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Technical Paper

# Lean rules extraction methodology for lean PSS design via key performance indicators monitoring

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ABSTRACT

Lean PSS (Product-Service System) design comprises a promising strategy for delivering sustainable PSS offerings, considering several well-established lean practices. However, automated ways to apply lean practices and more specifically lean rules in industry are limited. This work proposes a methodology for improving the leanness of PSS design, by combining real-time KPI monitoring with lean principles and practices. Through a correlation of typical wastes with the metrics used in the calculation of KPIs, the Total Leanness Index (TLI) of the procedures is defined. Based on automatically identified trade-off values for TLI, lean rules are extracted to improve the performance of PSS lifecycle phases. The proposed lean rules extraction methodology (LeanREM) is validated through a case study of power waste reduction and the concurrently maintenance time decrease in a mould-making company.



## 1. Introduction

For several decades, cost and production rates have been the most important performance indicators, while industry focused solely on the product as a means of value creation. The transition from local economies to the global competitive landscape, the current fluctuating customer demands, socio-political reasons, and the technological advances, led to the evolution of manufacturing systems from craftsmanship to customer-oriented manufacturing paradigms [1]. Thus, indicators related to customer, sustainability, and leanness have been embedded in manufacturing systems in order to meet the need for an environmentally conscious mass customisation paradigm [2], where value is encapsulated in the hybrid solution of Product-Service Systems (PSS) [3]. Practice nowadays focuses on strategies and methods for managing product, process, and production systems development that are capable of supporting product variety, adaptability, and leanness, built upon the paradigms of mass customization and product personalization [4]. Novel concepts for the servitisation of manufacturing are being adopted and a shift towards the Industrial Product Service System (IPSS) paradigm and leanness is observed, in order to sustain competitiveness [5]. Research carried out between 2007 and 11, shows that 30% of worldwide manufacturers shifted their business strategy to offer services [6]. Despite the importance and the adoption rate of PSS form of value proposition in the industry, research fields established by the constituents of PSS are still inadequately covered [7–9]. More specifically, methodologies and frameworks for assessing the performance of PSS to reach a higher level of leanness are still immature [10,11]. Contributing to the filling of these gaps, this paper proposes an automated of lean rules extraction methodology (LeanREM) via real time monitoring of Key Performance Indicators (KPIs), aiming to dynamic, adaptable, robust, and reconfigurable lean PSS designs.

In Section 2, a review of relevant state of the art on PSS and Lean concept is provided. Section 3 describes the LeanREM via KPIs. Section 4 presents an ontology model for lean rules extraction. Section 5 presents a case study from a mould-making SME. Finally, Section 6 concludes the paper.

## 2. State of the art

Since the resources and energy are finite, new sustainable ways of producing more with less, while focusing on eco-innovative technologies, as the PSS concept promises, ought to be established [12]. In line with this eco-friendly view, PSS has a clear heritage in lean

*Abbreviations:* PSS, product service system; KPI, key performance indicator; IPSS, industrial product service system; CM, context model; LR, lean rules; TLI, total leanness index; LI, leanness index; W, waste type; WSN, wireless sensor network; RPM, revolutions per minute; TPM, total productive maintenance; JIT, just-in-time; AHP, analytic hierarchy process; TW, typical waste; P, parameter; M, metric; Ph, PSS lifecycle; LP, lean practice; EC, energy consumption; MT, maintenance time; MC, maintenance cost; MRT, maintenance reporting time; SMED, single minute exchange of dies; OEE, overall equipment effectiveness; PDCA, Plan, Do, Check, Act; SBL, Six Big Losses.

