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| RESEARCH ARTICLE

Artificial Intelligence and Digital Twin-Based Framework for Automated New Product Introduction Management and Innovative Charger Prototyping: The InnovaNP Case at Salcomp

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| ABSTRACT

New product introduction (NPI) in contract manufacturing environments is traditionally slowed by manual, paper-based requirement gathering and fragmented information systems, producing costly divergences between quoted and actual costs and delaying time-to-market. This paper reports the ongoing applied research and experimental development project "InnovaNP", conducted through a technical cooperation agreement between Salcomp, a global manufacturer of power supply solutions for mobile and electronic devices, and the Conecthus Institute of Technology and Biotechnology of Amazonas, under the incentive regime of the Manaus Free Trade Zone (SUFRAMA, Decree No. 10,521/2020). The project integrates two complementary research fronts: (i) a software module that applies artificial intelligence — including time-series forecasting, Random Forest, and neural network models — together with Digital Twin concepts to support demand prediction, production planning simulation, and automated governance of the NPI process; and (ii) a hardware module that applies the Design for Six Sigma (DFSS) methodology, using the Define-Measure-Analyze-Design-Validate (DMADV) model, to design and prototype a family of electronic battery chargers of multiple power ratings (12W, 16W, 18W, 24W, and 45W). An extensive literature review situates the project within Industry 4.0, Digital Twin, machine learning forecasting, DFSS, and power-electronics design research streams. Partial results obtained through March 2026 show that the software platform has reached a stage of functional, integration, performance, and usability validation, while two hardware prototypes (P1 and P2) have undergone laboratory test campaigns whose preliminary findings point to the need for further specialized validation of electrical stability, thermal behavior, and electromagnetic interference. The paper discusses the expected contributions of InnovaNP to NPI management theory and practice and outlines the remaining validation milestones toward project closure.

| KEYWORDS

New Product Introduction, Digital Twin; Artificial Intelligence, Design for Six Sigma, DMADV, Industry 4.0, Power Electronics, Battery Chargers

| ARTICLE INFORMATION

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1. Introduction

Managing the introduction of new products is a central capability for manufacturing companies that seek to sustain competitiveness in fast-moving electronics markets. Despite the widespread adoption of digital tools in other corporate functions, many operations continue to rely on manual walkthroughs of the shop floor to collect requirement data such as Head Count (HC), Units Per Operator per Hour (UPOH), bill-of-materials (BOM) costs, investment lists for testing equipment, and certification requirements. This dependency on physical, non-integrated data collection routines is a known source of

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delay, rework, and estimation error in new product introduction (NPI), and it is particularly costly when it propagates into customer-facing quotations.

Salcomp is a global manufacturer of power supply solutions for mobile devices and other electronic equipment, holding a leading position in chargers for smartphones, tablets, notebooks, and point-of-sale terminals, and operating for nearly five decades under stringent international safety and quality certification regimes. An internal diagnostic conducted jointly by Salcomp engineers and Conecthus researchers identified a cluster of interrelated deficiencies in the company's NPI process: manual and error-prone requirement gathering; the absence of a standardized costing methodology, leading to divergence between quoted and actual costs; long lead times for developing test jigs and fixtures; low visibility of real plant capacity during the quotation phase; difficulty managing the proliferation of product variants and their customizations; excessive and poorly integrated technical documentation; and weak system-to-system integration, which undermines the reliability of production indicators such as First Pass Yield (FPY).

These deficiencies motivated the design of InnovaNP, an applied research and experimental development project registered under the Brazilian Informatics Law incentive regime (Decree-Law No. 288/1967; Law No. 8.387/1991, as amended; regulated by Decree No. 10,521/2020) and executed through a technical cooperation agreement between Salcomp and the Conecthus Institute. InnovaNP pursues two complementary objectives. First, it develops an integrated software framework — built on a Python technology stack — that applies artificial intelligence techniques for demand forecasting, production-planning simulation, and decision support, exposed through an intuitive dashboard interface for the various stakeholders involved in NPI. Second, it designs and prototypes, through Design for Six Sigma (DFSS) methodology, a family of electronic battery chargers spanning five power ratings, intended to meet or exceed current market standards for quality, performance, safety, and energy efficiency. The two fronts converge around the concept of a Digital Twin of the product and of the manufacturing process, allowing virtual prototyping, scenario simulation, and continuous feedback between the physical and digital layers of the NPI pipeline.

