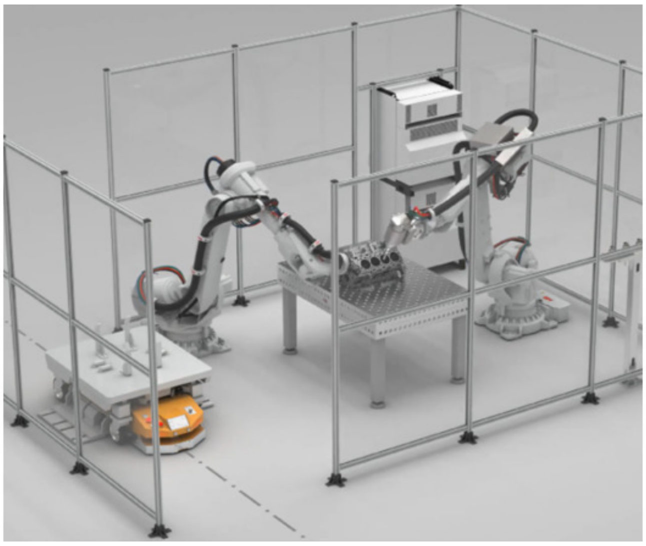

Figure 1 Spindle Packages for Machining Applications. Source: ABB Robotics, https://one.robotics.abb.com/en/solutions/p/Spindle-Packages, last access 06/09/2025

Products like the Spindle Package and the Function Package are part of ABB's offering portfolio and they are classified as Functional Modules, being used in many business areas of the company.[2] Combining pre-integrated software, hardware, and one or more robots, Functional Modules can substantially reduce the time, cost, and effort associated with systems building and integration. Furthermore, with all components proven to work together, the risks around potential incompatibility are also eliminated. The benefits for ABB are clear: being the only supplier for both robot and application (which also benefits the customer) and, thanks to standardization, being able to satisfy as many projects as possible without having to engineer the process for every sale.

1.2 The Need

The necessity to adapt the previously mentioned functional modules to the paint sector comes from market signals. Requests have been received from system integrators

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[1] https://new.abb.com/news/it/detail/84657/quando-non-basta-solo-un-robot

[2] https://new.abb.com/products/robotics/functional-modules

and line builders requiring ABB to provide the supply of pre integrated robot and peripherals, leaving only the remaining plant arrangement to them. The growing demand for pre-engineered functional modules in industrial painting applications reflects broader market pressures for efficiency and scalability. Across general industry segments, particularly in medium-scale manufacturing of plastic components, metal goods, and composite materials, system integrators increasingly seek turnkey solutions that reduce commissioning time and technical risk. This trend emerges from three converging factors:

- Cost Sensitivity: Non-OEM operators (e.g., tier-2 automotive suppliers, furniture manufacturers) require paint quality comparable to OEM standards at reduced costs.
- Shortened Lead Times: The proliferation of customized, low-volume production runs necessitates modular systems that can be rapidly adapted.
- Labor Constraints: Skilled workforce shortages in painting applications drive demand for pre-validated automation packages.

While ABB Robotics' traditional strength lies in high-precision OEM painting systems, this market shift presents an opportunity to leverage existing paint expertise for adjacent segments where process standardization is now feasible. The adaptation of function packages addresses these requirements while maintaining the core technological advantages of ABB's painting systems.

1.3 The Customer

ABB primarily aims to serve two key customer profiles: line builders and system integrators, with the latter being the primary focus of this project.

Line builders are specialized companies responsible for designing and implementing complete production lines for industries such as automotive, aerospace, and general manufacturing. In robotic painting applications, they integrate ABB robots into broader systems, combining them with auxiliary equipment (e.g., conveyors, drying ovens, or quality control stations) to create end-to-end solutions.

System integrators, on the other hand, act as technical partners who tailor robotic solutions to specific end-user needs. They select ABB robots and integrate peripherals such as spray guns, paint dosing systems, and overspray recovery units, ensuring full process compatibility. Critical pain points for integrators include plug-and-play readiness of components, comprehensive technical documentation, post-sale support, and the lack of competence in software configuration, all of which align with the goals of the proposed Function Package.

As can be seen, the customer is not (or not necessarily) the final consumer of the package. This condition is set for two main reasons. Firstly, line builders and system integrators are fundamental in handling non-scope activities related to plant organization. Secondly, paint processes are extremely difficult to understand for the end user, due to their complex components and rules. As a result, it often happens that the final customer doesn’t actually know the specific requirements needed to paint the product they produce. This makes it difficult for ABB to determine which configuration to use to achieve the best (or desired) quality in a context of a pre-engineered product, where adjustment must be kept at their minimum.

2. The Product

2.1 Paint

The types of paint are essentially two: liquid and powder. Within this distinction, there is the difference between high and low pressure liquid painting.

2.1.1 Liquid Paint

The choice between low-pressure painting and high-pressure painting, hinges on balancing aesthetic quality, operational efficiency and environmental constraints. There is low-pressure spraying with high voltage (HVLP), known as electrostatic spraying, and low lressure without high voltage. The first technology, in which ABB's bell applicators excel, uses an electrostatic charge to “attract” the atomised paint particles directly to the part being sprayed. Although it uses low fluid pressure, its main advantage comes from the high voltage, which drastically minimises overspray and achieves material transfer efficiencies of over 90%. The latter, reaches high-end result comparabre with the high voltage technology, but the transfer efficiency is considerably lower (usually aroud 60%).

On the other hand, high-pressure airless systems (up to 500 bar) prioritize speed and versatility. They are widely used in industrial construction or for protective coatings on metal structures, where the main goal is rapid coverage of large surfaces, even with high-viscosity materials like bitumen or fire-resistant coatings. While they might sacrifice some of the microscopic precision achievable with low-pressure systems, skilled applications can still yield high-quality, durable finishes suitable for demanding industrial and protective applications, but also for high quality furniture painting. However, the inherent high pressure can lead to challenges such as "orange peel" effects or drips if not meticulously managed, particularly with water-based paints, where bubble formation is also common, which is why this specific type of paint is not within the scope of the project.

A critical consideration, especially in explosive atmosphere (ATEX) environments, is safety. Low-pressure painting robots certified for explosive atmospheres, such as the ABB IRB 5500, incorporate anti-spark components and pressurization systems to operate safely in potentially explosive atmospheres, ensuring regulatory compliance.

In summary, while low-pressure painting excels in contexts where aesthetic quality and sustainability are mandatory, high-pressure airless painting remains irreplaceable for applications prioritizing speed, robustness, and adaptability to high-viscosity or complex materials. Its effectiveness in providing durable and high-quality finishes for demanding industrial and protective needs makes it the go-to choice in specific scenarios. The ultimate decision hinges on a technical-managerial evaluation of the trade-offs between precision, operational costs, and the desired product quality and performance for the specific application.

2.1.2 Powder Paint

Powder coating is utilized across multiple industries, from heavy manufacturing to consumer goods. In the automotive sector, it is commonly applied to high-stress components such as wheels, chassis, and engine parts, providing enhanced corrosion and abrasion resistance. The construction and architecture industries benefit from its durability for coating aluminum profiles, window frames, and outdoor metal structures exposed to harsh weather conditions. In appliance manufacturing, powder coating is used for washing machines, refrigerators, and ovens, where a uniform finish and solvent-free formulation are critical for both safety and aesthetics. Other sectors, such as furniture (metal cabinets, shelving) and lighting (fixtures, industrial lamps), leverage its color versatility and scratch resistance. Additionally, the aerospace and energy industries employ powder coating for components subjected to extreme conditions, including wind turbines and satellite structural elements.

