Recommendation Ranking Based on AHP Approach for Productivity Improvement in SME Context

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***Abstract*—This work deals with a multi-criteria decision making problem that consists in providing recommendations, which can improve productivity in Small and Medium-sized Enterprises (SMEs) based on measures comparison. This problem is very interesting because it allows SMEs to benefit from the expertise of a panel of experts avoiding pitfalls and bad decisions. On one hand, SMEs must stay competitive. Therefore, it is crucial to adopt efficient productivity improvement using the best methods. On the other hand, it is often necessary to implement facilitators knowing that SMEs do not have enough resources and technological experience to implement several methods. Therefore, how to chose the most important method or measure? This work answers this question and an attempt has been made to compare and rank the well-known measures in Lean Production and Industry 4.0 by applying the Analytic Hierarchy Process (AHP). The obtained results show that the top three methods are Design of the value Stream, Continuous Improvement Processes and Material Replenishment, respectively. The on-line platform of the INTERREG Prodpilot project provides access to the proposed recommendations and the obtained ranking.**

***Index Terms*—Recommendation ranking; AHP; Productivity improvement; Lean Production; Industry 4.0; SME.**

I. Introduction

Several countries around the world try to support their companies with different economic programs to improve their industrial sector. The objective is to increase their productivity. This becomes more important nowadays with the free international trade [1] where companies have to be able to propose their products at competitive prices and with high quality. This implies that productivity must be improved to remain competitive and gain in performance.

Furthermore, on one hand, there is a quick increase in production demand with continuous markets expansion gaining lands against competitors, which force the industries, particularly the small and medium-sized enterprises [2], to use their resources to the maximum of their capacity in order to make the highest profit. On the other hand, industries can no longer afford spending time to try several methods to gain in productivity. This could lead to failure and seeing sales contracts going to the competitors, which implies loses in terms of money and branding.

Other important variables of this complex equation are the proposed products prices, which are influenced by the increase in the price of consumables and raw materials, such as fuel or semi-conductors. Industries tend to find out the most economic process in provisioning, warehousing, production and delivery to handle this variability.

For all these challenges, companies can rely on the progress that technology makes nowadays, such as Internet of Things (IoT) [3] [4], Artificial Intelligence (AI) [5] and Big Data technologies [6]. Indeed, new doors are opened and new facilities are now possible. The key words "*Smart Companies*" and "*Digitalisation*" are more and more widespread in the industrial sector [7]–[10]. Every company wants to follow the fourth industrial revolution and to integrate the industry of the future into their methodology and process. Several advantages emerge with the industry of the future, such as real-time accessibility and flexibility, data-driven analysis and self-adjusting production. Companies that want to perform better, should begin utilizing methods coming from Lean and Industry 4.0. Thanks to new technologies, companies can identify the capacity of their active resources to allocate them accurately and to better plan and forecast peak periods with production levelling [11].

It seems that there are several existing approaches for production enhancement, and it is not always easy to make a reliable strategic plan in the top management with regards to created value, flexibility and durability avoiding a bad decision. Therefore, companies have a challenge when dealing with this heterogeneous, dynamic and complex decision making. The purpose of this article is to overcome that, and it introduces a prioritized list of recommendations for productivity improvement of well-known methods in Lean and Industry 4.0 based on Analytic Hierarchy Process (AHP). A decision-maker can rely on this ranking to orient its decision by taking into account the opinion of a panel of experts in productivity. We point out that the development of the Maturity Model for measuring the advancement in Lean and Industry 4.0 of SMEs is not part of this work.

The remaining part of this paper is organized as follows. In Section II, we introduce more in detail the concept of productivity, Lean Production and Industry 4.0 used in this work. In Section III, a survey of the available measures for productivity improvement and also the description of the general framework for comparative evaluation are presented. Following that, Section IV is devoted to the comparison and the ranking of measures for productivity improvement and discussion of the obtained results. Finally, the last part of the paper includes the conclusion and offers the future

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perspectives.

II. Productivity, Lean Production and Industry 4.0 concepts

This section introduces more in detail the concept of productivity, Lean Production and Industry 4.0 used in this work.