This paper analyzes how InnovaNP has been conceived and partially executed, situates the project within the relevant scientific literature on Industry 4.0, Digital Twin, machine learning-based forecasting, DFSS/DMADV, and power-electronics design, and reports the partial results obtained during the reporting period, together with the technical challenges that remain to be addressed before project closure.

2. Literature Review

2.1 Industry 4.0 and Digital Transformation in Manufacturing

The Industry 4.0 paradigm describes the convergence of cyber-physical systems, the Internet of Things, cloud computing, and data analytics within manufacturing environments, enabling self-organizing and self-optimizing production networks (Kagermann, Wahlster, & Helbig, 2013). Within this paradigm, the digitalization of NPI is frequently framed as a prerequisite for broader smart-manufacturing transformation, because product introduction defines the data structures, bill-of-materials logic, and process parameters that downstream production and quality systems will consume. Empirical studies on digital transformation in electronics contract manufacturing consistently report that firms retaining paper-based or spreadsheet-based NPI routines experience longer cycle times and higher rates of rework than firms that have digitized the same processes (Silva, Pereira, & Silva, 2022; Souza, Souza, & Silva, 2022), reinforcing the rationale for treating NPI digitalization as a strategic, rather than purely operational, investment.

2.2 Digital Twin Technology for Prototyping and Process Optimization

The Digital Twin concept, originally articulated by Grieves (2014) as a virtual representation that mirrors a physical asset across its lifecycle, has become a central enabler of virtual prototyping in Industry 4.0 settings. A Digital Twin allows engineering teams to evaluate design alternatives, simulate performance under varied operating conditions, and anticipate failure modes before committing resources to physical prototypes, thereby compressing development time and reducing the number of physical iterations required (Tao, Zhang, Liu, & Nee, 2018). Beyond the design phase, Digital Twins of production lines support bottleneck identification, predictive maintenance scheduling, and layout optimization, while Digital Twins of fielded products enable remote diagnostics and usage-informed design feedback loops. For a project such as InnovaNP, which spans both a software layer for NPI governance and a hardware layer for charger prototyping, the Digital Twin construct offers a unifying architecture: the same underlying models can be used to simulate demand and capacity scenarios in the software module and to validate electrical and thermal behavior of charger designs in the hardware module before physical test campaigns are executed.

2.3 Artificial Intelligence and Machine Learning for Demand Forecasting

Accurate demand forecasting is a well-established prerequisite for effective production planning, inventory management, and capacity investment decisions (Fildes, Ma, & Kolassa, 2022). Classical statistical approaches, most notably the Autoregressive Integrated Moving Average (ARIMA) family of models formalized by Box and Jenkins (1970), remain widely used for their interpretability and their capacity to capture trend and seasonality from historical series. More recent additive decomposition approaches, such as the Prophet model (Taylor & Letham, 2018), were designed specifically to be robust to missing data and abrupt trend changes, which makes them attractive for demand series associated with newly introduced products that lack long historical records. Machine learning approaches, including Random Forest and Gradient Boosting Machines, and deep learning architectures such as Long Short-Term Memory (LSTM) recurrent neural networks (Hochreiter & Schmidhuber, 1997), have demonstrated superior performance in capturing non-linear relationships between demand and multiple explanatory variables, at the cost of reduced interpretability relative to classical statistical models (Lu, Wang, & Zhang, 2022).