The primary strengths of powder coating lie in its environmental sustainability and operational efficiency. From an ecological standpoint, the absence of volatile organic compounds (VOCs) reduces emissions. The process allows for the recovery of up to 95–98% of oversprayed powder, minimizing waste and lowering disposal costs. Technically, powder-coated surfaces exhibit greater uniformity in film thickness and superior substrate adhesion due to the pre-gelling stage, which prevents dripping or cratering. The resulting finish demonstrates enhanced resistance to corrosion, chemicals, and UV radiation, making it particularly suitable for outdoor or high-wear applications. Furthermore, the elimination of solvent evaporation phases reduces curing times.

Despite its advantages, powder coating presents certain constraints that limit its adoption in specific scenarios. Achieving ultra-thin coatings (below 30–40 μm) or high-gloss, metallic finishes remains challenging, making liquid coatings preferred for premium aesthetic applications. Additionally, color changes require extensive system cleaning, reducing flexibility compared to liquid paint systems.

2.2 Components

2.2.1 The Robot

As a global leader in robotics, ABB has established its reputation through innovative and high-performance industrial robots, with the IRB5500 and IRB5510 models standing out in their painting and coating applications. Both robots are integral to ABB's functional packages, offering distinct advantages tailored to diverse operational needs.

The IRB5500 (Figure 2) is a large-scale robot designed for heavy-duty applications, featuring a unique Process Arm that integrates internal process equipment directly into the robot structure. This design minimizes external cabling, reduces maintenance complexity, and enhances precision by eliminating interference from external hoses or cables. With a payload capacity of up to 13 kg and a reach of 2.9 meters, the IRB5500 excels in applications requiring extensive coverage, such as automotive body painting[3]. A key innovation is its compatibility with a seventh axis, which can be configured as a linear track (for extended horizontal reach) or a rotary axis (for rotational flexibility), enabling access to complex geometries.

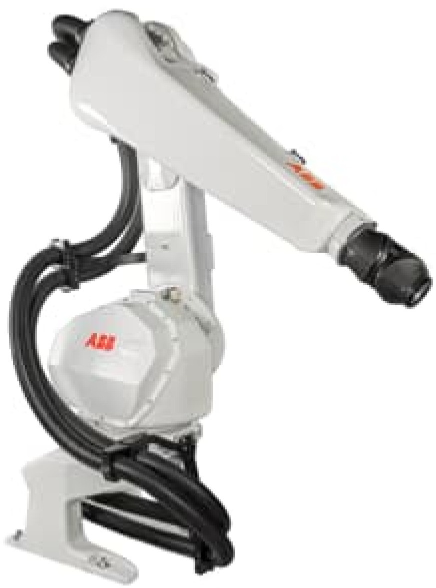

Figure 2 ABB IRB5500. Source: ABB Robotics, https://new.abb.com/products/it/3HNA016200-001/irb-5500, last access 06/09/20215

[3] https://new.abb.com/products/it/3HNA016200-001/irb-5500

In contrast, the IRB5510 (Figure 3) is a compact, agile robot optimized for high-speed operations. While it shares the seventh-axis adaptability with the IRB5500, its smaller footprint (reach of 2.5 meters) and lighter payload capacity (15 kg) make it ideal for confined spaces or applications demanding rapid motion cycles.[4] The IRB5510 boasts a repeatability of ±0.05 mm, ensuring exceptional accuracy for detailed coating tasks.

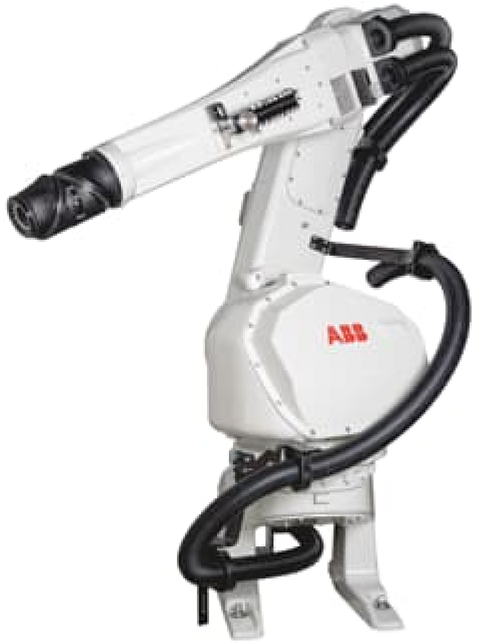

Figure 3 ABB IRB5510. Source: ABB Robotics, https://new.abb.com/products/it/3HNA028888-001/irb-5510, last access 06/09/2025

2.2.2 The Process

The functional model distinguishes between internal and external processes, each suited to specific applications. The IRB5500's integrated Process Arm enables internal processes with Low Pressure paint, where painting equipment (e.g., pumps, valves) is embedded within the robot structure.

For external processes, ABB typically partners with third-party suppliers when dealing with high-pressure and powder painting, where specialized equipment are required. However, ABB provides its own solutions for low-pressure processes. These systems emphasize energy efficiency and reduced material waste, achieving transfer efficiencies of over 90% with ABB's bell applicators. This modular approach, combining ABB's robotic

[4] https://new.abb.com/products/it/3HNA028888-001/irb-5510

precision with adaptable internal/external processes, ensures scalability and customization, meeting stringent industry standards for quality and sustainability.

2.2.3 The Applicators

Applicators are crucial components designed for the different paint technologies that will be treated in this thesis: high-pressure, low-pressure (with and without high voltage), and powder coating. ABB excels in low-pressure applications, especially their globally known bell applicators known for efficiency and sustainability, like the RB 1000i-S (Figure 4). For low-pressure guns and applicators used in powder and high-pressure coating, the project will utilize established suppliers with a long-standing relationship with ABB. This ensures quality, ease of configuration, and a balanced cost-quality ratio, which has been previously assessed.

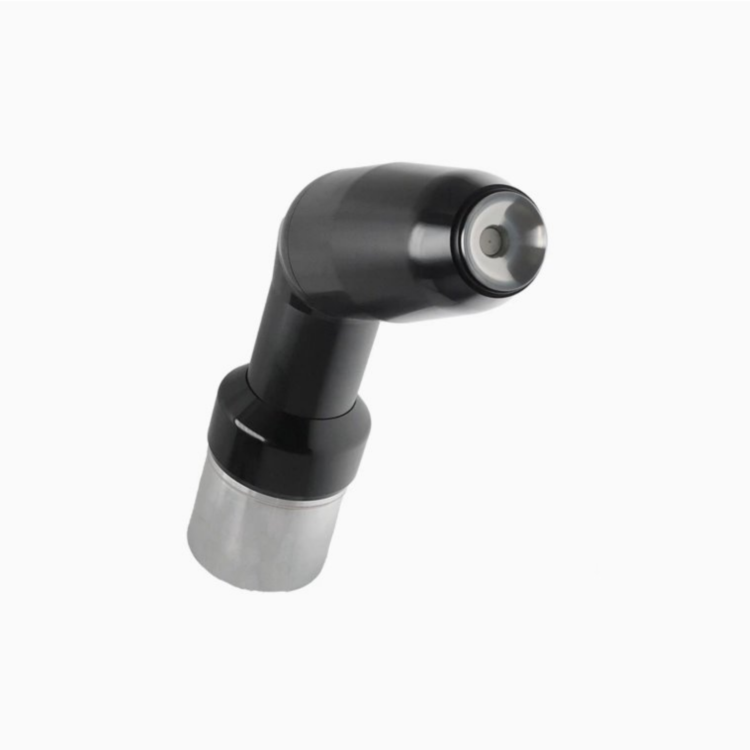

Figure 4ABB RB1000i-s, Source: ABB Robotics, https://www.abb.com/global/en/areas/robotics/products/equipment/painting/rb-1000i-s-atomizer, last access 06/09/2025

