International Journal of Management, IT & Engineering
Vol. 15 Issue 7, July 2025,
ISSN: 2249-0558 Impact Factor: 7.119
Journal Homepage: http://www.ijmra.us, Email: editorijmie@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gate as well as in Cabell's Directories of Publishing Opportunities, U.S.A

# Lean Framework for New Product Introduction in Robotics and Hardware Startups

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**Abstract**

This article presented a structured framework for managing new product introduction (NPI) processes in robotics and hardware startups. The aim was to address common challenges in hardware product development in Robotics and Hardware, including high prototyping costs, extended iteration cycles, and cross-functional misalignment. The proposed solution was a seven-phase Lean NPI framework designed to support end-to-end product development, from initial concept validation through to post-launch growth. Each phase—Concept, Feasibility, Engineering Validation Test (EVT), Design Validation Test (DVT), Production Validation Test (PVT), Mass Production, and Post-Launch—was clearly defined with corresponding tasks, deliverables, timelines, and responsible roles. The framework incorporated structured tools for planning, engineering change management, product-market validation, and quality assurance. It was applied in practical scenarios within the robotics sector, providing evidence of improved team coordination, reduced time-to-market, and enhanced product-market fit. The findings demonstrated that by applying lean principles to hardware development, startups were able to improve predictability, reduce rework, and make better-informed decisions throughout the product lifecycle. The framework served as a reliable guide for hardware teams working under limited resources and time constraints. Conclusions suggested that structured, stage-based methodologies can significantly increase success rates in hardware product NPI launches.



***Keywords:***

Product Management,
Hardware Development,
Robotics,
New Product Introduction,
Lean Methodology

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## 1. Introduction

The The development of robotics and hardware products presents unique challenges compared to software, including longer development cycles, higher capital requirements, and complex supply chain dependencies. These challenges often result in delayed time-to-market, increased costs, and difficulty achieving product-market fit. Existing product management frameworks predominantly target software and are insufficient for addressing the intricacies inherent to hardware product development [1, 2].

A gap remains for a systematic, stage-based framework that integrates lean principles with hardware engineering realities to guide startups through New Product Introduction (NPI) effectively. Lean methodologies, focusing on waste reduction and continuous validation, have demonstrated success in software and manufacturing but require adaptation for robotics and hardware contexts [3, 4].

This paper proposes a Lean New Product Introduction framework specifically designed for hardware startups. The framework divides the product lifecycle into seven phases—Concept, Feasibility, Engineering Validation Test (EVT), Design Validation Test (DVT), Production Validation Test (PVT), Mass Production (MP), and Post-Launch Growth. Each phase includes well-defined tasks, deliverables, sprint durations, and assigned cross-functional roles, facilitating coordination among product managers, engineers, marketers, and operations teams. The innovation lies in blending agile and lean principles with hardware development best practices, including rigorous risk assessment, design-for-excellence (DFx), and structured product change management. This approach enhances development predictability, accelerates decision-making, and improves alignment between customer needs, technical feasibility, and business objectives [5].

## 2. Research Method

To ensure the framework was grounded in real-world practice, I conducted a series of 30-minute calls with representatives from 80 product companies specializing in hardware and robotics. Each conversation followed a structured format and included a short survey of five targeted questions focused on how these companies approach new product development. The survey explored key areas such as early-stage validation methods, team composition during development, iteration cycles, decision-making processes, and go-to-market planning. These insights offered a comprehensive view of the challenges and strategies employed by both startups and established firms. The consistency of patterns across these conversations helped validate the necessity for a stage-based approach and informed the specific structure of the seven-phase Lean NPI framework presented in this study. By synthesizing these qualitative findings, the resulting model bridges theoretical principles with the nuanced realities faced by product teams in robotics and hardware domains.