2.4 Interpretable Machine Learning: Random Forest and Ensemble Methods

The Random Forest algorithm, introduced by Breiman (2001) as an ensemble of decision trees trained on bootstrap samples with randomized feature selection, combines the predictive robustness of ensemble learning with a comparatively higher degree of interpretability than deep neural architectures, through mechanisms such as feature-importance ranking (Prinzie & Van den Poel, 2007). This property is particularly relevant for NPI decision-support systems, where managers must be able to justify capacity and investment recommendations to internal stakeholders and, in regulated R&D&I contexts such as the Brazilian Informatics Law regime, to external auditors. Consequently, several industrial forecasting and process-modeling systems favor Random Forest or hybrid architectures over pure deep-learning models specifically to preserve a minimum level of explainability (Souza et al., 2022).

2.5 Design for Six Sigma and the DMADV Model in Hardware Development

Design for Six Sigma (DFSS) is a structured product-development methodology aimed at building quality and reliability into a design from its inception, rather than inspecting defects out of a finished product (Yang & El-Haik, 2008). The Define-Measure-Analyze-Design-Validate (DMADV) roadmap operationalizes DFSS for new product development: the Define phase establishes customer and regulatory requirements; Measure translates these requirements into measurable technical specifications; Analyze evaluates design alternatives against these specifications; Design produces detailed engineering specifications and prototypes; and Validate confirms, through structured testing, that the resulting design meets or exceeds the original requirements (Chowdhury, 2002). In power-electronics contexts, DMADV has been applied to balance competing design objectives — energy efficiency, thermal management, electromagnetic compatibility, safety certification, and manufacturing cost — that are difficult to reconcile through purely iterative, non-structured design approaches (Wang, Zhang, & Lu, 2021).

2.6 Power Electronics and Battery Charger Design

The design of battery chargers spanning multiple power ratings requires careful engineering of power-management integrated circuits (PMICs), DC-DC converters, and charge-control circuitry to regulate voltage and current delivery while protecting against overcurrent, overvoltage, and thermal runaway (Erickson & Maksimović, 2020). Compliance with international safety and efficiency standards — including IEC/UL/CE requirements and energy-efficiency labeling schemes — constrains component selection and printed-circuit-board (PCB) layout, particularly with respect to thermal dissipation and electromagnetic interference (EMI) mitigation (Ott, 2009). The literature on low-cost, multi-power charger platforms consistently identifies the trade-off between component-level flexibility (to serve a wide range of downstream devices) and manufacturing cost efficiency as the central engineering challenge, one that structured methodologies such as DFSS/DMADV are specifically intended to address (Silva & Santos, 2020).

2.7 Integrated Software-Hardware Development and NPI Management Systems

A growing body of research addresses the integration of concurrent engineering practices with digital NPI management platforms, arguing that software-based traceability of requirements, approvals, and design changes reduces both direct rework and indirect costs associated with miscommunication among sales, engineering, and manufacturing functions (Santos & Silva, 2021; Oliveira & Silva, 2021). System integration through application programming interfaces (APIs) is repeatedly identified as a critical enabler of this traceability, since it removes the manual re-entry of data across otherwise siloed enterprise systems such as ERP, MES, and product-lifecycle management (PLM) platforms (Santos & Silva, 2020; Silva, Pereira, & Silva, 2022).

2.8 Agile and PMBOK-Based Project Management in R&D Contexts

Applied R&D projects executed under multi-year technical cooperation agreements benefit from combining structured project-management frameworks, such as the Project Management Body of Knowledge (PMBOK) methodology (Project Management Institute, 2021), with agile development practices such as Scrum, which organize software delivery into short, iterative sprints that accelerate feedback and adaptation to evolving requirements (Schwaber & Sutherland, 2020). In the specific context of R&D&I projects executed under the Brazilian Informatics Law, project governance additionally has to accommodate periodic financial and technical reporting obligations to the regulatory authority (SUFRAMA), which places a premium on traceability mechanisms that can serve both engineering-management and regulatory-compliance purposes simultaneously.