A. Productivity

Productivity can be seen from different points of view, but commonly defined as the ratio between the output and the input used to product this output (see (1)), like goods or services [12] [13]. In general, productivity is an objective concept, where it measures how efficiently resources are used in the production process. For the industrial sector, productivity is expressed by the efficiency to transform inputs such as investments, raw materials, energy and labour into products. In other words, it is an overall measure of the ability of production per unit of used input. Other parameters can affect this equation like the supply chain reliability [14] and the efficiency of the delivery system or even also customers and employees satisfaction for a better quality of work life [15] [16].

$$Productivity = \frac{Outputs}{Inputs} \quad (1)$$

However, the productivity differs from production. The former is a quantitative relationship between the products and the converted inputs while the latter concerns the amount of outputs over a period of time. Furthermore, considering (1), higher productivity means either producing the same amount of products with less resources (i.e., smaller denominator) or producing with the same amount of resources more products (i.e., bigger numerator).

B. Lean Production

The Lean Production principle is to remove all unnecessary tasks from the production process, which waste resources without creating value and delaying the delivery time [17]. The base of Lean Production are continuous improvement (Kaizen) and Muda reduction (5S). It is built with two columns of Just-in-Time (JIT) [18] and autonomation (Jidoka) [19], which rely on 2 foundations production levelling (Heijunka) and standard working in order to absorb the demand fluctuations. Techniques like Single-Minute Exchange of Dies (SMED) and elimination of error causes (Poka-Yoke) are used to reach the delivery time, quality and costs objectives.

C. Industry 4.0

The fourth industrial revolution consists in integrating Data Science and Information and Communication Technology (ICT) in the process of companies digitalization [20]. Nowadays, with the technological progress, techniques and facilities can be categorized in three groups:

1) *Connectivity and data transmission*:
The Internet offers a large range of technologies to access information at any moment from any location, ensuring fluid communication between people, processes and equipment, especially IoT [21]. It is not longer necessary to invest in a large IT infrastructure to process big data thanks to Cloud and High-Performance Computing, which has contributed greatly to this information accessibility. Cybersecurity is another facet providing authentified connections in a trusted environment where the information can be transmitted without being intercepted by malicious third parties.
2) *Management and business intelligence*:
The use of software packages, like Enterprise Resource Planning (ERP), for business management has become more than a necessity. Such a generic tool is intended to manage different sections of the company including inventory, purchasing and sales for a centralized and irredundant information. Custom-made tools are more and more widespread in Intelligent Production relying on Effective Algorithms [22] and Machine Learning [23]. Those aim to provide an effortless and efficient tool to a decision-maker, which integrates its expertise in a user-centred algorithm, like in Active Learning [24], towards the optimized use of resources, pattern recognition in fault detection or accurate forecasting of product sales.
3) *Cyber-physical system*:
One can say that there is a bidirectional pipe between the real-world and the virtual world where devices can be used to enrich one world with information gathered from the other world. For instance, augmented reality with smart glasses for remote-guided maintenance [25] or improving manual production process [26]. On the other hand, sensors can be used for locating targets in indoor industrial locations [27] or in outdoor industrial locations, like GPS tracking of a fleet of trucks in order to optimize a real-time delivery system [28].

III. Measures and framework

This section presents more in details the measures that can be used in maturity assessments with the underlying enablers for productivity improvement, the general framework and the followed methodology.

A. Existing maturity models

Nowadays, almost all companies recognize what Lean Production and Industry 4.0 can bring to them in terms of progress. It has become a trend in this industrial era and every company wants to be part of it. Nevertheless, most of them cannot accurately determine their status-quo and do not really know how to adopt an appropriate transformation. In this context, a maturity model can be considered as a powerful tool to assess the degree of maturity and to define the next milestones. In this research field, there is no consensus regarding a common standard which characterizes the dimensions and the measures of the models. The objective of this article is not to make a survey of the numerous models, but a non-exhaustive list is presented in what follows.

In [29], the initial version of the Lean Enterprise Self-Assessment Tool (LEAST) is introduced. Based on a user needs identification, it is organized into three dimensions, namely Lean Transformation/Leadership, Life Cycle Processes, and Enabling Infrastructure Processes. Thereafter, other models are proposed including additional dimensions, like in [30].

Regarding Industry 4.0, Schumacher et al. propose an empirically grounded model to assess the Industry 4.0 maturity in the domain of discrete manufacturing [31]. Its main goal was to extend the dominating technology focus of the previous models by including organizational aspects. More recently, a 6Ps model for digital maturity has been introduced, which stands for Product-Services, Processes, Platform, People, Partnership, Performance [32].

Other models are assessing both Lean Production and Industry 4.0 aspects because they are intrinsically correlated. For interested readers, some surveys are given in [33]–[35].

