Analysing the support of sustainability within the manufacturing strategy through multiple perspectives of different business functions

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Abstract

This paper proposes an empirical study aimed at characterizing the evolution of a company towards a sustainable manufacturing strategy, with a special emphasis on the role played by the business functions within the industrial organization. In the study, a methodology to evaluate and rank the sustainable manufacturing strategy in different production contexts is developed, stemming from the fact that there is a lack of objective methods for sustainable manufacturing strategy ranking in the literature. The analysis method consists of an Analytic Hierarchy Process applied to competitive priorities and manufacturing performances. It enables a structured reflection that considers the multiple perspectives of different decision-makers in business functions relevant to the implementation of sustainability in the manufacturing strategy. The main objective of the approach proposed in this study is to provide a methodology able to give an integrated view of the economic, environmental and social dimensions of the manufacturing plants. The proposed methodology is applied in two application case studies referring to two different production contexts. The application cases show the usefulness of the methodology to assess how sustainability is supported in the manufacturing strategy, with specific concern to the evolution of a manufacturing plant towards a sustainable manufacturing strategy.

Keywords: Sustainable manufacturing; manufacturing strategy; competitive priorities; performances; Analytical Hierarchy Process **Abbreviations[1]:** SD, ESET, SM, MS, SMS, AHP

1. Introduction

The concept of sustainable development (SD) was defined by the Brundtland Commission as the "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (United Nations General Assembly 1987). Since then, SD has been recognized as a major driver, while economy, society, environment and technology (ESET) are claimed as leading factors within initiatives oriented to SD (Jovane et al., 2008).
In 2015, the United Nations (UN) invoked a universal call to action to protect the planet and ensure peace and prosperity by issuing seventeen Sustainable Development Goals (SDGs). Therefore, sustainability has increasingly moved up in the business agenda through companies' needs to integrate sustainability into their strategies (Galbreath, 2009; Mangla et al., 2019), especially addressing the 12th SDG – responsible production and consumption (Barletta et al., 2018) – while leading to a convergence of the research on sustainability and strategic management (Elms et al., 2010; Witek-Crabb, 2012; Akhtar et al., 2016; Allais et al., 2017).
Even if sustainability has become more and more relevant for management in the recent years, the discussion on Sustainable Manufacturing (SM) and Sustainable Manufacturing Strategies (SMS) has only initiated.

[1] SD = sustainable development; ESET = economy, society, environment and technology; SM = sustainable manufacturing; MS = manufacturing strategy; SMS = sustainable manufacturing strategy; AHP = Analytic Hierarchy Process

Kleindorfer (2005) affirmed that a sustainable operations management would consist of a set of skills and concepts allowing companies to structure and manage their business processes to be competitive and make a profit without sacrificing the needs of internal and external stakeholders, while caring about the impact that operations have on the community and the environment. Despeisse et al. (2012) recognized SM as "*a new paradigm for developing socially and environmentally sound techniques to transform materials into economically valuable goods*". Garetti and Taisch (2012) also stated that SM is "*the ability to smartly use natural resources for manufacturing, by creating products and solutions that, thanks to new technology, regulatory measures and coherent social behaviors, are able to satisfy economic, environmental and social objectives, thus preserving the environment, while continuing to improve the quality of human life*". Aligned with their reflections, Gupta et al. (2015) recently stated that manufacturing is influenced by the sustainability issues as it plays a key role in establishing a sustainable way to realize products and services for the market.

Overall, a number of recent outcomes confirm that SM is deemed as a fundamental issue in the corporate strategy (Taisch et al., 2015: Hermann et al., 2015, Pask et al, 2017) and, indeed, sustainability is a relevant aspect of the Manufacturing Strategy (MS) (Wu et al, 2017). Therefore, a SM strategy is defined as a business strategy, formulated by a manufacturing company, with the aim to embed SM in its corporate and operational goals (Barletta et al., 2018).

The current trends indicate that the concept of sustainability should be part of the operations strategies in manufacturing (Savino and Batbaatar: 2015; Propa et al., 2015; Allais et al., 2017). Furthermore, it may be necessary to know and evaluate the environmental strategies executed by managers, considering that sustainability has an integrative and holistic approach (Sarmiento et al., 2007). This may help not only in enhancing the financial performance of an organization, but also in satisfying the social and environmental objectives and regulations (Gunasekaran and Spalanzani, 2012; Propa et al., 2015).

If organizations could consider the environmental and social aspects together, then it would be easier to achieve business sustainability (Luthra et al., 2019). Nevertheless, despite the positive relationship between firm performance and sustainable development strategies, manufacturing companies are still slow to adopt sustainable practices in their operations strategies. To this regard, researchers highlight that the inability to identify and prioritize critical factors for strategy formulation and implementation is the main reason that inhibits companies to accrue the sustainability-related benefits (Khatri and Metri, 2016).

Therefore, it is worth studying how manufacturing is effectively changing its *ability* of being sustainable. In particular, this paper uses the Manufacturing Strategy (MS) joint with Analytic Hierarchy Process (AHP) as a lens to investigate the *competitive priorities* and *performances* within the MS of a firm.