2.2.4 The Tool Cleaner

The tool cleaner is the first optional element in ABB's functional package, automating applicator maintenance to minimize downtime and ensure consistent coating quality. Two primary types are available:

- High-Pressure Water Jet (Contactless) Cleaners: Designed for liquid painting processes, these systems use pressurized water to remove residual paint without physical contact. A single cleaning cycle takes less than 30 seconds, ensuring compatibility with fast-paced production lines. They are ideal for high-pressure and electrostatic applications, preventing cross-contamination between color batches.

- Brush Cleaners: Employed for high-pressure liquid or powder coating processes, these devices use rotating brushes (often made of anti-static nylon) to scrub applicator surfaces. They are particularly effective for removing powder buildup or cured paint residues.

Both cleaners integrate seamlessly with ABB’s robots, enabling fully automated cleaning schedules.

2.2.5 The Pneumatic Cabinet

The pneumatic cabinet is a critical subsystem in ABB’s functional model, ensuring safe and efficient control of compressed air for painting processes. Composed of a pneumatic panel and a purge unit, it plays a dual role: regulating airflow for applicators and maintaining compliance with ATEX (Atmosphères Explosives) standards to prevent ignition risks in explosive environments.

Main components of a Pneumatic Cabinet will be:

- Pneumatic Panel: The pneumatic panel serves as the command center for air supply management. Key components include:
- Filtration Units: Remove particulates, moisture, and oil from compressed air, ensuring clean airflow critical for paint atomization.
- Purge Unit: The purge unit is specifically designed to maintain an ATEX-compliant environment within the cabinet.

By integrating these features, the pneumatic cabinet guarantees operational safety in volatile environments while optimizing airflow precision for consistent paint application. Its modular design allows seamless integration with ABB’s robotic systems, ensuring compliance with global safety standards .

Although it might seem like this component should be mandatory, the choice is to keep it optional. This is because some plants may already possess a pneumatic cabinet that only requires integration with the cables and pipes provided with the robots.

2.2.6 The Software

The software is a critical element of painting processes, enabling control, programming, and interaction with the robotic system and its peripherals. For the target market of system integrators in General Industry, the software offering is structured into two tiers: an included base package and an optional premium component.

The included software package comprises RobView and RobotStudio Online Programming. RobView typically serves as the Human Machine Interface (HMI), providing a user-friendly graphical interface for operators to monitor the process, manage recipes, and execute basic commands on the robotic cell. It offers essential functionalities for daily operation and supervision. RobotStudio Online Programming, on the other hand, involves directly programming the physical robot while it is connected and typically paused or running specific test routines. This method allows for real-time teaching of points and basic movements by physically guiding the robot or jogging it via the teach pendant. It is suitable for simple tasks, minor adjustments, troubleshooting, and fine-tuning existing programs directly on the factory floor. However, it requires the robot to be taken out of production for programming activities, which can lead to downtime.

The optional, premium software component is RobotStudio Offline Programming. This powerful PC-based software allows system integrators to design, program, and simulate the entire robotic cell and its processes in a virtual environment without needing access to the physical robot. The advantages of RobotStudio Offline for system integrators in the GI sector are significant. Firstly, it enables programming and optimization of complex robot paths and application logic off-site and parallel to cell construction or production, drastically reducing the time required for on-site commissioning. Secondly, it provides advanced simulation capabilities, including collision detection, reach analysis, and cycle time optimization, allowing integrators to virtually validate the cell design and process before implementation, thereby mitigating technical risks and costly on-site modifications. Furthermore, offline programming facilitates the creation of highly detailed and efficient programs for varying product types or geometries, enhancing the flexibility and capability offered to the final customer. This premium option offers greater efficiency, reduced downtime, and enhanced planning capabilities, making it particularly valuable for integrators handling diverse projects and aiming to minimize disruption at the customer's site.

Table 2.1 summarizes the components of the function package.

Table 2.1 Classifications of Core and Optional Elements of the Function Package

Element	**Purpose**	**Key Metrics**	**Allowable Customisation Margin**	**Core/Optional**
Robot	Precise movement and positioning of the paint applicator	Accuracy, cycle time, number of axes, payload, reachability	Choice and configuration of the 7th axis, type of robot	Core
Process	Paint supply	Max Pressure	Type of process, choice of paint type	Core
Applicators	Paint application	Paint category, transfer efficiency, air consumption, flow rate	Bell or gun, paint type, brand	Core
Tool Cleaner	Automatic applicator maintenance	Cycle time, water consumption	Brand, contactless or brush	Optional
Pneumatic Cabinet	Safe and efficient compressed air control for painting processes	Air pressure, air filtration, ATEX compliance	Possibility of integration with existing pneumatic cabinets in the plant	Optional
Software	Control, programming, and interaction with the robotic system and peripherals	Ease of use, simulation capabilities	Choice between basic package (RobView, RobotStudio Online Programming) and premium package (RobotStudio Offline Programming)	Core + Optional

3. Quality Function Deployment (QFD): A Framework for Customer-Centric Product Development

3.1 QFD Principles and Purpose: Origin, Core Philosophy, and Organizational Benefits

Quality Function Deployment (QFD) is a highly structured methodology for product and service design, originating in Japan in the late 1960s by Professors Shigeru Mizuno and Yoji Akao, and furtherly defined by Professor Akao in 2004.[5]

At its core, QFD is a system for systematically capturing the "Voice of the Customer" (VoC), encompassing both explicit and implicit needs, and rigorously translating this voice into tangible, measurable design targets and specific production processes. The fundamental principle is to ensure that customer desires guide every decision throughout the entire product development process, from initial concept generation to final production and delivery. This methodology is often described as a structured approach that enables a development team to define what will satisfy the customer and then to "deploy" the functional methods to achieve that satisfaction.

The primary purpose of QFD is to translate qualitative customer needs, often expressed in vague terms such as "easy to use" or "reliable," into precise, quantifiable engineering specifications and detailed production planning requirements. This systematic translation ensures that product development efforts are directly aligned with customer expectations.

Implementing QFD offers numerous potential benefits to an organization:

- Enhanced Customer Focus: It compels the development team to deeply understand, prioritize, and consistently address customer needs throughout the product lifecycle.
- Improved Communication: QFD provides a common framework and a visual language through its matrices, significantly facilitating clear and effective communication across different functional departments, including marketing, design, engineering, manufacturing, and sales.