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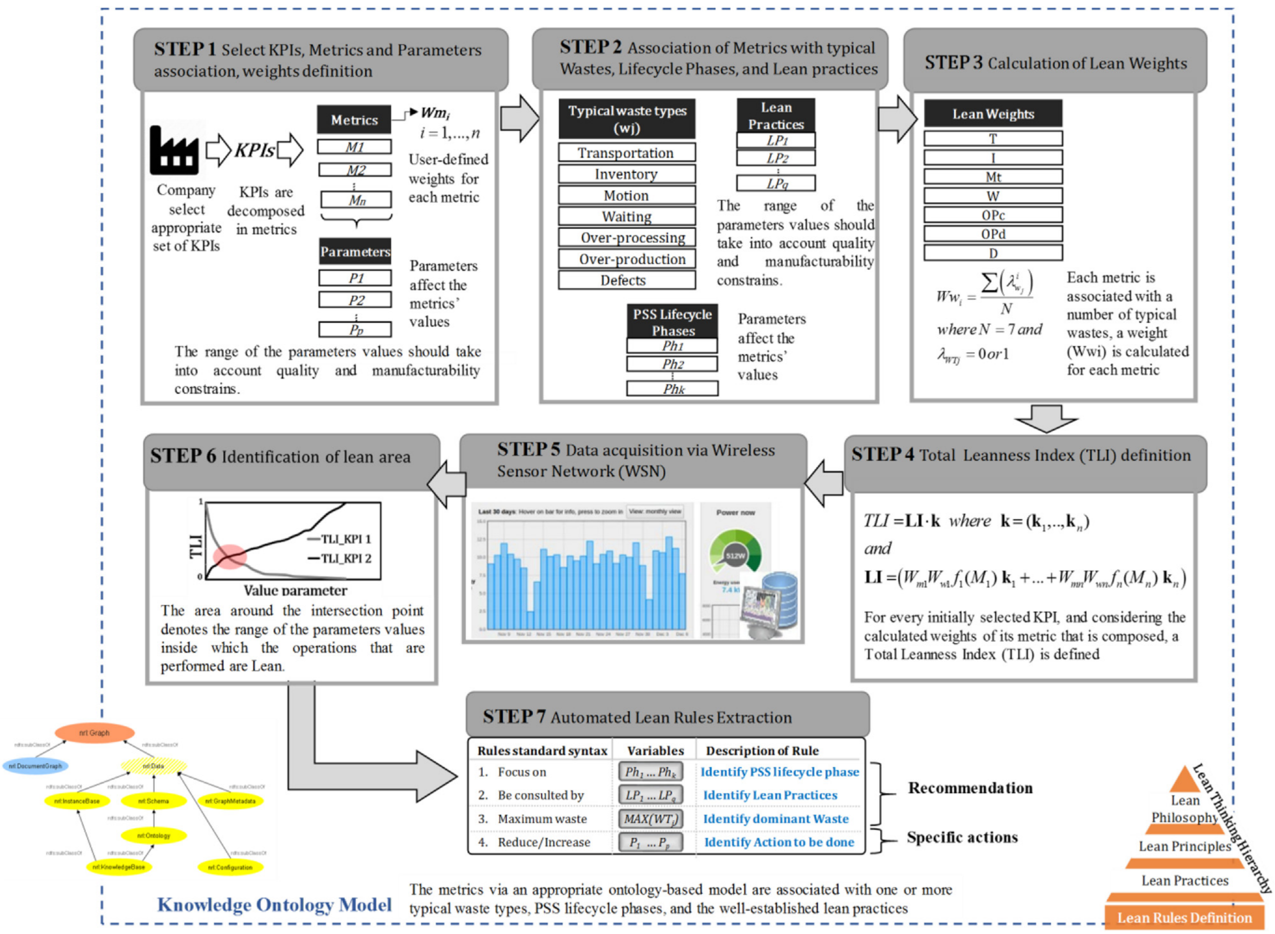


**Fig. 1.** Lean Rules Extraction Methodology (LeanREM) based on real time monitoring KPIs.

manufacturing, as defined in [13], and in Lean Product Development methodology. Over the years, Lean Thinking has been defined and coded as a dynamic, knowledge-driven, continuous effort to eliminate waste, with the goal of creating value, in which, customers' satisfaction should always be the primary goal [13]. Yet, Baines et al. first mention the relation between the PSS concept and lean manufacturing in 2007 [14] nearly a decade after the introduction of the PSS term [15].

Lean was primarily conceived as the practice (or group of practices) for eliminating and avoiding muda (wastes), adding more value to products and processes [16]. Muda reduction can be achieved by the implementation of lean principles and tools in the whole business environment. Several lean manufacturing practices are described in [17], such as the well-known TPM (Total Productive Maintenance) and JIT (Just-In-Time). The continuous monitoring of the KPIs can contribute to waste elimination, better process control, efficient manpower utilisation, and employment of flexible systems [2].

In the literature, it is very common to find the term Lean Rules conflicted with the term Lean Practice [18]. Usually, the term Lean Rules is used to describe teaching procedures about Lean philosophy [19,20]. However, there is a significant distinction between Lean Rules and Lean Practices. Lean Practices have been established many year ago [21,22], while Lean Rules first appeared in 2010 [18] as a new concept and its definition has been added very recently according to the following paper [23]. Particularly, according to the definitions, lean practices are specific tools that express a general philosophy that should govern the company and the production process, guiding the company towards leanness, while lean rules express straightforward instructions and actions, usually by using appropriate imperative verbs.

In general, the amount of literature work devoted to the combined Lean PSS ecosystem is limited, while most of the existing works focus on state of the art analyses. Specifically, after an extensive literature review, Sassaneli et al., identify which aspects of Lean thinking have already been applied in PSS development, and outline gaps for potential research, such as the definition of what is waste and value in a PSS design process [24]. Elnadi et al., bridge some gaps between Lean Thinking and PSS by focusing on the existing challenges, such as the understanding of leanness, definition of wastes, and the nature of the Service Process [25]. Also, a Lean PSS framework, along with a description of the fundamental elements which characterise Lean Production and Lean Service operations, is proposed in [26]. Two best-in-class lean PSS companies (Toyota Motor Italia and Alpha, Italy) are examined in order to analyse PSS activities under the aspect of Lean Thinking. A KPIs evaluation model is proposed in [27], which measures the degree of PSS leanness for UK manufacturing industries, through the definition of lean criteria. Similarly, in [8], KPIs for PSS design evaluation, related to leanness among others, are collected and classified.

In addition to the KPIs monitoring, context sensitivity tools would also be capable of supporting the PSS design phase. However, the adoption of context sensitivity tools during PSS design has not been sufficiently examined yet [28]. The basis for context-aware applications is a well-designed Context Model (CM). A CM enables applications to understand the user's activities in relation to situational conditions. There are various types of context-aware systems. In general, a context-aware system follows four steps