In fact, two main elements define a MS: the *manufacturing capabilities* and the *manufacturing objectives*, known also as *competitive priorities*. Decisions in a MS determine the *manufacturing capabilities* and *competitive priorities* to support company's business (Amoako-Gyampah and Moses, 2008; Cai and Yang, 2014).

Borrowing the term from the management and business strategy literature focused on resource-based view of the firm (Corbett and Claridge, 2002; Wu et al, 2008; Savino and Batbaatar, 2015), the *capabilities* in the MS literature are often conceptualized within business units, that are intended as units able to obtain performance or operational strengths (Noble 1995; Boyer and Lewis, 2002; Koufteros et al., 2002; Flynn and Flynn, 2004; Größler and Grübner, 2006). *Manufacturing capabilities* are then assessed by the operational performance (Savino and Batbataar, 2015). This is typically based on multidimensional performances, which frequently include *cost*, *quality*, *flexibility*, and *delivery* measures. It enables to operationalize capabilities through quantitative and qualitative metrics in order to measure the effectiveness in achieving the competitive priorities (Ward *et al.*, 1998), also identifying the relationships among different performance dimensions (Ferdows and De Meyer 1990), and understanding the linkage between operational performance and business and manufacturing strategy (Ward and Duray 2000; Hallgren 2007). Therefore, performance measurement is a strong area of interest for MS during the last decades (Dangayach and Deshmukh, 2001).

This study is primarily grounded on the i) *competitive priorities* and the ii) *performances*. The former includes a set of dimensions that represent the manufacturing objectives driving the decisions taken for a manufacturing plant to enable the achievements requested by market's requirements. The latter enables to measure such achievements, allowing also a continuous improvement approach (Ward and Duray, 2000; Díaz et al., 2005; Butt, 2009; Savino and Mazza, 2014, Rehman et al, 2016).

Henceforth, this paper investigates how a company gives prominence to a SMS through the *competitive priorities* and *performances* of its manufacturing plants. A specific focus is provided on the different business functions of the company, looking at their influence for the effective implementation of the MS.

In particular, the present paper aims to fill one of the main gaps found in literature regarding the lack of objective methodologies that can be used to evaluate and rank the SMS in different production environments, through a multi-criteria decision-making. Among the several multi-criteria decision-making techniques, the analytical hierarchy process (AHP) is among the most powerful. Therefore, a methodology based on the use of AHP is applied for the analysis, in order to spot out the relative importance of the competitive priorities and the performances that may drive the behavior of different decision makers in business functions relevant to the implementation of sustainability in the MS. According to Ishizaka et al. (2012) and Lee and Drake (2010), AHP is a reliable and flexible tool to current situations because it provides optimal solutions for several complex multi-criteria decision issues. This model is useful especially in cases where there are a large number of factors (Giovidan et. al, 2015). Mathiyazhagan et.al, (2014), Giovidan et.al. (2014) and Liberatore and Nydick (2008), show the advantages of AHP in their research, arguing that AHP allows decision-makers to ensure the consistency of their judgements on the different factors. Besides, many recent studies point out that most of the successful applications of the traditional AHP approach, concerns precisely the manufacturing sector (Shankar et. al., 2016, Xu et.al., 2013, and Ho, 2008).
The paper is organized as follows. Section 2 provides a state of the art on the competitive priorities and the performance measures for a SMS. Section 3 outlines the research objectives, questions and framework. The investigation, the related model and analysis process is detailed in section 4. The empirical evidences were got in two different contexts, a white appliances manufacturer and an elevators manufacturer, discussed in section 5, while section 6 eventually provides an outlook on future implications interesting to different stakeholders.

2. Literature review

2.1 Competitive priorities in the manufacturing strategy

The academic and business discussion on competitive priorities gives evidence of the constant presence of the four traditional priorities since many years, which are cost, quality, flexibility and delivery performance (Hayes and Wheelwright, 1984; Kathuria, 2000; Größler and Grübner, 2006; Miltenburg, 2008; Vachon et al., 2009). Besides, it demonstrates that authors have varied their definition of competitive priorities over time.
Martin-Pena and Diaz-Garrido (2008a) selected 22 papers, published during the period 1980-2006, for their literature review on typologies and taxonomies of operations strategy, with the purpose to identify the generic configuration of MSs in various journals. Thanks to this sample, it is worth observing that new competitive priorities are appearing, that is: innovation, after sales service, protection of environment, advertising, wide product distribution, customer relationships. Table 1 shows the main priorities as identified by the selected papers:

- Miller and Roth (1994) defines 11 competitive priorities; the majority – low price, design flexibility, volume flexibility, conformance, performance, speed, dependability – is a further specification of the traditional priorities; the remainder is including new issues motivated by the importance to integrate manufacturing with other business functions, as the marketing function – after sales service, advertising, broad distribution and broad line;
- Christiansen et al. (2003) specifies a number of additional priorities as the time to market, design, product features, variety and customization, besides the traditional ones; the new competitive priorities are needed to characterize the strategies built upon an offer of products of high quality and a quick responsiveness to the customer's needs and preferences;
- Martin-Pena and Diaz-Garrido (2008b) include a new priority, the protection of environment. It is defined by the capacity of the manufacturing system to reduce the environmental impact of its operations, and to produce environmental-friendly products; Diaz et al. (2005) and Savino and Batbaatar (2015) consider it as important as the other priorities in a company that aims at pursuing manufacturing excellence.
  Based on these findings, we may argue that sustainability should be integrated in the content of a MS. This consideration is in line with the proofs gathered by Martin-Pena and Diaz-Garrido (2008b) with their survey conducted within a wide set of Spanish companies. These findings are also consistent with the ones of more recent works (Garetti and Taisch, 2012; Trentin et al., 2015; Nawaz et al. 2016), remarking the need for a change of manufacturing management models towards sustainability. Therefore, it could be expected that SMSs would also emerge, enriching the existing theories on capabilities and competitive

priorities, to finally improve the impacts on environmental, economic and social dimensions of business processes and products. Nevertheless, there is still a challenge to select the most appropriate strategy for each case study (Chen et al., 2012).

In more recent publications, (Barletta et al., 2018) develop a methodology to help manufacturing companies align their manufacturing capabilities to the desired strategy for SM, addressing for a holistic view of sustainability. Thus, the introduction of sustainability in manufacturing strategy has been proposed. On the other hand, deployment strategies and inter-dependencies among competitive priorities and their impact on decision categories remain unexplored (Mirvis, Googins, and Kinnicutt, 2010, May and Stahl, 2017). Overall, the relation between sustainability priorities and other competitive priorities, such as cost, quality, delivery, flexibility, innovation and service, is substantially under-researched.

Table 1 – Main competitive priorities in the manufacturing strategy as from the literature review

Competitive priorities	**References**
Cost, quality, flexibility, delivery performance *(traditional priorities)*	(Hayes and Wheelwright, 1984; Kathuria, 2000; Größler and Grübner, 2006; Miltenburg, 2008; Vachon et al., 2009; Miller and Roth, 1994; Christiansen et al., 2003).
After sales service, advertising, broad distribution, broad line	Miller and Roth (1994)
Time to market, design, product features, variety, customization	Christiansen et al. (2003)
Protection of environment	(Martin-Pena and Diaz-Garrido, 2008b; Diaz et al., 2005; Savino and Batbaatar, 2015)

2.2 Performances in the economic, environmental and social dimensions

Skinner (2015) argued that managers need to give serious thought to the role that MS could have on firms' performance and a number of authors have also remarked similar statements during the last two decades (Gupta and Somers, 1996; Ward and Duray, 2000; Dangayach and Deshmukh, 2001, Amoako-Gyampah and Acquaah, 2008; Sumit al., 2015). The discussion is nowadays updated, including the link between MS and firm performance in sustainability. In this regard, it is worth mentioning that the most recent trends show that businesses are increasingly paying more attention to the social dimension, primarily owing to a shift in stakeholders' pressures from environmental to social-related concerns. In fact, different issues – as the ever changing customer expectations, regulatory shifts, capacity excessing, and environmental concerns themselves – are becoming all influent for firm's strategy and, thus for its performance, inclusive of the all dimensions, i.e. economic, environmental and social (Valkokari et al., 2014).

Taking the purpose of regulating and establishing recommendations for environmental and social affairs, it is worth remarking that several standards and management frameworks are nowadays available. Some are meaningful for the social dimension, e.g. Accountability – AA 1000, Social Accountability – SA 8000, International Guidelines for Corporate and Social Responsibility – SR ISO 26000; some others are focused on the environmental dimension, e.g. Global Reporting Initiative – GRI; Environmental Management Standards – ISO 14000 (Castka and Balzarova, 2008; Mitra and Webster, 2008; Porter and Kramer, 2006; de Lima et al., 2011; Savino and Batbaatar, 2015; Nazari et al., 2017). The state of the art of such standards and management frameworks is advanced concerning the environmental dimension, while the social dimension appears a more recent focus. Therefore, standards and management frameworks are useful sources as they provide sets of recommended performances. In this regard, we may refer to Global Reporting Initiative – GRI 3.1, 2011 (Global Reporting Initiatives, 2011); the EMAS III Regulation of 2009 (European Union law, 2009; European Commission, 2017); the International Guidelines for Social Responsibility – ISO 26000, 2010 (ISO/TMB Working Group on Social Responsibility, 2010) and the ISO 14031:2013 (ISO/TC 207/SC 4, 2013). To the best of our knowledge, the GRI Sustainability Reporting Guidelines are considered as the most comprehensive reporting framework up to date (Szekely and Knirsch, 2005), containing performances in all the three dimensions – environmental, economic and social – that make-up the so called "*triple bottom line*" evaluation of SD (Lee and Kim, 2009; Nawaz et al; 2016).