B. Used maturity model - dimensions and measures

This article introduces a prioritized list of measures of a self-assessment tool providing recommendation for productivity improvement. This self-assessment tool is based upon Lean Production and Industry 4.0 principles with a SME scope. It is organized into five dimensions, 36 measures and 4 levels (beginners, intermediate, experienced and expert for each measure) illustrated in Figure 1. We point out that the development of the used self-assessment tool is not part of this work. For more details, we refer to the INTERREG Prodpilot project (040-4-09-104) [36].

C. Framework

In order to prioritize the measures for productivity improvement in a SME context, we adopt the Analytic Hierarchy Process (AHP) method as framework. AHP is one of the most widespread methods in Multiple Criteria Decision Making (MCDM) methods [37], offering to a decision-maker an effective tool for ranking alternatives based on quantitative comparisons. Indeed, a numerical scale reflecting qualitative superiority/inferiority can be used to solve complex decision problems with conflicting alternatives. AHP was introduced by Saaty in 70's and its major strengths are to consider several criteria simultaneously and making subjective trade-offs to arrive at a consensus [38]. To obtain this ranking, an Eigen value problem is solved using as input the pairwise comparison matrix. Thus, the first normalized Eignen vector represents weights (prioritized alternatives) while the Eigen value represents the Consistency Ratio (CR). The latter expresses the degree of cohesion through transitivity when the expert is filling in the comparison matrix. The closer this ratio is to the value 1, the more randomly the comparison matrix has been filled.

AHP can be applied in various complex decision issues, such as raking solution techniques for reactive scheduling [39], evaluating flexible manufacturing systems [40], management

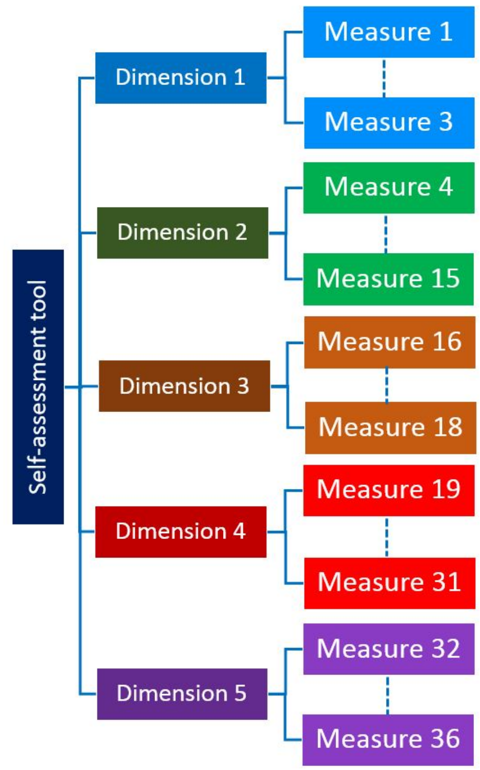

Figure 1. Self-assessment tool.

of construction projects [41], healthcare research [42], supplier selection [43] and choosing ERP Systems [44].

In this field, building an appropriate hierarchical structure of the addressed problem (i.e., goal, criteria and alternatives) is the cornerstone of an accurate prioritization. Figure 2 shows the different levels of the proposed AHP hierarchy to rank the productivity improvement measures. In Level 3, it is envisaged to compare 14 preselected measures (alternatives) of the aforementioned self-assessment tool. The root of the hierarchy represents the objective, which is the most effective measure for productivity improvement in the SME context. The intermediate level represents the criteria on which the experts will rely to make their judgements and rank measures for recommendation.

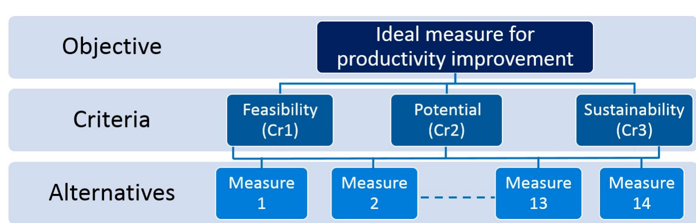

Figure 2. Defined hierarchy for AHP.

Each criterion is defined accordingly to reach the targeted objective.

1) *Feasibility (Cr1)*:

In a SME context, there are not enough resources and technological experience to implement several methods. Feasibility stands for how easily a measure can be implemented by a company. How much does the company need additional resources or experience?