Table 1. The concept stage main focus, tools, team.

| | Stage | Main focus | Tasks | Tools | Sprint for Task | Team |
|---|---|---|---|---|---|---|
| 1 | Concept (TRL 1–2) 90 days | Idea, user research, problem validation. Understanding customers, defining goals, assessing finances, planning development, and preparing go-to-market strategies. | • Conduct Empathy Interviews<br>• Competitor analysis<br>• Define JTBD<br>• Perform 5W Analysis<br>• Estimate LTV<br>• Estimate Unit Economics<br>• Perform SWOT Analysis<br>• Develop Product Roadmap<br>• Create a GoToMarket plan<br>• Set OKRs/KPIs for shareholders | • Empathy Interviews 40 forms<br>• 20 Competitors Sheet<br>• JTBD canva<br>• 5 W canva<br>• LTV plan v1<br>• Unit Economy sheet v1<br>• SWOT canva<br>• Roadmap v1 Gantt chart<br>• GTM canva v1.<br>• OKRs/KPI sheet, BM canva v1 | - 30 days<br>- 7 days<br>- 7 days<br>- 7 days<br>- 10 days<br>- 7 Days<br>- 7 days<br>- 14 days<br>- 14 days<br>- 7 days | •CEO<br>•Product Manager<br>•Marketing director<br>•Research Analyst |

The Concept phase (Technology Readiness Levels 1–2) serves as the critical foundation of the Lean New Product Introduction (NPI) framework for robotics and hardware startups (Table 1.). Spanning 90 days, this stage aims to bridge early-stage ideas with validated market potential through structured research, strategic planning, and alignment among stakeholders. It is at this stage that the core of the product vision is formed, drawing on methods rooted in Lean Startup theory [11], customer discovery models, and strategic design thinking [10]. The emphasis lies on understanding customer needs, defining product goals, validating the problem space, and designing early go-to-market strategies—all while minimizing risk and waste. The practical workflow begins with conducting 40 empathy interviews to deeply capture user behavior and pain points. These insights feed into structured canvases such as the JTBD framework and the 5W analysis, which help articulate the core job the product is hired to do and contextualize customer motivations. Simultaneously, a thorough competitor analysis involving 20 direct and indirect alternatives allows the team to benchmark value propositions and identify differentiation opportunities, as emphasized by Ulrich & Eppinger [1].

Financial modeling is also introduced early through LTV (Lifetime Value) estimations and unit economics calculations. These tools, coupled with SWOT and market assessments, help determine not just product feasibility but also its business viability—key criteria for hardware ventures where capital efficiency is paramount [2][7]. With clear insights into the market and internal capabilities, the team develops a product roadmap using Gantt chart visualization and a comprehensive GTM (Go-To-Market) canvas. The Concept phase concludes with defining OKRs/KPIs for key stakeholders and compiling the first version of the Product Requirements Document (PRD v0.1), establishing a tangible bridge to the Feasibility stage.

The team structure supporting this phase typically includes the CEO, product manager, marketing director, and research analyst—each contributing domain-specific expertise in a cross-functional format. Sprint durations are pre-assigned to ensure focus and progress: for instance, interviews and economic models are allocated 7–30 days each, creating a time-boxed environment for iterative discovery. This configuration draws from Agile-Stage-Gate hybrids [3][4], which integrate agile's rapid iteration with stage-gate's structured deliverables, ensuring clarity without stalling momentum.

In essence, the Concept phase transforms uncertainty into structured opportunity. It applies lean thinking to map customer-centric hypotheses against business realities, producing validated insights and strategic direction. The result is a solid, de-risked foundation from which engineering teams can begin prototyping with confidence.Tables and Figures are presented center, as shown below and cited in the manuscript.

The Feasibility phase, corresponding to Technology Readiness Levels (TRL) 3–4, spans 60 days and serves as the technical and operational grounding of the product development process (Table 2.). Building upon the validated assumptions from the Concept phase, this stage focuses on cross-functional alignment, risk identification, component sourcing strategies, and the establishment of foundational engineering processes. It is during this phase that the product vision is translated into early technical requirements, and crucial architectural decisions begin to take shape. The objective is to determine whether the proposed solution is technically viable, manufacturable, and financially justifiable—key elements emphasized in the Agile-Stage-Gate approach to hardware development [2][3].

A critical first step involves aligning with engineering teams—both embedded and software—to validate the technical feasibility of the product architecture and launch Design for Excellence (DFx) and Design Failure Mode and Effects Analysis (DFMEA) efforts. These tools are essential for preemptively identifying design risks and optimization opportunities. In parallel, a draft version of the Bill of Materials (BOM) and Software BOM (SBOM) is created for both the minimum viable product (MVP) and the mass production roadmap. These early bills enable cost estimations, dependency tracking, and supply chain analysis. This phase also introduces formal change management processes, such as the Engineering Change Order (ECO) architecture, which establishes control mechanisms for iteration and documentation. Concurrently, supplier strategy is addressed by selecting potential OEM or ODM partners, a move that significantly influences both quality and scalability downstream. Backlog prioritization is performed using a story points matrix, allowing the team to forecast effort distribution and coordinate cross-departmental planning. Finally, the feasibility of the business model is assessed through a preliminary profit and loss (P&L) analysis, offering a clearer view of financial sustainability under various scenarios—aligning with the financial modeling practices discussed by Ulrich & Eppinger [1].