Coherently with the presence of standards and management frameworks, numerous sustainability assessment methodologies have been discussed in the extant body of literature, in which the majority of them focuses on one specific sustainability dimension (Gokan and Stahl, 2017). Within this dimension, few impact categories are addressed (Negri et al., 2016). Indeed, it is rare that these methodologies reach a complete integration over the "*triple bottom line*", even if authors wish for it (Klöpffer, 2008; Rebitzer et al., 2003). Nonetheless, combining the assessment methodologies from the extant literature, a consistent set of performances, related to various impact categories, can be derived. In regard to the environmental dimension, the well-known Life Cycle Assessment (LCA) due to the ISO 14040 provides a capability to compare and assess impacts of different techno-economic alternatives for products under various environmental aspects (such as climate change, stratospheric ozone depletion, smog creation, eutrophication, acidification and similar). Besides, the MIPS methodology (material input per service unit) developed by the Wuppertal Institute for Climate, Environment and Energy (Lettenmeier, 2009; Ritthoff et al., 2002), aims to support the quantification of materials and energy needed to provide a service, considering the lifecycle of products and then expanding the evaluation to a wider service perspective through the concept of service unit. The economic dimension is rich in terms of assessment methodologies that provide appropriate indicators related to the Life Cycle Cost (LCC), which is the economic counterpart of the environmental LCA (see, e.g., a review of indicators in (Negri et al., 2016)). Concerning the social dimension, the assessment methodologies are being adapted to achieve the social life cycle assessment (SLCA) (Dreyer et al., 2006). SLCA has still a theoretical basis, while social impact categories are usually referring to principles expressed in the Universal Declaration of Human Rights, in the SA8000, in the Tripartite Declaration of Principles concerning Multinational Enterprises and Social Policies and in International Labour Organisation conventions (Dreyer at al., 2006; Hauschild et al., 2008). It is apparent that there is still no widely accepted assessment approach while social consequences are difficult to quantify into flows related to the product-services. Overall, whereas environmental accounting methods have been embraced by both academics and corporations (Burritt and Saka, 2006; Schaltegger and Dyllick, 2002; Zhang et al, 2017), the landscape of social impact assessment provides methods that have yet to be categorized in a comprehensive way.

Focusing now on the literature concerned with the MS, it is worth observing that this confirms the background known from standards, management frameworks and assessment methodologies. In fact, relying on a sample of selected references, it is evident that the economic dimension is full of references as expected, while more recent development is observable in terms of the environmental and social dimensions.

Starting from the sample, it is worth reflecting on some deducible key messages. An early work of Rangone (1996) outlines the inclusion of non-financial performance measures, besides cost measures, in order to control the support to the achievement of the MS with respect to all the traditional competitive priorities, such as flexibility, quality, dependability, etc. Thus, he shows the potential of the AHP for assessing the overall performance of different manufacturing departments. In line with this early outcome, Boyer and McDermott (1999) explicitly focuses on the debate over the need for trade-offs in MSs, while relating to the traditional priorities of quality, cost, flexibility, and delivery. In their survey, the priorities are expressed as abilities to improve performances in different dimensions that contribute to the trade-offs. White (1996) also provides the result of a wide survey, now built on accounting, manufacturing and managerial literature, to develop a taxonomy which categorizes, amongst the others, the performances according to the dimension of the competitive priorities of cost, quality, flexibility, delivery reliability, or speed. The trade-off models and the different categorizations due to the competitive priorities are a foreground of other similar works. For example, Yurdakul (2002) proposes a multi-criteria performance measurement model in order to measure the profitability performance of a manufacturing system. Relating to SM, Veleva and Ellenbecker (2001) is worth of a mention, as it provides one of the first meaningful framework inclusive of core and supplemental indicators of sustainable production. It is organized in six aspects, i.e. energy and material use, natural environment (including human health), economic performance, community development and social justice, workers and products, which is a good example of inclusion of performances across the three dimensions of sustainability. Labuschagne et al. (2006) also propose a framework to assess the sustainability performances of a company and its operational activities, with special emphasis to process industry. Other works are also focused on sustainability in operations strategies as well as performance indicators for SM evaluation – see de Araujo and de Oliveira (2008), Amrina and Yusof (2011), de Lima et al. (2011), Carrell (2013).

As such, they are a useful source where performances related to the social and environmental dimensions can be found as linked to the support of the MS. Eventually, regarding the influence of organizational factors, which is of interest of this paper, it is worth reflecting on the perception of managers on competitive priorities

and performance of manufacturing units. Based on their empirical evidences, Joshia et al (2003) enables to point out that the performance of a manufacturing unit is potentially enhanced when management agrees on the strategic priorities. On the other hand, it is evident the influence of organizational factors on the performance of the manufacturing unit and its alignment with respect to the strategy: they may lead either to enhance or undermine the support to the achievement of the MS.
To complete the background, other interesting references are advisable to the reader interested in the role of performances for the evaluation of manufacturing systems as essential task for supporting the achievement of a MS – see, e.g., Hon (2001), Gole and Taskin (2007), Hallgren (2007), Awwad (2008), Yang et al. (2009), Boon-itt (2009).
Overall, the literature review – joining the knowledge available from standards and frameworks, assessment methodologies related to the impacts of products and services, as well as contributions related to performances relevant for MSs – allowed to build the background where to select seventy performance measures. These are reported in annex 1, where they are grouped in six main categories defined upon the most relevant competitive priorities. It enables to inform the development of the model proposed in this work (see section 4).