[5] Akao, Y. (2004). Quality Function Deployment: Integrating Customer Requirements into Product Design

- Reduced Development Time and Cost: By systematically identifying potential issues, conflicts, and design flaws early in the design phase, QFD can substantially reduce costly redesign loops, rework, and delays later in the product development process.
- Better Design Decisions: It provides a structured, data-driven basis for making informed design trade-offs and prioritizing specific product features based on their impact on customer satisfaction.
- Documentation and Knowledge Capture: The QFD matrices serve as a valuable, centralized repository of the rationale behind design decisions, market understanding, and customer insights, which can be leveraged for future projects.
- Competitive Advantage: By focusing on unmet customer needs and ensuring superior technical execution, QFD helps organizations identify opportunities to differentiate their products in the market and gain a competitive edge.

3.2 The House of Quality (HoQ) Methodology: Structure and Construction

The House of Quality (HoQ) matrix stands as the fundamental and most recognized tool within the QFD methodology, particularly for the Product Planning phase. Its distinctive visual structure, resembling a house, provides a comprehensive framework for systematically relating customer needs to technical requirements, comprising several key sections, each serving a specific analytical purpose. Constructing the House of Quality is typically a collaborative, team-based effort involving cross-functional expertise.

3.2.1 Identifying Customer Requirements

This initial step is arguably the most critical, as any inaccuracies or omissions at this stage will propagate and negatively impact the entire subsequent QFD process. The objective is to fully identify and understand the needs and expectations of the target customer.

Gathering the Voice of the Customer (VoC): Techniques for collecting the VoC are diverse and include direct customer interviews, structured surveys and questionnaires, facilitated focus groups, and direct observation of customers using products or performing relevant tasks. Crucially, for a product like the Function Package that targets intermediaries (integrators) rather than end-users, the emphasis on collecting VoC from *indirect* sources is particularly vital. This includes analyzing existing market research data, sales data, customer support logs, and warranty claims. This approach allows ABB to infer end-user needs and pain points, providing a more accurate understanding of the market's underlying demands. For example, recurring issues identified in warranty claims from end-users would signal a critical underlying need for enhanced robustness or simplified maintenance. This is especially important given that paint processes are extremely difficult to understand for the end user, implying that end-users' stated needs might be vague, but their operational data can be very specific and actionable.

Structuring Needs: Once collected, the raw customer feedback must be organized and structured into a clear, hierarchical list of customer requirements. It is crucial to state these needs in the customer's own language where possible, or at least from their perspective, focusing explicitly on *what* the customer wants the product to *do*, rather than prescribing *how* it should be done.

Importance Ranking: Simultaneously, the relative importance of each customer requirement must be determined, as customers typically do not value all features equally. Various scaling methods can be employed to rank the relative importance, often obtained directly from customer surveys or through cross-functional team consensus based on the gathered data. This weighting is crucial for effectively prioritizing technical efforts later in the process.

3.2.2 Translating to Technical Requirements

The next step involves translating the identified customer requirements into measurable, precise technical characteristics or specifications. These are the "Hows" – defining *how* the organization will achieve the "Whats" that the customer desires. This phase necessitates significant cross-functional expertise, particularly from engineering and design teams.

Technical requirements should be expressed in precise, quantifiable terms whenever feasible. For instance, if a customer requirement is "easy to use," a corresponding technical requirement might be quantified as "time to complete basic task" or "number of steps in setup process". It is paramount to ensure that these technical requirements are actionable and represent aspects of the product that the design and engineering teams can directly control and measure. Common methods for identifying these "Hows" include structured brainstorming sessions and rigorous technical analysis of existing products or relevant technologies.

3.2.3 Building the Relationship Matrix

The core of the House of Quality is the relationship matrix, which visually illustrates the interdependencies between the customer requirements ("Whats" listed on the left side of the matrix) and the technical requirements ("Hows" listed across the top). For each intersection point in the matrix, the cross-functional team assesses the strength of the relationship between a specific customer need and a specific technical characteristic.

A commonly used symbolic system represents the strength of these relationships:

- Strong Relationship: Depicted by a solid circle (•) or a high numerical value (e.g., 9), indicating a significant and direct impact on satisfying the customer requirement.
- Medium Relationship: Depicted by an open circle (○) or a moderate numerical value (e.g., 3), indicating a moderate impact.
- Weak Relationship: Depicted by a triangle (△) or a low numerical value (e.g., 1), indicating a minor or indirect impact.
- No Relationship: Left blank or represented by a zero (0), indicating no significant connection.

3.2.4 Conducting Competitive Analysis

To gain a comprehensive understanding of the market landscape and identify strategic opportunities for competitive advantage, the House of Quality typically incorporates dedicated sections for competitive analysis.

- Customer Competitive Assessment: Located to the right of the customer requirements, this section evaluates how well key competitors (and potentially the organization's current product offering) are perceived by customers in satisfying each of the listed customer requirements. This assessment can be derived from customer surveys or expert panel evaluations. The insights gained are crucial for identifying areas where competitors are strong or weak from the customer's perspective, and for highlighting customer needs that are currently underserved by the market.
- Technical Competitive Assessment: Positioned below the technical requirements, this part evaluates how well competitors perform on each of the defined technical requirements. This evaluation is typically based on objective measurements or rigorous engineering analysis. Comparing the organization's current or planned technical performance against competitors provides invaluable insights into technical

feasibility, potential areas for product improvement, and opportunities for strategic differentiation in the market.

3.2.5 Defining Technical Correlations (The "Roof")

Above the technical requirements, a triangular matrix known as the "roof" or "correlation matrix" is constructed. This critical section illustrates the relationships and interdependencies between the technical requirements themselves. It acknowledges that altering one technical specification can have either a positive or negative impact on another.

Common symbols represent the strength and direction of these correlations:

- Strong Positive Correlation: (++) or a symbol signifying strong reinforcement, meaning improving one technical requirement strongly aids another.
- Positive Correlation: (+) or a symbol signifying moderate help, suggesting improving one technical requirement moderately helps another.
- Negative Correlation: (-) or a symbol signifying difficulty, implying improving one technical requirement makes another more challenging.
- Strong Negative Correlation: (--) or a symbol signifying strong opposition, denoting that improving one technical requirement significantly hinders another.

Analyzing these correlations is crucial for the design team as it helps identify potential design conflicts, trade-offs, or synergistic opportunities early in the development process. For instance, increasing a product's speed might negatively affect its energy efficiency, and the "roof" matrix would highlight this trade-off, indicating an area that requires careful management during design.

3.2.6 Prioritizing Technical Requirements and Setting Target Values

The final step in constructing the House of Quality involves synthesizing all the information gathered in the previous steps to prioritize the technical requirements and set specific, measurable target values for the new product's design.

This is often achieved by calculating the "raw weight" or "absolute importance" of each technical requirement. This is typically calculated by summing the product of the customer importance rating for each "What" and the strength of its relationship with a given "How". The relationship strengths are usually converted to numerical values for this calculation (e.g., 9 for strong, 3 for medium, 1 for weak). For example, if Customer Need A

(Importance 5) has a Strong relationship (9) with Technical Requirement 1, and Customer Need B (Importance 3) has a Medium relationship (3) with Technical Requirement 1, the contribution to Technical Requirement 1's weight from these two needs is (5 * 9) + (3 * 3) = 45 + 9 = 54. Summing these values across all customer needs yields the total raw weight for Technical Requirement 1.

These calculated raw weights are then used to rank the technical requirements in order of priority. The results from the competitive analysis (both customer and technical) and the insights from the technical correlations are also critically considered when setting the final target values for the most critical technical requirements. Realistic and achievable targets are established based on technical feasibility, competitive benchmarking, and the desired market positioning for the product.