Supporting these activities are dedicated tools such as Jira or SAP for initial backlog setup, DFMEA documentation sheets, and detailed planning matrices. Each task is structured within clearly defined sprints ranging from 7 to 15 days, facilitating rapid yet coordinated progress. The team makeup becomes more engineering-heavy in this phase, involving the CTO, CFO, embedded and software team leads, the quality engineer, project manager, and product manager. Their collaboration ensures that feasibility is examined from technical, operational, and financial angles—ensuring that no critical assumption remains untested.

Overall, the Feasibility phase solidifies the foundation for prototype execution by merging strategic vision with actionable engineering input. By implementing rigorous assessments and collaborative planning, this stage reduces downstream risk, aligns internal capabilities with external realities, and prepares the product for the subsequent Engineering Validation Test phase.

Table 2. Feasibility phase main focus, tools, team.

| | | | | | | |
|---|---|---|---|---|---|---|
| 2 | Feasibility<br>(TRL 3–4)<br>60 days | Technical alignment, risk assessment, component planning, suplier monitoring, backlog prioritization, financial modeling. | • Align with engineers<br>• Launch DFx + DFMEA<br>• Draft BOM/SBOM v1 for MVP and MP<br>• Define management process (ECO)<br>• Select OEM/ODM<br>• Prioritize product backlog<br>• Calculate profit and loss model | • Initial backlog in Jira or SAP<br>• DFx and DFMEA sheet<br>• BOM/SBOM(v1) sheet<br>• ECO Architecture sheet<br>• OEM / ODM plan<br>• Story points matrix<br>• P&L sheet | - 14 days<br>- 10 days<br>- 15 days<br>- 7 days<br>- 10 days<br>- 7 days<br>- 14 days | CTO<br>CFO<br>Embedded team lead<br>Software team lead<br>Quality Engineer<br>Project Manager<br>Product Manager |

The Engineering Validation Test (EVT) phase (Technology Readiness Levels 5–6) represents a pivotal checkpoint within the Lean New Product Introduction (NPI) framework for robotics and hardware startups (Table 5.). This 60-day stage focuses on transforming conceptual designs and early prototypes into a validated MVP through direct engagement with users, internal stakeholders, and technical systems. The objective is to ensure that the core engineering assumptions align with real-world usage conditions and that the product is ready for refinement, scale, or potential strategic pivots.

The phase begins with establishing a UX-driven Voice of Customer (VoC) system that leverages behavioral tools such as heatmaps and meta-analysis to reveal user interaction patterns. In parallel, a Product Lifecycle Management (PLM) system—such as Arena—is deployed to ensure traceability, version control, and visibility for stakeholders across departments. Based on the outcomes from prior testing and planning phases, priorities are re-evaluated, and risk-adjusted pivot strategies are formulated using structured tools like the pivot canvas.

This phase also includes MVP kick-off meetings and the execution of first field demos. These real-world trials help validate whether the technical implementation holds under expected operating conditions, a step considered critical in literature on hardware development cycles [1][9]. Supporting tools—such as OKRs/KPIs (v2), the Product-Market Fit canvas, and field testing documentation—allow the team to assess both usability and performance against defined benchmarks.

Team members involved in EVT include the CEO, UX researcher, product manager, and PLM manager—ensuring cross-functional oversight with a blend of strategic, customer, and operational expertise. Sprint durations are distributed across 5 to 15 days to maintain a balance between agility and depth. The comprehensive overview of roles, tasks, tools, and sprint lengths for this phase is presented in Table 3: Engineering Validation Test Phase – Tools, Tasks, and Team Configuration. Altogether, EVT de-risks the path to DVT by surfacing and resolving critical issues while there's still room for structural change—helping ensure that the product not only works but is desirable and viable in its intended context.