2.3 Existing gaps in the literature

Based on the state of art analysis, it is evident that the introduction of sustainability in the manufacturing strategy has been proposed; nevertheless, as main gap identified and addressed in this research, deployment strategies and inter-dependencies between sustainability priorities and other competitive priorities, such as cost, quality, delivery, flexibility, innovation and service, remain substantially under-researched. In particular, one of the major lacks is the poor number of assessments of sustainability objectives within a manufacturing plant: what is missing is an assessment of the economic, social and environmental issues as competitive priorities in the strategy of the company and of its manufacturing plant(s). Moreover, the introduction of new competitive priorities would generate more trade-offs that should be assessed under the SMS viewpoint; this assessment would also enable, in the frame of a multi-criteria decision-making approach, to consider different viewpoints due to the business functions responsible for decision-making and influent for the trade-offs.

3. Research objective, questions and framework

3.1 Research objective and questions

Based on the identified gaps in the scientific literature, the present study has the main objective to develop a methodology that enables: i) the investigation of the SMS through an evaluation of the relative importance of the competitive priorities, and ii) the assessment of the relative importance of the competitive priorities for different business functions within the organization. Then, we identified the following two research questions (RQ) to guide the development of the methodology.

RQ1: How to envision the evolution of a company towards a SMS?

RQ1 requires to characterize a SMS in a manufacturing plant. Starting from the state of the art, we assume that characterization is based on a selection of the competitive priorities and performances of interest, as elements to express the content of the MS. Besides, an assessment of relative importance of competitive priorities and performances is needed. Envisioning the long-term evolution of the manufacturing plant towards SM is then allowed.

RQ2: What can be the alignment of the business functions to the SMS?

RQ2 assumes to diagnose whether the behavior of different business functions within the industrial organization is consistent – i.e. aligned – with what expected by the SMS or not. It builds on the identification of the most important competitive priorities and related performances for each business function. It eventually allows reflecting on competitive priorities and performances driving the behavior of the business function, also verifying the consistency of the SMS.

3.2 Research methodology

The research methodology uses AHP as a lens to spot out the possible competitive priorities considered by the managers towards the SMS, with special emphasis on industrial management. AHP allows to model complex decisions in a hierarchical representation, with a series of pairwise comparisons and rankings in which both qualitative and quantitative decisions-related criteria are considered (Yurdakul, 2002; Gole and Taskin, 2007). In this work, AHP has been adopted with the purpose to express the trade-offs among the competitive priorities and performances, as decisions-related criteria of a MS. Hence, within the research methodology, the AHP is aimed to support the decision-maker in fronting the complex problem of measuring the SMS with a structured approach where the competitive priorities and their performances are assessed within the manufacturing plant. The framework of the methodology is reported in figure 1.

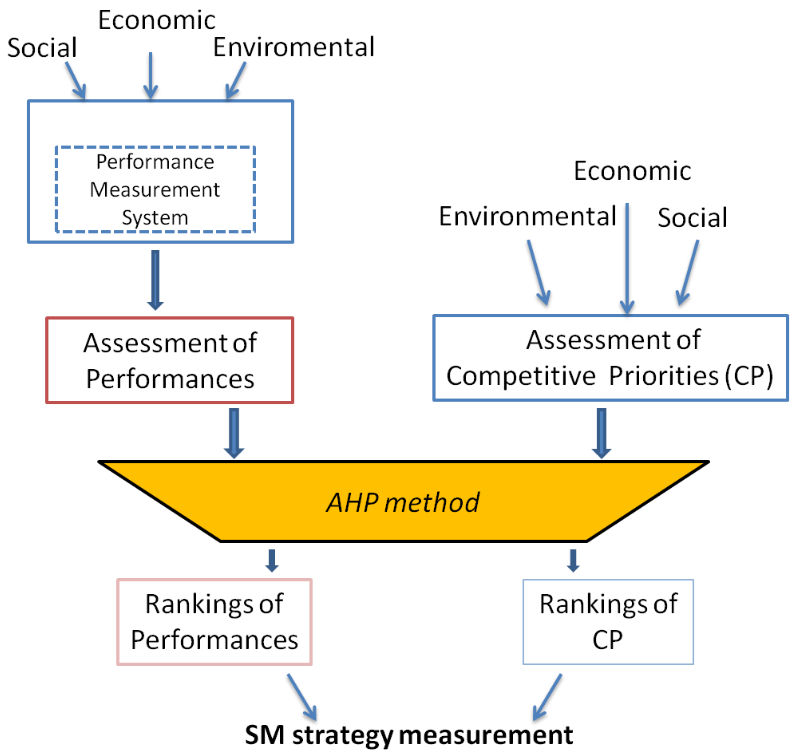


Figure 1 – The research methodology

4. Model and analysis process

4.1 Model structure

The model developed in this study aims to provide a hierarchical process that identifies the mutual influences between competitive priorities and performances in order to assess the sustainable manufacturing strategy implemented in a manufacturing plant of a company. The process is built on the background from the analysis of the extant literature. It is assessed on field by engaging different managers of two similar companies in accordance with the working protocol for the case studies specified in the reminder.

In particular, this portion of the study resulted in the AHP structure of Figure 2, consisting of six competitive priorities at the 2nd level, twelve grouping criteria at the 3rd level, and seventy performances, spread among the grouping criteria, at the 4th level.