4 Defining Function Packages HoQ

4.1 The Voice of Customer

As anticipated, the first and most critical part of the construction of the house of quality, is about gathering the customer requirements, the so called whats or voice of customer.

In a project like the function package, this has to be done retrieving information from customer requests and, since the provision is of a painting station, something ABB has a strong expertise on, also from colleagues' experience.

To better understand what the customer needs are, a sort of competitive analysis has to be done. As already stated though, there is no package as a product in the painting environment yet, so the way-to-go here is to look for analogies found on the market, to have a perception of the winning points of competitors.

Last but not least, there have been structured interviews with the side of the team which deals with system integrators and line builders. These people, especially during the last meetings with potential customers, tried to understand the needs and the pain points.

All these procedures combined together generated a list of customer requirements to fill the section of the “whats” of the house of quality that will be built.

Based on the analysis, the following key customer requirements were identified and grouped by theme, the relative explanation of each requirement is given:

Performance and Operational Efficiency

- Efficient Work Cycle Time: This is a cornerstone of any production process. For the customer, an efficient work cycle translates directly to higher throughput and increased productivity. The requirement is to design a system that operates smoothly and predictably, minimizing idle time and eliminating bottlenecks to maximize the number of parts processed per hour.
- Quick Color Change: This is a critical factor for customers who employ high-mix, low-volume production strategies, requiring frequent changes to the paint color. An

effective color change process minimizes production downtime. This operation encompasses not just the mechanical act of supplying a new color but also the automated or semi-automated purging and cleaning of all paint lines and the applicator itself. Reducing this changeover time is a significant driver of Overall Equipment Effectiveness (OEE).

- Efficient Automated Cleaning Cycle: Directly supporting the previous requirements, an automated cleaning cycle is essential for customers seeking to maximize automation and efficiency. It ensures that the applicator and paint system are cleaned to a consistent standard without manual intervention, which in turn enables faster color changes and guarantees the quality of the subsequent painting process.
- Fast Setup and Commissioning: The value of a "Function Package" is heavily dependent on its ability to be deployed rapidly. Customers expect to minimize the time between system delivery and the start of production (time-to-production). This requirement benefits the customer by accelerating their return on investment and also benefits the supplier (ABB) by reducing the deployment costs associated with on-site engineering personnel, a saving which can be reflected in the product's overall price.

System Flexibility and Adaptability

- Compatibility with Various Paint Types: For a system integrator, the ability to propose the Function Package for a wide array of end-customer applications is paramount. This requirement ensures that the system is engineered to handle different paint chemistries (e.g., water-based, solvent-based, powder coatings), thereby maximizing the potential market share and making the Function Package a versatile and broadly applicable solution.
- Flexibility in Applicator Choice and Interchangeability: A wide selection of compatible applicators provides the customer with the ability to optimize their painting process based on specific needs, balancing factors like finish quality, application efficiency (transfer efficiency), and cost. Furthermore, applicator interchangeability empowers the customer to autonomously re-tool the robotic system for different products or applications, enhancing the long-term value and flexibility of their investment.
- Ease of Integration with Pre-existing Systems: It is common for this Function Package to be installed in established facilities ("brownfield" projects). Therefore, the system must be designed for seamless integration with existing production

lines, both upstream and downstream. This implies the use of standardized communication protocols and interfaces that minimize the complexity and cost of integration.

Quality, Reliability, and Usability

- System Reliability and Robustness: In an industrial environment, system downtime has immediate and significant financial consequences. This requirement reflects the fundamental need for a durable and dependable system that can operate continuously with minimal unplanned interruptions. It is also a hallmark of the ABB brand, which builds its reputation on the quality and longevity of its automation solutions.
- Efficient Integration Among Package Components: The core value proposition of a "Function Package" is that the customer receives a pre-validated, turnkey solution. The responsibility for ensuring that all components (the robot, controller, paint supply, and applicator) work together seamlessly lies with the supplier. Delivering a product where this integration is not optimized would negate the primary value of the package itself, as it would shift the integration burden back to the customer.
- Ease of Use and Programming: An intuitive and user-friendly system reduces the learning curve and the required skill level for operators. This leads to shorter training times, lower operational costs, and a reduced likelihood of human error during production, thereby enhancing overall safety and productivity.

Economic Efficiency and Support

- Cost Efficiency: This requirement extends beyond the initial purchase price to encompass the Total Cost of Ownership (TCO). The key economic advantage of the Function Package stems from its scalable, pre-configured engineering, which is amortized over many units sold. This model minimizes the non-recurring engineering and on-site personnel costs for each installation, delivering a highly cost-efficient solution to the customer.
- Space Efficiency: In many manufacturing facilities, floor space is a limited and valuable resource. A compact system footprint is therefore a significant practical advantage, allowing the Function Package to be integrated more easily into crowded or space-constrained production environments.

- Availability of Technical and After-Sales Support: The customer relationship does not end after the sale. Providing comprehensive and accessible support throughout the product's lifecycle is critical for building long-term trust and ensuring the customer achieves maximum uptime and value from their investment. This includes technical assistance, service, and spare parts availability.

4.1.1 Customer Requirements Importance Ranking

Following the identification and categorization of the Voice of the Customer, the next crucial step in the Quality Function Deployment (QFD) methodology is to assign a relative importance ranking to each requirement.

These importance ratings were determined through a series of structured brainstorming sessions and collaborative workshops. These sessions involved not only the core project team but also drew upon the extensive experience of colleagues from outside the immediate team, particularly those in roles with direct and frequent contact with line builders and system integrators. This cross-functional consensus was used to assign a value to each customer need on a scale of 1 to 5, where 1 indicates low importance and 5 represents a critical, must-have requirement from the customer's perspective.

The consolidated data from this analysis is detailed in **Table 4.1**. The resulting averages show that "Cost efficiency" emerged as the most critical requirement (4.875), followed closely by "Efficient integration among package components" (4.375), "Ease of Integration with pre-existing system" (4.125), and "Ease of use and programming" (4.125). Conversely, "Quick color change" and "Space efficiency" (both 2.25) were identified as lower priorities in this context. These average values are utilized as the final reference for the Customer Requirements (CR) ranking.

Table 4.1 Customer Requirements Importance Ranking, Cross-Functional Team Evaluations and Average Values

	Rankings (1-5)								
Customer Requirement	**Colleague 1**	**Colleague 2**	**Colleague 3**	**Colleague 4**	**Colleague 5**	**Colleague 6**	**Colleague 7**	**My Values**	**Average Value**
Efficient work cycle time	3	1	2	3	4	5	5	4	3.375
Quick color change	1	4	3	2	2	2	2	2	2.25
Efficient automated cleaning cycle	4	5	3	1	2	2	3	3	2.875
Fast Setup and Commissioning	5	5	4	5	5	1	2	5	4
Compatibility with various paint types	1	2	3	2	3	2	3	3	2.375
Flexibility in applicator choice and interchangeability	2	4	4	4	4	4	4	4	3.75
Ease of Integration with pre-existing system	5	2	4	5	5	4	4	4	4.125
System reliability and robustness	4	4	4	2	4	3	5	4	3.75
Efficient integration among package components	4	5	4	5	4	4	4	5	4.375
Ease of use and programming	4	4	4	5	5	3	4	4	4.125
Cost efficiency	5	4	5	5	5	5	5	5	4.875
Space efficiency	2	3	3	1	1	1	4	3	2.25
Availability of technical and after-sale support	3	4	5	3	1	4	4	3	3.375

These values represent the vision of the cross functional team, composed of people with different roles and areas of expertise. This is also enlightened by the different values attributed to the same characteristic by different colleagues.