2.9 Synthesis and Research Gap

Taken together, the reviewed literature indicates that (i) Digital Twin architectures provide a coherent conceptual bridge between AI-based software simulation and physical hardware prototyping; (ii) forecasting accuracy and interpretability are frequently in tension, motivating hybrid approaches that pair classical or ensemble models with mechanisms for explainability; (iii) DFSS/DMADV is a well-validated methodology for multi-objective hardware development under safety and cost constraints; and (iv) the integration of these strands into a single, auditable NPI governance platform for a multinational contract manufacturer operating under a regional fiscal-incentive regime remains comparatively underexplored in the published literature. InnovaNP is positioned to address this gap by jointly instrumenting the software and hardware fronts of NPI within a single project architecture and reporting structure.

3. Methodology

This research is classified as applied, of an experimental-development nature, combining a case-study design with iterative engineering methodologies. The project is structured according to a Work Breakdown Structure organized into four macro-phases: (i) Project Management, encompassing procurement, material acquisition, cost and scope control, and adherence to the PMBOK methodology; (ii) Planning and Requirements Gathering, comprising problem and requirement surveys, technical requirement definition, data analysis, and solution presentation; (iii) Solution Development, covering demand-forecasting model development, production-process modeling, system integration, dashboard development, and hardware prototyping; and (iv) Testing, Validation, Closure, and Delivery, covering functional and integration testing, implementation and training, scientific publication, and formal project closure.

For the software module, the methodological approach follows a data-science pipeline: (a) data analysis and preparation across sales, production, inventory, and cost datasets; (b) development of demand-forecasting models drawing on ARIMA, Prophet, Random Forest, and LSTM architectures, benchmarked against historical data from comparable previously manufactured models; (c) production-process modeling, initially under an infinite-capacity assumption, to be refined in a subsequent phase incorporating finite-capacity constraints; (d) system integration through application programming interfaces linking forecasting outputs to planning and governance modules; and (e) development of managerial dashboards reporting sales, production, inventory, and profitability indicators. Distributed-processing architectures, sampling and aggregation techniques, and NoSQL/cloud storage were adopted to address anticipated data-volume and scalability requirements, alongside encryption, access-control, and anonymization measures to address data-privacy obligations analogous to those of the General Data Protection Regulation.

For the hardware module, the DFSS methodology was applied through the DMADV roadmap. In the Define phase, market and safety requirements were established for a family of chargers rated at 12W, 16W, 18W, 24W, and 45W. In the Measure phase, these requirements were translated into measurable electrical, thermal, and mechanical specifications. In the Analyze phase, candidate topologies for power-management integrated circuits, DC-DC conversion, and charge-control circuitry were evaluated. In the Design phase, printed-circuit-board layouts, thermal-dissipation solutions, and protection circuitry (against overcurrent, overvoltage, short-circuit, and overheating) were specified and two physical prototypes, designated P1 and P2, were built. In the Validate phase, laboratory test campaigns were executed to assess functional performance, safety compliance, and conformity with the target specifications, with rapid-prototyping techniques (including 3D-printed enclosures and low-cost PCB iterations) used to accelerate design cycles.

Verification and validation activities for the integrated solution combined functional, integration, load, security, usability, and cross-validation testing, following an iterative test-and-refine cycle consistent with agile software-delivery practice. Governance and traceability requirements were addressed through role-based access control, approval-and-rejection workflows for project

phases and milestones, and automated dashboard updates, all subject to periodic technical and financial reporting to SUFRAMA in accordance with Decree No. 10,521/2020 and its subsequent amendments.

4. Results and Findings

As InnovaNP remains an in-progress project — with contractual execution running from May 2024 through April 2026 — the results reported here correspond to the partial outcomes achieved by the reporting cut-off (March/April 2026) and to the outcomes the project is designed to obtain by its scheduled closure.