Consistently with the literature findings of section 2.1, the traditional competitive priorities are broadened by including the environmental and social dimensions. Thus, besides *Cost*, *Quality*, *Dependability* and *Flexibility* as priorities for the economic dimension, *Protection of environment* and *Social-wellbeing* are considered for the environmental and social dimension. The complete list of performances for each competitive priority is reported in Annex 1.

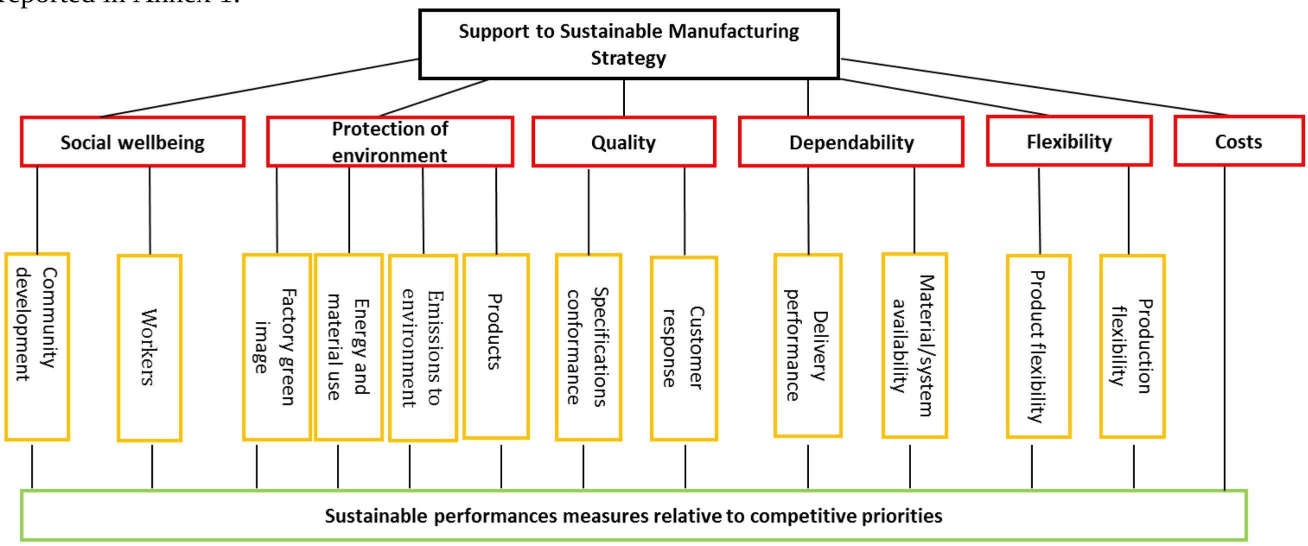


Figure 2 – The hierarchical structure developed for the AHP analysis

The manufacturing plants of two multinational companies have been the workbench of the analysis. The first one is a consumer products manufacturer producing white appliances, while the second one is a business products manufacturer of industrial and civil elevators.

The investigation was conducted through a set of interviews to different business functions of each plant. Therein, the production engineering and management units were addressed to identify the target of the interviews. In Table 2 we give a synthesis of the working protocol as applied in these two plants. It is worth remarking that the target of interviews was selected by the head of the unit in each case, considering the roles as decision makers within the SMS.

Table 2 – Working protocol executed during the case study

Step	Activity	Responsibility	
		Case #1	**Case #2**
1	Selection of performances (from a checklist) and provision of scores for self-positioning	Head of the industrial engineering unit	Head of the manufacturing management unit
2	Assignment of relative importance of competitive priorities	Product costing manager and Maintenance manager	Production manager and Lean production master
	Calculation of consistency index whose high values may indicate a potential inconsistency	Analyst	Analyst
3-4	Assignment of relative importance of grouping criteria and performances	Product costing manager and Maintenance manager	Production manager and Lean production master
	Calculation of consistency index whose high values may indicate a potential inconsistency	Analyst	Analyst
5	Measurement of the support to the manufacturing strategy of the plant	Analyst	Analyst
6	Analysis of the overall information collected through the model	Analyst Head of the industrial engineering unit	Analyst Head of the manufacturing management unit

The working protocol is based on a stepwise approach, in which the first step is the selection of the performances for the manufacturing plant under assessment (basing on the checklist of performances of annex 1). Furthermore, the benchmarks for positioning the plant under assessment are defined by the head of the unit target of the interview.
In a second step, the relative importance of each competitive priority is assigned by the managers of each business activity as explained in table 2. In this portion of the study, we aim to characterize the objectives that the plant must achieve according with the competitive strategy of the company. Here the analysis expresses the prioritization that should be attained by the plant to allow the company to succeed in the market. Third and fourth step repeat the assignment of the relative importance, now applied to grouping criteria and performances selected at the first step. The pairwise comparisons matrixes due to the AHP analysis are then carried out at respective levels of the hierarchical structure of figure 2 to obtain the relative importance of competitive priorities, grouping criteria and performances as perceived by each target of interview.
The overall measurement and the subsequent analysis of the SMS of the plant – fifth and sixth step – aims i) to characterize the evolution of each company towards a SMS (RQ1) and ii) to verify the alignment of the business functions in the industrial organization to the SMS (RQ2). As a further result, the investigation enables also to remark the most relevant performances according to the competitive priorities of the SMS.