These carefully weighted priorities thus provide a robust and realistic foundation for the next phase of the QFD analysis: translating customer needs into measurable technical characteristics.

4.2 The Technical Characteristics

To define the Hows or Technical Characteristics, the objective is to translate the Voice of Customer into specific, measurable, and controllable technical parameters.

So the list of the Technical characteristics is as follows:

1. Corresponding to "Performance and Operational Efficiency"

- Robot maximum speed (m/s)
- Automated cleaning cycle time (seconds)
- Total installation & commissioning time (hours)

2. Corresponding to "System Flexibility and Adaptability"

- Supported paint viscosity range (cPs - centipoise)
- Compatibility with all paint types (Yes/No)
- Standardized applicator interface/flange (Yes/No)
- Time to change applicator (minutes)
- Supported industrial communication protocols (List: e.g., PROFINET, EtherNet/IP)

3. Corresponding to "Quality, Reliability, and Usability"

- Mean Time Between Failures (MTBF) (hours)
- System availability (%) (Probabilità che il sistema sia in funzione quando deve essere utilizzato)
- Operator training time (hours)

4. Corresponding to "Economic Efficiency and Support"

- Initial purchase cost (€)
- Energy consumption per cycle (kWh)
- Paint transfer efficiency (TE) (%)
- System footprint (m^2)
- Guaranteed support response time (hours)

4.3 Building the relationship Matrix

The core of the House of Quality translates the Customer Requirements (VoC) into measurable Technical Characteristics (TCs). This relationship matrix, detailed in **Table 4.2**, identifies the strength of the relationship between each "What" (customer need) and each "How" (technical solution), utilizing a scale where 9 signifies a strong correlation, 3 a moderate, and 1 a weak relationship.

Table 4.1 The House of Quality Relationship Matrix

	Robot maximum speed	Automated cleaning cycle time	Total installation & commissioning time	Supported viscosity range	Compatibility with all paint types	Standardized applicator interface/flange	Time to change applicator	Supported industrial communication protocols	Mean Time Between Failures	System availability	Operator Training Time	Initial Purchase Cost	Energy Consumption per Cycle	Paint Transfer Efficiency	System Footprint	Guaranteed Support Response Time
Efficient work cycle time	9	3				1	3		1	1				3		1
Quick color change		9					1									
Efficient automated cleaning cycle	1	9														
Fast Setup and Commissioning			9			3					9					
Compatibility with various paint types				9	9	3					3					
Flexibility in applicator choice and interchangeability				3		9	9				1					
Ease of Integration with pre-existing system				3	3			9								
System reliability and robustness								1	9	9						
Efficient integration among package components									3	3	3					
Ease of use and programming										1	3					
Cost efficiency						9						9	3	9		
Space efficiency															9	
Availability of technical and after-sale support																9

A noticeable diagonal trend of strong (9) correlations is evident in the matrix. This is a logical result of the methodology, as customer requirements have often been translated sequentially into their most direct technical counterparts. Consequently, while this diagonal highlights the most obvious relationships, the off-diagonal correlations are crucial for uncovering less apparent, yet significant, interdependencies.

The analysis reveals several direct and defining relationships, rated with the highest score of 9. For instance, the requirement for a "Quick color change" is almost exclusively dependent on the "Automated cleaning cycle time." Similarly, customer needs such as "Fast Setup and Commissioning," "Space efficiency," and "Availability of technical and after-sale support" are directly quantified by their corresponding technical metrics: "Total installation & commissioning time," "System Footprint," and "Guaranteed Support Response Time," respectively . The critical demand for "System reliability and robustness" is directly measured by both "Mean Time Between Failures (MTBF)" and "System availability."

Strong correlations also highlight key value drivers. "Efficient work cycle time" is strongly correlated with "Robot maximum speed," as this is the primary physical limitation on process speed . The requirement for "Flexibility in applicator choice and interchangeability" is strongly met by having both a "Standardized applicator interface/flange" and a low "Time to change applicator," which together enable swift and simple hardware modifications . Furthermore, "Cost efficiency" is strongly influenced by the "Initial Purchase Cost" and the "Paint Transfer efficiency," as the latter directly minimizes material waste and operational expenses, but also strongly affected by “Standardized applicator interface/flange”, as this allows the customer to install different applicators on the same robot. Critically, the "Ease of Integration with pre-existing system" is strongly dependent on the "Supported industrial communication protocols," as this technical feature is the primary enabler for interoperability within a factory environment.

Moderate relationships (3) identify significant secondary interactions. For example, "Efficient work cycle time" is moderately affected by the "Automated cleaning cycle time" the "Time to change applicator" and the “ Paint transfer efficiency”, since these activities contribute to the overall time of a production sequence . The "Ease of use and programming" is logically linked to "Operator Training Time," as a more intuitive system requires less training.

Finally, weak relationships (1) denote minor or indirect influences. For example, a "Standardized applicator interface/flange" has a weak, indirect impact on "Efficient work cycle time" because while it does not dictate the painting speed, it can marginally reduce time during maintenance or applicator swaps within a larger operational window.

4.4 Competitive Analysis: A Blue Ocean Strategy in a Crowded Market

Defining the competitive landscape for the Function Package presents a unique analytical challenge. A conventional competitive analysis proves difficult because, as a pre-integrated, productized solution combining a robot with all necessary peripherals for painting, the Function Package currently has no direct market equivalent. This absence of direct competitors initially suggests the product is positioned within a "blue ocean," an uncontested market space ripe for growth. However, this view is only partially accurate. While the *product* itself is novel, the *service* of integrating a robot with its peripherals is a well-established practice offered by system integrators themselves. In fact, ABB has traditionally provided such highly customized, project-based solutions for its clients, particularly in the demanding automotive OEM sector.

This situation gives rise to a strategic dichotomy: is the Function Package a pioneering product entering a blue ocean, or does it face competition from every system integrator capable of engineering a similar custom solution? This apparent paradox, operating in what seems to be a new product category within a mature and well-understood market, was the subject of considerable internal debate and required extensive analysis by the project team to clearly delineate the strategic path forward.

The resolution to this strategic dilemma was found by shifting the analytical focus from the immediate customer, the system integrator, to the ultimate beneficiary: the end-user who will utilize the robotic station to paint their products. From the end-user's perspective, the Function Package creates new, unexplored market opportunities by delivering exceptional cost efficiency. By standardizing the offering and moving from a bespoke engineering *project* to a pre-engineered *product*, the associated management and operational costs are drastically reduced. This makes advanced robotic painting solutions accessible to a segment of the General Industry market, such as SMEs, that previously could not consider such automation due to the prohibitively high costs and complexity of custom integration projects.

While these new entrants to automation represent a significant future market for the Function Package, the reality is that the largest initial customer base will likely consist of companies already familiar with robotic painting. For this segment, the Function Package offers a compelling value proposition: a solution from a trusted brand like ABB at a more competitive price point compared to a fully engineered, custom system.

This brings us back to the fundamental question: who are the true competitors of the Function Package? As established through this analysis, the answer is not straightforward. System integrators can deliver a solution with an analogous outcome, but it is a service-based *project* with a higher cost structure, not a comparable *product*. Critically, system integrators are positioned not as competitors, but as the primary customers for the Function Package. They benefit by acquiring a pre-integrated, reliable core system, allowing them to avoid non-core activities like peripheral integration and software configuration, thus addressing their key pain points. This relationship is not one of "coopetition," but a clear supplier-customer dynamic.