Table 3. Engineering Validation focus, tools, team.

| | | | | | | |
|---|---|---|---|---|---|---|
| 3 | EVT (Engineering Validation Test) MVP development (TRL 5–6) 60 days | User feedback, validating demos, stakeholders, adjusting priorities, assessing pivot risks, MVP development | • Set up UX Customer VoC<br>• Set up PLM for shareholders<br>• Refine priorities based on results<br>• Consider pivot plan and risks for MP<br>• Run MVP kick-off meetings<br>• Run first field demos | • UX heatmaps+ meta<br>• PLM setup (Arena)<br>• OKRs / KPIs v2 sheet<br>• Pivot canva<br>• MVP Kick-off session<br>• Product-Market Fit canva | - 10 days<br>- 10 days<br>- 14 days<br>- 7 days<br>- 5 days<br>- 15 Days | CEO<br>UX Researcher<br>Product Manager<br>PLM Manager |

The Design Validation Test (DVT) phase (Technology Readiness Level 7) is a 60-day stage in the Lean New Product Introduction (NPI) framework where the product evolves into its final-looking MVP and undergoes rigorous validation against user expectations and market readiness (Table 4.). This phase emphasizes gathering and analyzing user data, quantifying satisfaction levels, and making iterative improvements that prepare the product for production. It is at this point that assumptions about usability, value, and experience are tested at scale through empirical evidence.

Central to DVT is the use of A/B testing at scale—typically involving 100 test conditions—to evaluate the impact of design and feature variations on user behavior. Alongside this, UX surveys are conducted and compiled into comprehensive results sheets that highlight usability strengths and friction points. These inputs form the basis for a Voice of Customer (VoC) report, a qualitative and quantitative synthesis of customer feedback, which informs decision-making across teams. To support business and UX alignment, the team also calculates Net Promoter Scores (NPS) and usability scores, establishing benchmarks for satisfaction and engagement. On the operational side, the Mass Production BOM and SBOM (v2) are updated to reflect all design iterations, ensuring that technical documentation aligns with validated use cases. The Unit Economics sheet is revised accordingly to reflect current cost structures and financial projections based on updated market feedback. These updates are essential for transitioning from prototype to mass production, where precision and cost control become critical.

The tasks within DVT are executed using dedicated tools such as A/B Testing sheets, UX survey data, VoC reports, and score matrices. Each task is time-boxed with sprint durations ranging from 5 to 20 days, enabling focused execution without sacrificing agility. The team for this phase includes the CTO or Technical Program Manager (TPM), UX researcher, product manager, marketing director, and research analyst. This multidisciplinary structure ensures that feedback loops inform not only product features but also communication strategy and business modeling.

By the conclusion of DVT, the team holds a data-driven, user-approved product ready for validation in full production settings. The structure, timelines, and key activities of this phase are consolidated in Table 4: Design Validation Test Phase – Tools, Tasks, and Team Structure, providing an operational blueprint for startups preparing to enter the final stages of product launch.

Table 4. Design Validation Test Phase focus, tools, team.

| | | | | | | |
|---|---|---|---|---|---|---|
| 4 | DVT (Design Validation Test) MVP development (TRL 7) 60 days | Final-looking MVP, user data, reporting customer insights, measuring satisfaction, and updating product. | •Analyze A/B Testing results<br>•Compile UX survey results<br>•Prepare Voice of Customer (VoC) report<br>•Calculate NPS and usability scores<br>•Update MP BOM/SBOM (v2)<br>•Revise Unit Economy sheet (v2) | • A/B Testing sheet (100 list)<br>• UX surveys result sheet<br>• VoC Report<br>• NPS, usability score sheet<br>• MP BOM/SBOM(v2) sheet<br>• Unit Economy sheet v2 | - 20 days<br>- 10 days<br>- 7 days<br>- 7 days<br>- 5 days<br>- 5 days | •CTO or TPM<br>•UX Researcher<br>•Product Manager<br>•Marketing director<br>•Research Analyst |

The Production Validation Test (PVT) phase (Technology Readiness Level 8) is a 90-day milestone within the Lean New Product Introduction (NPI) framework where engineering transitions into controlled manufacturing and operational readiness (Table 5.). At this stage, the product is no longer just a prototype—it must now meet the rigorous standards of repeatable production, yield predictability, and quality assurance at scale. PVT ensures the systems, documentation, and supply chain operations are fully synchronized to support mass production with minimal risk.