4.2 Analysis process

The next subsections detail the analysis process defined within the working protocol shown in the previous table 2.
Step 1: selection of performances and self-positioning
A checklist of performances is submitted to the head of the unit who expresses an opinion about the level achieved by the plant in regard to the selected performances. The opinion is expressed according to Gole and Taskın (2007) scale in which: i) the score *0* indicates that the performance of the plant is considered regularly worse than the benchmark; ii) the score *0.5* states that performance is considered comparable; iii) the score *1* states that the performance of the plant is considered regularly better. The scale is completed by scores corresponding to intermediate judgments as shown in the table 3.

Table 3 – Scale for the level of achievement in regard to the selected performances

Judgments of preference	**Numerical Score**
Regularly it is the worst compared to most competitors	0
Usually it is the worst compared to most competitors	0.2
Usually it is the worst among the main competitors	0.3
Very often it is close to the levels of the main competitors	0.4
It is about the same as most competitors	0.5
Often it is slightly better than most competitors	0.6
Regularly it is slightly better than the nearest competitor	0.7
Regularly it is clearly better than the nearest competitor	0.8
Systematically it is significantly better than the nearest competitor	1

Even if there is an obvious difficulty in obtaining information as regards to the performance of other plants, it is worth using the judgements of the heads of the units as they are significant for understanding the perception of how the plant is performing compared to other ones, which may drive the decisions in the MS.
As outcome, after self-positioning two scores have been got. The first one – as internal benchmark – reflects the positioning with respect to a competitor represented by another plant of the same company. The second score, as external benchmark, expresses the position in relation to the plant of a competitor.
This step results in two indices:

- IS_p: the internal score expressed for the performance p, compared to another plant of the company;
- ES_p: the external score expressed for the performance p, compared to a plant of other companies.

The self-positioning scores are used later in order to calculate an overall score of the plant. This score reflects an overall assessment of the sustainable manufacturing strategy, being a system of performance evaluation which includes, in addition to the “traditional” competitive priorities, also environmental and social ones.

Step 2: assignment of relative importance of competitive priorities

In this step, a judgment matrix is constructed, considering the competitive priorities as independent, to provide a simple format for the pairwise comparisons required by the AHP analysis. To define the semantics of the different degrees of importance in order to make the comparisons, we adopted the typical Saaty's scale (Saaty, 1987) with the following five answers: i) equally strong, ii) slightly strong, iii) strong, iv) very strong, v) absolutely strong.

This step results in the relative importance set as normalized weights of the six competitive priorities under analysis. Moreover, in order to eliminate the possible inconsistency of the interviewees' opinions, a further validation is carried out considering the consistency ratio (CR). It is used in order to determine potential inconsistencies in the pairwise comparison matrices. The AHP method considers *n* elements to be compared, denoting the weight of one element in relation with the other ones to compute a square matrix A = (aij) of order n. This matrix exists if a_{ij} is calculated with the measured data. It has a vector ω of order n for which Aω = λω where ω is an autovector and λ is an autovalue. The matrix is coherent if λ = n. The indication of the incoherence of judgements is given by the difference between λ_{max} and n. In fact, if λ_{max} = n the judgements are consistent. In addition, the consistency index (CI) can be calculated from CI = (λ_{max} - n) / (n-1).

Saaty et al. (1981) have set the acceptable CR values for different matrices' sizes. The CR value is obtained from the ratio between the Consistency Index (CI) and the Random Index (RI). The values of RI are obtained as the mean of the CI values from a set of six reciprocal matrices of the same rank. In particular, the interviewee makes a comparison to couples between the six competitive priorities of the system that support the manufacturing strategy.

Fifteen comparisons are required, due to an order matrix of six, , as follows (see table 4).

Table 4 – Random Index values used in the CR calculation for consistency check

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

As a result, considering the case of the Consumer Products manufacturer as example, we obtained the value of CI = 0.0444 and the values of the Random Index RI = 1.24. Therefore, the value of the consistency ratio is CR = 0.0358 < 0.1, thus confirming the consistency of the analysis. Likewise, the other case of Business products manufacturer got the consistency of the analysis as well.

Both for the calculation of the weights vector and for the analysis of the consistency of the judgments, the software Super decisions (Adams and Saaty, 2003) is used. In this case, the hierarchical problem is structured as summarized in the reminder.

1) Cluster: to define the levels of the hierarchy, to which it is necessary to associate a name. In our case, the clusters are 4: the goal, the competitive priorities, the grouping criteria and, finally, the performances.
2) Node: to define the individual elements belonging to the hierarchical levels defined above. Thus, within the cluster "competitive priority", there will be 6 nodes: protection of the environment, social wellbeing, cost, quality, dependability and flexibility. This analysis shows that the final matrix is consistent for all respondents. The input of the model provides the standard carrier of the X_i weights of the competitive priorities and, in Figure 3, we report the results obtained for the standard weights vectors. Each weight expresses the importance of each competitive priority in supporting the strategy, therefore it serves in order to understand those characteristics to which the plant must give importance, *alias* to understand where it is necessary to concentrate the resources.