Therefore, the final conclusion reached by the team is that the Function Package, as a product, effectively has no direct competitors. It is positioned in a market environment that ABB understands intimately, and this deep knowledge was invaluable for benchmarking during the product's conception. Ultimately, the team has committed to pursuing a "Blue Ocean Strategy," recognizing that the product's pioneering approach creates an entirely new value proposition and opens up a previously untapped segment of the market.

4.5 Analysis of the Technical Correlations (The Roof)

Table 4.4 represents the relationship between the technical characteristics and will compose the roof of the House of Quality.

	Robot maximum speed	Automated cleaning cycle time	Total installation & commissioning time	Supported viscosity range	Compatibility with all paint types	Standardized applicator interface/flange	Time to change applicator	Supported industrial communication protocols	Mean Time Between Failures	System availability	Operator Training Time	Initial Purchase Cost	Energy Consumption per Cycle	Paint Transfer efficiency	System Footprint	Guaranteed Support Response Time
Robot maximum speed												-	-			
Automated cleaning cycle time													-			
Total installation & commissioning time																
Supported viscosity range					+							-				
Compatibility with all paint types																
Standardized applicator interface/flange																
Time to change applicator																+
Supported industrial communication protocols										+		-				
Mean Time Between Failures										++						
System availability																
Operator Training Time																
Initial Purchase Cost														--		
Energy Consumption per Cycle																

Paint Transfer efficiency																
System Footprint												--				
Guaranteed Support Response Time																

Table 4.4 The Technical Correlation Matrix (The "Roof" of the HoQ)

The technical correlations in the roof of the House of Quality are based on key engineering principles and product-specific trade-offs. The rationale for these relationships is as follows:

A significant negative correlation (-) is established between Robot Maximum Speed and Initial Purchase Cost. This is driven by the product options available; the faster IRB 5510 robot is also the more expensive model. A similar negative correlation exists between Robot Maximum Speed and Energy Consumption per Cycle, as operating the robot at higher speeds logically increases its power consumption during a work cycle. Furthermore, a negative relationship is identified between Automated cleaning cycle time and Energy Consumption per Cycle, because the operation of the automated cleaning system itself adds to the total energy consumed during a full production sequence.

Synergies and trade-offs are also evident in the paint handling characteristics. A positive correlation (+) exists between Supported viscosity range and Compatibility with all paint types. This is because the ability to handle a wider range of viscosities is a prerequisite for supporting different paint chemistries, such as higher-viscosity solvent-based paints. However, this creates a negative correlation (-) with Initial Purchase Cost, since an applicator capable of managing a broad viscosity range is technologically more complex and therefore has a higher manufacturing cost. Similarly, supporting multiple Supported Industrial Communication protocols introduces a trade-off with Initial Purchase Cost, as broader compatibility requires additional hardware or software licensing, increasing the overall price.

The matrix highlights two strong negative correlations (--) that represent major design challenges. The first is between Initial Purchase Cost and Paint Transfer efficiency. High transfer efficiency is primarily achieved using rotary atomizers (bells), which, despite being proprietary ABB components, represent a significant cost increase over standard applicators. The second strong trade-off exists between System Footprint and Initial Purchase Cost. This may seem counterintuitive, but the smallest footprint is achieved with the more advanced and costly IRB 5510 robot. Therefore, customers must trade a higher initial cost for the advantage of a more compact installation.

The matrix highlights a strong positive correlation (++) between Mean Time Between Failures (MTBF) and System Availability. This is because the two metrics are mathematically and intrinsically linked. System Availability is a direct function of a system's reliability (MTBF) and its maintainability, represented by the Mean Time To Repair (MTTR).

The relationship is defined by the formula:

$$System\ Availability = \frac{MTBF}{MTTR + MTBF}$$

Given this direct mathematical dependence, an increase in MTBF necessarily leads to an increase in System Availability, representing a clear and powerful synergy.

4.6 Prioritizing Technical Requirements and Setting Target Values

The culmination of the House of Quality methodology involves synthesizing the gathered information to prioritize the identified Technical Characteristics and establish specific target values for the Function Package. This crucial step ensures that design and development efforts are strategically aligned with the most impactful customer needs.

The prioritization process begins by calculating the "raw weight" or "absolute importance" for each Technical Characteristic. This is achieved by multiplying the "Average Value" (importance ranking) of each Customer Requirement by the corresponding strength of its relationship with a given Technical Characteristic, as defined in the Relationship Matrix. The relationship strengths are assigned numerical values for this calculation: 9 for a strong relationship, 3 for a medium relationship, and 1 for a weak relationship. The products are then summed vertically for each Technical Characteristic to determine its total raw weight.

This calculation provides a quantitative measure of how much each Technical Characteristic contributes to satisfying the overall customer requirements. A higher raw weight indicates that the Technical Characteristic has a greater impact on customer satisfaction, either by strongly influencing a few critical needs or by moderately influencing many needs.

Following the calculation of raw weights, "relative weights" are determined by expressing each raw weight as a percentage of the total raw weights. This allows for an easier comparison of the proportional importance of each Technical Characteristic. The competitive analysis insights (both customer and technical assessments) and the interdependencies identified in the "roof" matrix (technical correlations) are then critically considered. These insights help in refining the priorities and setting realistic and ambitious target values for the Function Package. The target values are established based on technical feasibility, competitive benchmarking, and the desired market positioning to ensure the product not only meets customer expectations but also offers a competitive advantage.

Table 4.5 presents the calculated raw and relative weights for each Technical Characteristic, serving as a guiding framework for the subsequent product development phases.

Table 4.5 Final QFD Matrix: Technical Characteristic Prioritization (Absolute and Relative Weights)

	Robot maximum speed	Automated cleaning cycle time	Total installation & commissioning time	Supported viscosity range	Compatibility with all paint types	Standardized applicator interface/flange	Time to change applicator	Supported industrial communication protocols	Mean Time Between Failures	System availability	Operator Training Time	Initial Purchase Cost	Energy Consumption per Cycle	Paint Transfer efficiency	System Footprint	Guaranteed Support Response Time
Efficient work cycle time	9	3				1	3		1	1				3		1
Quick color change		9					1									
Efficient automated cleaning cycle	1	9														
Fast Setup and Commissioning			9			3					9					
Compatibility with various paint types				9	9	3					3					
Flexibility in applicator choice and interchangeability				3		9	9				1					
Ease of Integration with pre-existing system				3	3			9								
System reliability and robustness								1	9	9						
Efficient integration among package components									3	3	3					
Ease of use and programming										1	3					
Cost efficiency						9						9	3	9		
Space efficiency															9	
Availability of technical and after-sale support																9
Absolute Weight	33,25	56,25	36	45	33,75	100,125	46,125	40,875	50,25	54,375	72,375	43,875	14,625	54	20,25	33,75
Relative Weight	4,52%	7,65%	4,90%	6,12%	4,59%	13,62%	6,28%	5,56%	6,84%	7,40%	9,85%	5,97%	1,99%	7,35%	2,76%	4,59%

A paramount finding from the analysis is the importance of Operator Training Time, which emerged as one of the leading technical characteristics with a relative weight of 9.85%. This result strongly aligns with the core value proposition of the Function Package, which is to deliver a "plug-and-play" system designed to minimize complexity and accelerate deployment. For the target customers, a reduction in the time required for their personnel to learn and operate the system translates directly into lower on-site engineering costs and faster commissioning. This underscores the strategic necessity of engineering a product that is intuitive and can be rapidly brought into production with minimal on-site support from ABB, fulfilling the "plug-and-play" promise.