2) *Potential (Cr2)*:
This criterion refers to the degree of improvement in productivity that the company reaches after implementing a measure. To what extent the implementation of a measure allows for a noticeable progress in terms of productivity?

3) *Sustainability (Cr3)*:
Last but not least, sustainability represents the durability of an action over time before it becomes obsolete. Obviously, the longer the company benefits from the measures implementation, the better the measure.

D. Methodology

Figure 3 depicts the followed methodology for ranking measures as recommendation toward productivity improvement. An explication is given in what follows for the pre-processing steps in contrast to AHP steps.

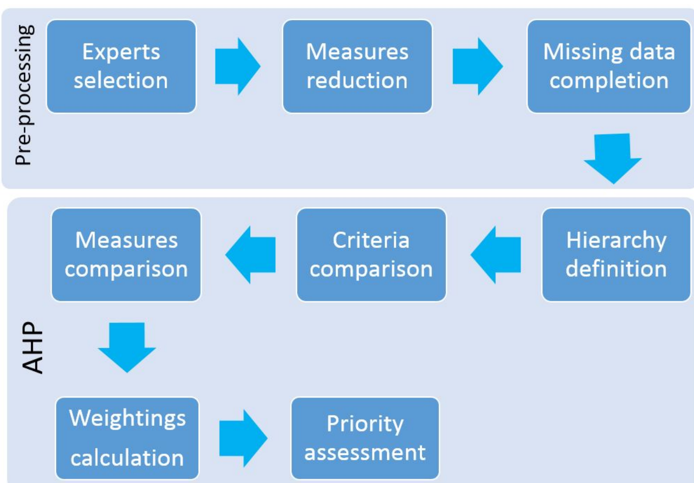

Figure 3. Pre-processing and AHP steps.

- *Experts selection*:
The criteria and measures with their relative importance impacting productivity are investigated using a specially designed questionnaire. The self-assessment tool is joined with the questionnaire for an explanatory purpose. The experts pool is composed of either academics or manufacturers with at least 5 years of experience in Lean Production and Industry 4.0.
- *Measures reduction*:
It is obvious that providing consistent pairwise comparison of 36 measures of the initial self-assessment tool is not a task that a human can perform. We asked the experts to keep only the most important 14 measures according to them, and to determine which are the most representative of the 5 dimensions. After the reduction step, the most preselected 14 measures is considered as the ideal set of measurements. Therefore, $\simeq$ 80% of the aggregate comparison matrix was filled in because the experts did not necessarily select the same measures during the reduction step. Nevertheless, this shows an agreement among the experts concerning measures reduction giving rise possibly to a shorter self-assessment tool for productivity improvement in SME context.
- *Missing data completion*:
One question might be raised, namely, how to fill in the $\simeq$ 20% of missing data. To answer this question, the first approach consists to apply the Harker's method. The idea is to replace the missing values in the comparison matrices with the most consistent values, which minimize CR [45]. However, it is not recommended to apply Harker's method when all entries of a row in the comparison matrix are missing. In this case, bias could be introduced in the data. The second approach relies on the Shannon's entropy principle of the Information Theory [46]. In particular, having no prior knowledge, the entropy is maximal for a source whose symbols are all equi-probable. Analogously to our context, having no prior knowledge regarding the superiority/inferiority of one measure over the others for an expert, then the relative measures are equi-important. The latter approach is used in this work for missing data completion.
- *AHP steps*:
The described hierarchy in Figure 2 is utilized as AHP hierarchy structure. Furthermore, the criteria and the preselected measures are compared with each other using the comparison scale [1-9]. Indeed, 1 denotes equal importance, 2 low importance and 9 extreme importance.

IV. Obtained Ranking

This section describes the obtained results by applying the framework presented in Figure 3. Table I shows the importance of each criterion with the respective weightings.

TABLE I
PAIRWISE COMPARISON OF CRITERIA WITH RESPECT TO THE IDEAL MEASURE FOR PRODUCTIVITY IMPROVEMENT

Criterion	Importance	
	Level	***Weighting***
Feasibility (Cr1)	Hight importance	0.505
Potential (Cr2)	Moderate importance	0.301
Sustainability (Cr3)	Low importance	0.192
CR		**0.094**

According to the experts, the feasibility criterion is the most important, followed by potential and finally the sustainability criterion. This could be argued by the fact that SMEs suffer from lack of resources and technological experience to implement or adapt all measures. Indeed, compared to larger companies having an Research and Development (R&D) department where processes are continuously optimized and where new technologies are supported at all hierarchical levels, the feasibility is not as important as in a SME context. Furthermore, the potential of productivity improvement has an intermediate level of importance in the SME context, which can clearly be considered as the highest level of importance by larger companies. Finally, sustainability has obtained relatively the least important degree due to technology obsolescence for which companies of all sizes are aware.

