ImproveXpert4.0: A Big Data-Driven System to Support Continuous Improvement Initiatives and Decision-Making in 4.0 Companies

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Abstract

Continuous Improvement has long been integral to business strategy, a focus intensified by the advent of Industry 4.0 and 5.0, where automation, data exchange, and digitalization have transformed operations. Data is not only a tool for analysis, but also a foundation for empowering employees to lead evidence-based continuous Improvement. Building on this premise and following the Design Science Research methodology, this Doctoral Thesis contributes two primary outcomes. First, it presents four original data-driven models designed to reveal "hidden" improvement opportunities, even within seemingly optimized environments. Developed and validated in real manufacturing and logistics environments, their core innovations include: a Bottleneck Detection model built under the assumption of minimal information; a Process Performance Analysis model that incorporates a static and a variation-oriented version of performance; a Root Cause Analysis model combining Machine Learning and eXplainable Artificial Intelligence techniques that indicate the most relevant variables that explain (in)efficient processes/workers; and a Human Performance Variation Prediction model emphasizing worker-centered process improvement. Second, the Thesis introduces ImproveXpert4.0, a digital platform to drive data-driven Continuous Improvement. It includes two supporting design elements, the DMAIC-PDCA Structural Flowchart and its High-Level Architecture. The flowchart illustrates the platform's practical use and its integration with the developed algorithms, merging top and operational KPIs towards organizational alignment and cross-functional collaboration. The architecture provides an overview of the platform's technological components and interactions, supporting software and hardware specialists in

implementation. The goal is to move beyond statistics-level dashboards to uncover hidden wastes and inefficiencies, enabling organizations to unlock untapped performance potential.

Keywords
Decision Support System, Design Science Research, Data-Driven Root Cause Analysis, Performance Benchmarking Analysis, Continuous Improvement.

Biographies
Ângela F. Brochado is currently a Research Fellow in Industrial and Engineering Management, with an Integrated Master's Degree (July 2020) and a PhD (January 2025) in Industrial Engineering and Management from the University of Aveiro. She has worked as a Teaching Assistant in the Department of Mathematics at the University of Aveiro, teaching Biostatistics, Linear Algebra and Analytical Geometry, Mathematical Techniques for Big Data and a Seminar course, all rated as *Excellent* in teaching performance. Currently, she has been involved as a Training Assistant for the industrial course *Analysis, Optimization & Benchmarking of Industrial and Logistics Processes*, cooperating with international and Portuguese-based companies such as BOSCH Thermotechnology, Microplásticos S.A., HORSE Aveiro, Simoldes S.A., among others. She has published 4 articles in specialized journals, 2 articles in international conference proceedings and has 1 book chapter. During her PhD, she received 2 international awards and 1 national award. Currently she is also involved in the NEXUS project (analysis and digitalization of Logistics and Value Chain processes from the Port of Sines), merging the areas of Industrial Engineering and Management and Applied Mathematics. She also has experience in the Manufacturing industry through the Augmanity project. In her CV, the most frequent terms used to contextualize her scientific production are Root Cause Analysis, Continuous Improvement, Performance Benchmarking, Bottleneck Identification, Logistics, Last-mile, Intermodal Transport, Multi-criteria Decision Making, Multi-directional Efficiency Analysis.

Eugénio M. Rocha is an Associate Professor at the Department of Mathematics of the University of Aveiro, who graduated in Computer Science (Artificial Intelligence) from the University of Coimbra in 1994, concluded the Masters in 1998, and his PhD in Mathematics (Nonlinear Control Theory) in 2004, both from the University of Aveiro. He has been member of the Board of Directors of the Portuguese Mathematical Society, and member of the Committee Electronic Publishing of the European Mathematical Society. Currently he is the President of the Portuguese Mathematical Society, coordinator of the Thematic Line from Theory to Computational Frameworks/CIDMA, co-coordinator of the Thematic Line Geometrix/CIDMA, ex-director of the Master's in Mathematics and Applications, and director of the Master's in Data Science. He has participated in 30 projects, where one received the Portuguese Scientific and Technological Innovation Prize Engo Jaime Filipe 2019, and other was awarded a special mention on the Innovation Prize in Information Technology and Communication APDC/Siemens 2006. He has more than 100 communications and 100 publications in theoretical and/or applied Mathematics, using techniques of Ordinary and Partial Differential Equations, Functional Analysis, Formal Logics, Nonlinear Control Theory, and Optimisation, with applications in Biological Systems and Epidemiology, Civil Engineering, Computational Chemistry and Nanotechnology, Econometrics, and Education. Along the years, he has also contributed to the development of educational applications, serious games, and projects that combine artificial intelligence with mathematics. Recently, has coordinated/coordinates teams on the context of P2020, P2030, and Agendas PRR projects for manufacturing or logistics; using mathematics, machine learning, and big data.

Carina Pimentel is an Industrial Engineering Assistant Professor at the Department of Production and Systems at the University of Minho and a researcher at the Algoritmi Research Unit. Over the last few years she has been involved in several funded research projects, either as principal researcher, co-principal researcher, or researcher, such as the: BioAgroFloRes - Sustainable Supply Chain Management Model for Residual Agro-forestry Biomass Supported in a Web Platform (PCIF/GVB/0083/2019), Augmented Humanity (Projeto Mobilizador n.º 46103), SOLFI - Optimization System for Urban Logistics with Integrated Flows of Goods and Passengers (POCI-01-0247-FEDER-039870), and DRIVIT_UP - DRIVIng forces of urban Transformation: assessing pUblic Policies (02/SAICT/2017). Her main research interests are related to Operations Management, Logistics, Supply Chain Management and Operational Research areas, including lean production, production planning and scheduling, production scheduling in human–robot collaboration, urban logistics, maritime logistics, and supply chain sustainability. Recently, she has also been researching the links between Industry 4.0/5.0 and the above-mentioned areas. During her professional career, she has supervised three PhD theses and 76 master's dissertations, all successfully finished. She mainly publishes the results of her research work in international scientific journals in the Operations Management, Supply Chain

Management/Logistics and Operations Research areas, in edited books and in conference proceedings, having around 100 published papers. Moreover, she has active participation in the Industrial Engineering professional and research community, being a member of several professional and scientific associations. She is also a member of the drive group of the European Professors of Industrial Engineering and Management.