The phase begins with selecting at least two qualified contract manufacturers, establishing redundancy and benchmarking for cost, capability, and reliability. The team proceeds to update the Mass Production BOM and SBOM (v2 → v3), reflecting all modifications derived from DVT feedback and manufacturing constraints. A critical deliverable is the assembly of the complete manufacturing documentation package, which includes inspection templates, work instructions, and component specifications. In parallel, a Product Certification Log is maintained to track all required regulatory and compliance processes, ensuring alignment with international standards and shipment legality—especially important in hardware-focused global markets [7]. Additional tasks include updating the Product Logistics Log and developing a Yield Rate Sheet to assess production stability and defect rates. These metrics form the baseline for evaluating manufacturing efficiency and highlight potential issues early. A Quality Assurance (QA) Plan is then designed and implemented to formalize inspection routines, test protocols, and response procedures. Simultaneously, the team creates a Customer Support Plan, which sets expectations for issue resolution, return logistics, and customer communication channels—a component often overlooked in early-stage hardware projects.

Each task in PVT is time-boxed, with longer sprints (20–30 days) dedicated to documentation-heavy outputs like the manufacturing package or BOM updates, and shorter 7–14 day sprints for logs, QA, and support systems. The team expands to include operational and commercial functions—such as the procurement manager, support manager, and logistics manager—alongside technical roles like the CTO, embedded and software team leads, and the quality engineer. This broader composition ensures that supply chain, support, and quality considerations are built directly into the pre-production setup.

In essence, PVT validates the product's ability to be produced at scale, shipped globally, and supported reliably. The structure, responsibilities, tools, and durations specific to this phase are summarized in Table 5: Production Validation Test Phase – Manufacturing Readiness and QA Infrastructure, providing a turnkey guide for hardware startups preparing to scale their operations from validated MVP to production-ready product.

Table 5. Production Validation Test main focus, tools, team.

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 | PVT (Production Validation Test) (TRL 8) 90 days | Manufacturing selecting manufacturers, updating production documents, certifications and logistics, analyzing yield, QA & stability | •Select min 2 Contract Manufacturer<br>•Update MP BOM/SBOM (v2)<br>•Assemble Manufacturing Doc. Package<br>•Maintain Product Certification Log<br>•Update Product Logistics Log<br>•Create Yield Rate Sheet to analyze<br>•Develop and implement QA Plan<br>•Create Customer Support Plan | • Inspection templates<br>• Update MP BOM/SBOM (v3)<br>• Manufacturing Doc. Package<br>• Product Certification Log<br>• Product logistics log<br>• Yield rate sheet<br>• QA plan<br>• Customer Support plan | - 30 days<br>- 30 days<br>- 20 days<br>- 14 days<br>- 7 days<br>- 7 days<br>- 7 days<br>- 7 days | •Procurement Manager<br>•CTO<br>•CFO<br>•Embedded team lead<br>•Software team lead<br>•Quality Engineer<br>•Support Manager<br>•Marketing director<br>•Logistic manager |

The Mass Production (MP) phase (Technology Readiness Level 9) is the final operational phase of the Lean New Product Introduction (NPI) framework and spans 70 days (Table 6.). It marks the transition from controlled pilot production to full-scale manufacturing and commercial rollout. The focus during this stage shifts toward aligning product delivery with sales, marketing, logistics, and customer support systems. The overarching goal is to build market trust, ensure consistent supply, and support the customer journey from first contact through post-purchase engagement.

One of the primary activities in this phase is refining the Go-To-Market (GTM) strategy using updated customer and channel insights. The GTM canvas is revised to reflect current positioning, distribution, and messaging aligned with product capabilities validated in previous phases. Parallel to this, the Lifetime Value (LTV) plan is updated to incorporate new behavioral and financial data, helping the team project retention, upsell potential, and overall revenue contribution per user.

To support sustainable revenue generation, a Lean Sales plan is developed alongside KPI definitions to measure performance across channels and segments. A structured retention and upsell strategy is created to ensure long-term customer engagement and monetization. Equally important is the Customer Education plan, which provides end-users with onboarding, setup, and troubleshooting guidance—vital for hardware products where friction in usage can negatively impact perception and churn [10].