4.1 Software Platform: Governance, Traceability, and Analytical Modules

The InnovaNP software platform reached a stage of consolidated functional and integration validation during the reporting period. Testing cycles confirmed the stability of phase-management, approval/rejection, and rollback-for-adjustment workflows; the integrity of historical audit trails recording user-driven changes; the correct synchronization between tasks, phases, and milestones; and the automatic, accurate updating of managerial dashboards. Additional validation rounds addressed system behavior under an increased volume of historical records and concurrent multi-user access, leading to targeted refinements in query optimization and dashboard load times. Usability testing with end users from the engineering and project-management teams informed adjustments to screen organization, message clarity, and interface standardization, indicating that the platform is approaching production-grade maturity for its governance and traceability functions as shown in Figure 1.

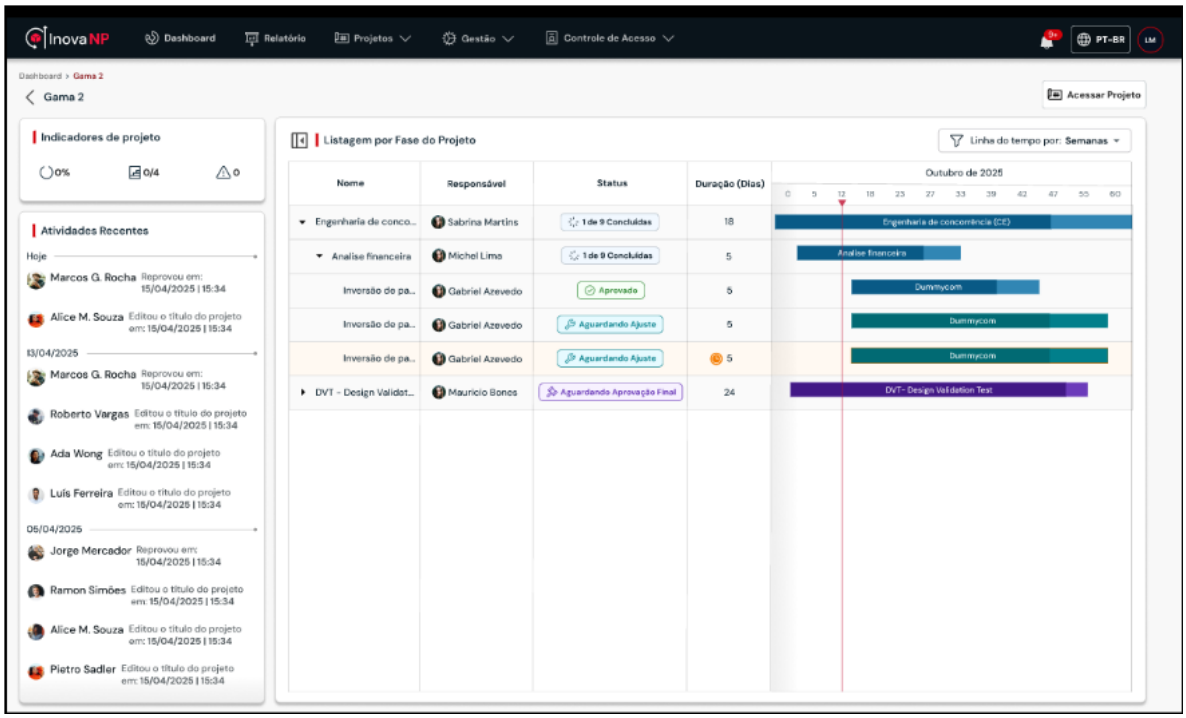


Figure 1. InovaNP web platform prototype. The figure shows the project management moved by different PMOs of the project.

4.2 Hardware Prototypes: Multi-Power Charger Development

On the hardware front, two physical prototypes (P1 and P2) advanced through structured laboratory test campaigns encompassing electrical, thermal, and functional measurements. The consolidation of these laboratory results within the software platform's analytical layer — including dynamic filters, historical comparisons across hardware revisions, and exportable technical reports — was validated during the reporting period, confirming the intended integration between the Digital Twin data layer and the physical test evidence. The preliminary laboratory findings indicated that, while baseline functional performance of both prototypes met design expectations, further specialized validation is required in three areas before the DMADV Validate phase can be considered complete: electrical stability under critical power-supply scenarios, thermal behavior of high-power components under sustained load, and conducted/radiated electromagnetic interference in the power circuit architectures under development.