Standardized Applicator Interface/Flange is identified as a vital feature, commanding a significant relative weight of 13.62%. The importance of this characteristic comes from many factors. A standardized interface is the primary enabler for applicator interchangeability, allowing customers to seamlessly switch between different guns or bells to suit various products or paint types. This flexibility not only enhances the system's adaptability but is also a major contributor to reducing robot setup times. Consequently, it is a cornerstone of the package's versatility and long-term value proposition for the customer.

Directly linked to process efficiency is the Automated Cleaning Cycle Time, which ranks highly with a relative weight of 7.65%. This feature is one of the few controllable parameters that directly impacts the overall work cycle efficiency, a customer requirement that received a notable importance rating from the team. Optimizing the cleaning cycle is therefore crucial for minimizing production downtime, especially in high-mix, low-volume manufacturing environments that require frequent color changes.

Further emphasizing efficiency, Paint Transfer Efficiency (TE) also emerges as a key driver with a relative weight of 7.35%. This metric is critical as it directly influences both the quality of the final painted surface and the overall Cost Efficiency of the operation by minimizing material waste.

The fundamental need for system reliability in any industrial setting is clearly reflected in the high importance assigned to System Availability (7.40%) and Mean Time Between Failures (MTBF) (6.84%). These two metrics are intrinsically linked and address the customer's core requirement for a durable and robust machine capable of continuous, uninterrupted operation. This aligns with the reputation of the ABB brand, which is built on the quality and longevity of its automation solutions.

Other noteworthy characteristics identified through the analysis include the Supported Viscosity Range (6.12%) and the Time to Change Applicator (6.28%). The ability to handle a wide range of paint viscosities is an important prerequisite for the system’s market versatility, as customers often require specific paint properties for their products. Likewise, a short changeover time for the applicator directly enhances the system's flexibility and contributes to a more efficient overall cycle time, addressing another key customer need.

Conversely, while still relevant, characteristics such as System Footprint (2.76%) and Energy Consumption per Cycle (1.99%) were identified as having a lower relative impact on the core customer requirements for this specific product offering. This suggests that while space and energy efficiency are valued, they are secondary to the primary demands for ease of use, reliability, and operational flexibility in the target market.

5. Final product and conclusions

The final product is therefore the direct outcome of the considerations made during the Quality Function Deployment. After identifying the key parameters through an analysis of their relative weights, the team addressed the challenge of determining how to meet these requirements.

First and foremost, key partners capable of satisfying all the defined needs were identified. Consequently, the selected suppliers are companies with a global reputation in painting and automated paint applicator cleaning systems. For cup applicators, however, as previously mentioned, the supply remains internal to ABB.

For each process type, two to four applicators were selected. This selection included at least one high-quality, higher-cost product to meet the demands of the Automotive OEM market, and at least one for the General Industry (GI) market. To minimize preliminary configuration and testing times, solutions already adopted by other ABB paint teams were prioritized. To achieve this, colleagues from the main US and Asian sites were contacted to gather crucial product information. Combining their know-how with that of the Turin team resulted in a curated list of paint guns that met the specifications defined in the analysis. Suppliers were subsequently contacted, the project was outlined to them, and specific information regarding the selected applicators was requested.

This rigorous selection and data-gathering process enabled the team to address multiple criteria defined during the analysis. The collected data allowed for the design of standard flanges adaptable to multiple applicators and simple to replace. The choice of international suppliers ensures reduced training times, thanks to their well-structured manuals tested across a large customer base and the high probability that operators will have prior experience with that particular supplier's equipment. This data-driven approach also ensured that standards for transfer efficiency, compatibility with a wide variety of paints, and instrument reliability were met.

Concurrently with the applicators, the paint distribution processes were selected. For low-pressure systems, the supply is exclusively internal. For high-pressure and powder coating applications, the decision was made to pair each gun exclusively with a distribution process from the same manufacturer. This strategy meets efficiency requirements and streamlines after-sales support by eliminating the risk of contacting multiple service centers that might shift responsibility to the other component's supplier in case of an issue. Furthermore, using applicators and processes designed to work together minimizes potential problems during training, drastically reduces time spent researching compatibility, and leads to a clearer and more straightforward product presentation.

For the automated cleaning technology, suppliers were chosen based on extensive prior experience and their proven ability to guarantee minimal cycle times.

The other components, while important, are of secondary relevance in this analysis as they are already standardized. The ABB robot offering consists of just two models, the pneumatic cabinet contains standard and mandatory components, and the software is ready-to-use and can be quickly configured by ABB technicians.

Once the network of suppliers, both internal and external to the organization, was consolidated and the possible configurations of the function packages were defined, the process moved on to estimating the setup hours required for each package. This complex evaluation was conducted through a collaborative process involving in-depth consultations between the engineering and technical teams. The goal was to obtain accurate and realistic estimates, which are essential for planning and customer quoting.

In line with what was stated in the initial phases of the project, a detailed questionnaire was developed. This tool is intended to be sent to clients during the proposal stage and aims to serve as a communication bridge. Its main function is to translate the often generic or poorly defined requests of less experienced clients into clear specifications that can guide the selection of the most suitable function package for their specific project needs.

In parallel, a sophisticated function package configurator was developed within ABB. This is a highly versatile Excel worksheet that integrates a complete database of all possible components, a counter for automatic calculation, and a section dedicated to indicative prices and hours. This tool allows for the rapid generation of preliminary budget offers, streamlining and automating the process of defining the function package for the client, making it more efficient and smart.

The final phase of the internship project involved the creation of a PowerPoint catalog. This catalog was structured to clearly outline the different types of application processes and their associated products. Its main purpose is to be used in strategic meetings with system integrators and line builders, presenting them with the opportunity to adopt a complete and optimized function package capable of fully meeting their specific requirements.

For the upcoming months, the crucial phases of testing and software configuration are scheduled. These activities will be carried out by specialized technicians at the Vittuone site, where ABB's state-of-the-art laboratories are located. Particular attention will be paid to high-pressure applicators, a sector in which ABB, despite being a leader, intends to further strengthen its experience and expertise to ensure cutting-edge solutions and maximum performance.

List of Acronyms

- **ABB:** Asea Brown Boveri
- **ATEX:** ATmosphères EXplosibles
- **CAGR:** Compound Annual Growth Rate
- **CFM:** Cubic Feet per Minute
- **GI:** General Industry
- **HMI:** Human Machine Interaction
- **HVLP:** High Voltage Low Pressure
- **IECEx:** International Electrotechnical Commission System for Certification to Standards Relating to Equipment for Use in Explosive Atmospheres
- **IRB:** Industrial Robot
- **MTBF:** Mean Time Between Failures
- **NEC:** National Electrical Code
- **OEM:** Original Equipment Manufacturer
- **OEE:** Overall Equipment Efficiency
- **PLC:** Programmable Logic Controller
- **PSI:** Pounds per Square Inch
- **QFD:** Quality Function Deployment
- **SME:** Small and Medium-sized Enterprises
- **TCO:** Total Cost of Ownership
- **VoC:** Voice of the Customer

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