On the operational side, the product roadmap is updated to reflect future feature releases, maintenance cycles, and technical upgrades. Simultaneously, warehouse management systems are set up or refined using PLM add-ons (e.g., Arena) to synchronize inventory, shipment, and support processes. Each task is clearly time-boxed, with sprints ranging from 7 to 20 days, allowing the team to balance execution speed with depth of implementation.The MP phase involves a broader cross-functional team including the CEO, product manager, marketing director, research analyst, procurement manager, logistics manager, and for the first time— the sales director. This team composition ensures that go-to-market efforts are tightly coordinated with production and logistics infrastructure, allowing for seamless scaling.

Altogether, the Mass Production phase operationalizes the product's commercial success. The detailed structure of tasks, sprint durations, and team roles are outlined in Table 6: Mass Production Phase – Go-to-Market Execution and Logistics Setup, offering a replicable roadmap for startups aiming to transition from MVP validation to market leadership.

Table 6. Mass Production Phase main focus, tools, team.

| | | | | | | |
|---|---|---|---|---|---|---|
| 6 | MP (TRL 9)<br>Mass Production<br>70 days | Start of MP, coordination with sales and marketing, build trust with customers | •Update Go-To-Market (GTM) strategy<br>•Revise Lifetime Value (LTV) plan<br>•Develop Lean Sales plan and set KPIs<br>•Create Retention and Upsell plan<br>•Design Customer Education plan<br>•Update Product Roadmap<br>•Set up warehouse management | • GTM canva v2<br>• LTV plan v2<br>• Lean Sales plan KPI<br>• Retention and upsell plan v1<br>• Customer education plan v1<br>• Roadmap v2 Gantt chart<br>• PLM addon setup (Arena) | - 10 days<br>- 10 days<br>- 14 days<br>- 14 days<br>- 14 days<br>- 7 days<br>- 20 days | •CEO<br>•Product Manager<br>•Marketing director<br>•Research Analyst<br>•Sales director<br>•Procurement Manager<br>•Logistic manager |

The After Mass Production / Growth phase marks the final stage of the Lean New Product Introduction (NPI) framework, corresponding to the post-launch period and spanning 70 days (Table 7.). This phase is centered on consolidating feedback from real users, upgrading the product experience, and scaling sales efforts based on validated market traction. With the product now in customers' hands, the focus shifts to optimizing retention, identifying upsell opportunities, and establishing sustainable growth mechanisms.At the heart of this phase is the collection and synthesis of post-launch feedback. A Voice of Customer (VoC) post-launch report is compiled to capture real-world usage patterns, pain points, and enhancement requests. These insights inform the v2 iterations of the retention and upsell plans, ensuring that customer value continues to expand beyond the initial purchase. This feedback loop is essential for refining positioning, pricing strategies, and communication tactics across the customer lifecycle.

Simultaneously, the Customer Education plan is updated to v2, integrating new insights on onboarding challenges, user errors, or gaps in documentation. These improvements reduce friction, improve satisfaction, and reduce support overhead. Alongside this, the product roadmap is scaled to version 3, outlining long-term plans for features, maintenance, and potential product extensions. A new Product Growth Stage plan is also developed to align teams on scaling strategies, experimentation frameworks, and KPIs for sustained growth—aligning with modern growth-stage methodologies discussed by Blank [11].Each of these tasks is structured with clear sprint durations, ranging from 7 to 30 days, depending on complexity and dependencies. The team expands to include roles such as the UX researcher and support manager, whose functions become increasingly vital as customer interaction volumes grow. The broader team—including the CEO, product manager, marketing director, sales director, and research analyst—collaborates to ensure that post-launch operations remain agile, user-informed, and commercially viable.

In summary, the After MP Launch / Growth phase ensures that product momentum is not only maintained but strategically accelerated. It institutionalizes learning from the market and turns early traction into repeatable, scalable success. The detailed breakdown of tasks, timelines, tools, and roles for this stage is presented in Table 7: Post-Launch Growth Phase – Feedback Integration and Scaling, providing hardware teams with a roadmap to transition from product delivery to product-led growth.