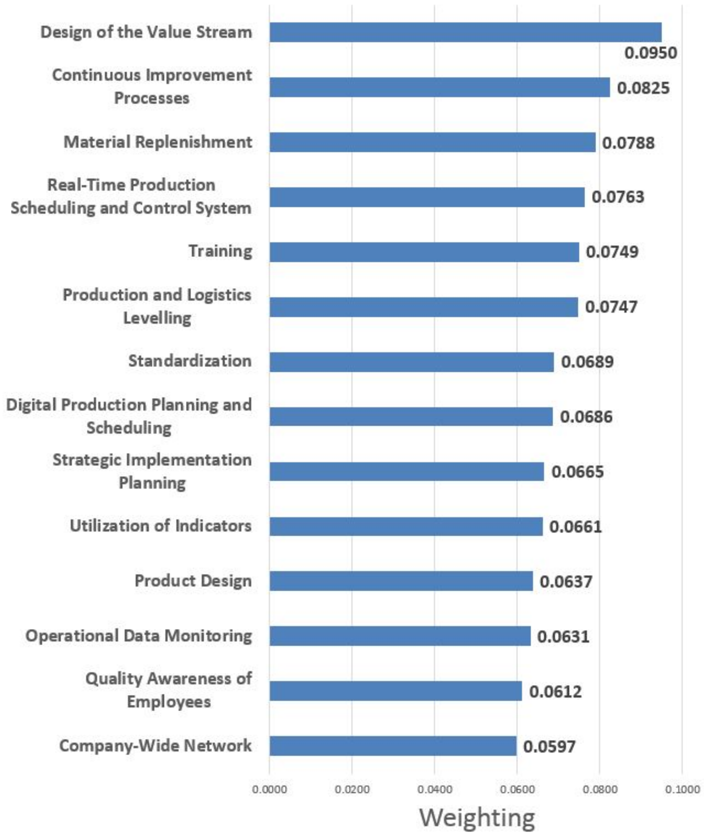

Figure 4. Ranking of measures for productivity improvement taking into account Cr1, Cr2 and Cr3.

Figure 4 presents the obtained prioritization of the 14 measures for productivity improvement considering the criteria. The recommendations based upon experts' opinions places Design of the Value Stream (DVS) at the top followed by Continuous Improvement Processes (CIP) and Material Replenishment (MR), respectively. Table II presents the potential pitfalls and the related aspects to be tackled for the top three measures.

Obviously, the above subjective ranking is very sensitive to experts opinions. Therefore, the choice of the pool of experts is a very important step to achieve an effective and qualitative recommendation based on AHP for which the researchers must pay attention. Moreover, the cohesion ratio is acceptable ($CR < 0.1$, see Table I) knowing that incoherence is part of the experts' judgement. Of course, the CR could be lowered by reinterviewing experts whenever inconsistency is observed. However, automatic methods should be avoided to reduce CR because they may alter the pairwise comparisons leading to unrepresentative data [47].

TABLE II
TOP THREE MEASURES, POTENTIAL PITFALLS AND THE ASSOCIATED ACTIONS

	Potential pitfall	***Action***
DVS	Persisting non-value added tasks	Continuous analysis and optimization of the whole value chain from the supplier to the customer end to reach the desired value-added percentage
CIP	Unstructured complex problem solving	Problem structuring and utilization of intelligent tools like Active Learning
MR	High inventory and material stock-out	Optimization of material stocks via collaborative tool involving different parties of supply chain

V. CONCLUSION

This work deals with recommendation making for productivity improvement in the SME context. The obtained prioritization is based upon experts judgements to rank the important measures in Lean Production and Industry 4.0 with respect to three criteria, namely feasibility, potential and sustainability. Companies can rely on these recommendations to adopt efficient productivity improvements and to choose the most important measure according to the experts in their strategic action plan. Particularly, in a SME context, there are not enough resources and technological experience to implement several measures. Therefore, the resulting measures ranking by applying AHP is presented in this paper and can be also accessed via the on-line platform of the INTERREG Prodpilot.

Regarding the perspectives, this work could be extended and it will be worth to consider other criteria to rank measures for productivity improvement, such as the reticence of SMEs regarding some measures.

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