4.3 Expected Outcomes Toward Project Closure

Building on the partial results above, InnovaNP is expected to deliver, by project closure, the following outcomes: (i) a fully validated, production-ready software framework — registered as a computer program with technological innovation content — capable of supporting demand forecasting, production-planning simulation, and end-to-end NPI governance for Salcomp; (ii) a validated family of multi-power electronic chargers (12W to 45W) demonstrated, through completed electrical stability, thermal, and EMI test campaigns, to meet or exceed applicable safety and efficiency standards; (iii) documented evidence, through the DMADV Validate phase and the corresponding pilot implementation, of measurable reductions in NPI cycle time and in the divergence between quoted and actual production costs, relative to the pre-project baseline described in Section 1; and (iv) two peer-reviewed scientific publications disseminating the methodological and technical contributions of the project to the R&D&I community, consistent with the project's registered result indicators (prototypes with scientific or technological innovation content and a computer program with scientific or technological innovation content).

These expected outcomes are consistent with, and extend, the reviewed literature on Digital Twin-enabled NPI (Grieves, 2014; Tao et al., 2018) and on DFSS-based hardware development (Yang & El-Haik, 2008), by demonstrating their joint application within a single, auditable, industrially embedded R&D&I project operating under a regional fiscal-incentive regime.

5. Discussion

The partial results reported in Section 4 suggest that the central premise of InnovaNP — that a shared Digital Twin architecture can coherently link AI-based software governance of NPI with DFSS-based hardware prototyping — is technically viable and is progressing according to the project's original scope. The consolidation of governance and traceability functions ahead of the full validation of forecasting-model accuracy is consistent with an implementation strategy that prioritizes auditable process control before analytical sophistication, a sequencing choice that is particularly appropriate given the regulatory reporting obligations attached to R&D&I projects executed under the Brazilian Informatics Law.
At the same time, the identification of outstanding electrical, thermal, and electromagnetic-interference validation needs for the hardware prototypes underscores a broader finding from the power-electronics literature: multi-power, low-cost charger platforms present an inherent tension between design flexibility and the granularity of safety validation required across each power tier (Wang, Zhang, & Lu, 2021; Silva & Santos, 2020). Addressing this tension will likely require the specialized test campaigns already identified by the project team as the next validation milestone, and their outcomes will determine whether the current prototype architecture can be carried forward without redesign.

A limitation of the present analysis is that, because InnovaNP is still in execution, the quantitative demand-forecasting accuracy and NPI cycle-time reduction metrics that would most directly validate the project's central hypotheses are not yet available in final form; the results presented here are therefore necessarily partial and should be read as an interim technical account rather than a definitive outcome evaluation.

6. Conclusion

This paper analyzed the design, literature grounding, and partial execution results of InnovaNP, an applied R&D&I project developed through a technical cooperation agreement between Salcomp and the Conecthus Institute of Technology and Biotechnology of Amazonas, under the Manaus Free Trade Zone incentive regime. The project responds to well-documented deficiencies in the manual, non-integrated NPI processes typical of contract electronics manufacturing, and proposes a Digital Twin-based architecture that jointly instruments a software front — combining artificial intelligence-based demand forecasting with automated NPI governance — and a hardware front, applying Design for Six Sigma and the DMADV model to the development of a family of multi-power electronic chargers.

Partial results indicate that the software platform has reached a mature stage of functional, integration, and usability validation, while the physical prototypes have undergone structured laboratory test campaigns that have already clarified the remaining validation agenda in electrical stability, thermal behavior, and electromagnetic interference. As future work, the project is expected to complete these specialized hardware validations, finalize the quantitative assessment of forecasting accuracy and NPI cycle-time reduction, and disseminate its full technical and methodological contributions through peer-reviewed scientific publications, thereby consolidating InnovaNP as a replicable model for the joint digital and physical governance of new product introduction in regionally incentivized manufacturing operations.

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