Table 7. Post-Launch Growth Phase main focus, tools, team.

| | | | | | | |
|---|---|---|---|---|---|---|
| 7 | After MP Launch / Growth 70 days | Post-launch feedback, upgrades, Sales scaling | • Collect user feedback<br>• Upgrate Retention and Upsell plan<br>• Update Customer Education plan<br>• Scale roadmap v3<br>. Create Product Growth Stage plan | • VoC post-launch Report<br>• Upsell plan v2<br>• Customer Education plan v2<br>• Upgrade Roadmap v3<br>• Product Growth Stage plan | -30 days<br>- 7 days<br>- 14 days<br>- 14 days<br>- 30 days | •CEO<br>•Product Manager<br>•Marketing director<br>•Research Analyst<br>•Sales director<br>•UX Researcher<br>•Support Manager |

## 3. Results and Analysis

This section presents the practical results of the study and introduces a comprehensive discussion based on the application of the Lean New Product Introduction (NPI) framework in robotics and hardware startups. The core output of the research is a structured, seven-phase framework for hardware product development, validated through empirical interviews, field application, and expert feedback.

### 3.1. Validation through Industry Interviews

The framework was shaped through 80 structured interviews with product managers, engineers, and executives from hardware-focused companies. Each session lasted 30 minutes and included a set of five targeted questions on new product development practices. The findings revealed a consistent lack of tailored methodologies for hardware NPI. Respondents often reported extended iteration cycles, fragmented stakeholder communication, and limited structure in early validation stages. This validated the hypothesis that a phase-based model with lean integration would improve efficiency and coordination. Each of the seven phases—Concept, Feasibility, Engineering Validation Test (EVT), Design Validation Test (DVT), Production Validation Test (PVT), Mass Production (MP), and Post-Launch Growth—was developed with precise deliverables, toolsets, responsible roles, and time-boxed sprints. Tables 1 to 9 summarize the configuration of each phase, highlighting key tasks such as empathy interviews, BOM/SBOM versioning, customer feedback loops, and product-market fit assessment.

### 3.2. Measurable Outcomes from Pilot Implementation

The model's practical implementation in robotics startups demonstrated measurable improvements in several key areas. Time-to-market was reduced by an average of 20%, largely due to early prioritization and structured decision-making checkpoints. Team alignment improved due to clearly defined cross-functional roles and sprint-based task tracking, minimizing costly misunderstandings and duplicated effort. Moreover, customer satisfaction metrics such as NPS increased post-DVT, as usability and feedback were systematically incorporated into product iterations. Tools like the JTBD canvas, PLM systems (e.g., Arena), and structured VoC reports were repeatedly cited by pilot teams as instrumental in reducing ambiguity and anchoring technical decisions to real user needs. This aligns with prior research on hybrid Agile-Stage-Gate models [2][3], which emphasize structured agility for hardware innovation. The results confirm that applying lean principles to a structured phase-based framework can significantly improve hardware NPI outcomes in resource-constrained startup environments.

## 4. Conclusion (10pt)

The goal set forth in the introduction—to create a structured, lean-based framework for New Product Introduction (NPI) tailored to the unique challenges of robotics and hardware startups—has been successfully addressed through this research. By synthesizing insights from 80 industry interviews and aligning them with best practices from Agile-Stage-Gate literature, the study produced a practical seven-phase model that supports product development from concept to post-launch growth. The results presented in the previous section confirm that the framework enhances team coordination, reduces time-to-market, and strengthens product-market fit by embedding lean principles into each stage of development. Tables 1 through 9 detail the operational structure of the model, providing a replicable playbook for early-stage hardware teams working under time and resource constraints.

Looking ahead, this framework lays a foundation for further research and adaptation across various subfields within hardware, including medical devices, consumer electronics, and industrial robotics. Future studies could test the model in different market environments, measure long-term product success, or explore its integration with AI-driven product lifecycle tools. Ultimately, the structured NPI model presented here offers both immediate tactical value and long-term strategic potential for scaling hardware innovation.

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## List of Abbreviations

NPI – New Product Introduction
TRL – Technology Readiness Level
EVT – Engineering Validation Test
DVT – Design Validation Test
PVT – Production Validation Test
MVP – Minimum Viable Product
MP – Mass Production
PLM – Product Lifecycle Management
BOM – Bill of Materials
SBOM – Software Bill of Materials
DFx – Design for Excellence
DFMEA – Design Failure Mode and Effects Analysis
ECO – Engineering Change Order
OEM – Original Equipment Manufacturer
ODM – Original Design Manufacturer
LTV – Lifetime Value
GTM – Go-To-Market
JTBD – Jobs To Be Done
VoC – Voice of Customer
NPS – Net Promoter Score
QA – Quality Assurance
UX – User Experience
OKRs – Objectives and Key Results
KPI – Key Performance Indicator