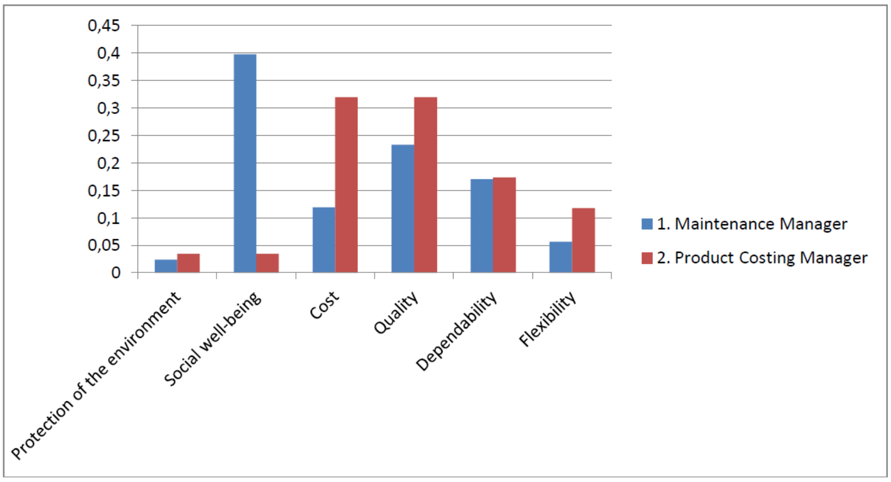


Figure 3 – Normalized weighted vectors in the AHP application – case Consumer products manufacturer

Figure 4 provides an example of the relative importance as normalized weights X_i, and thus the subsequent ranking, of the competitive priorities.

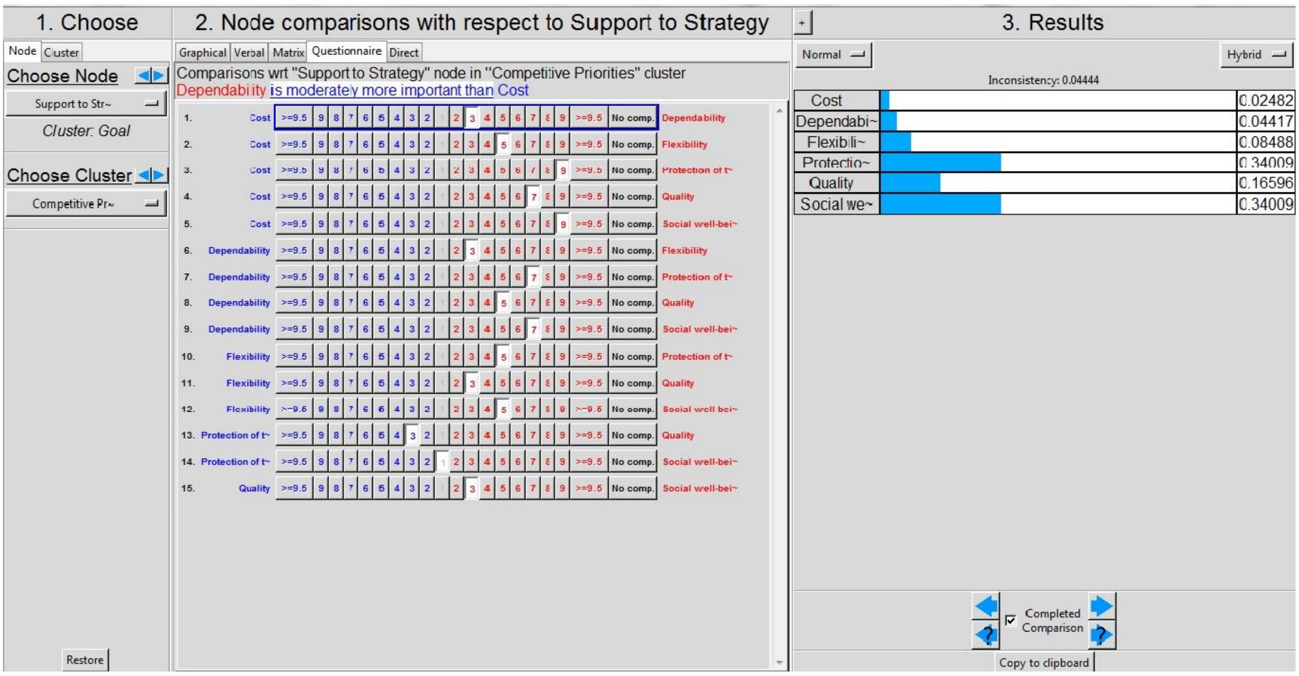


Figure 4 – Example of results for the relative importance of competitive priorities

Step 3-4: assignment of relative importance of grouping criteria and performances

The same analysis is conducted at the next levels of the hierarchy of figure 2, resulting in the following values:

(i) X_{cp}, the performance weight, where *c* indicates the grouping criterion of a competitive priority, and *p* a performance associated to the grouping criterion *c*;

(ii) X_{ic}, the grouping criterion weight, where *i* indicates a competitive priority, and *c* a grouping criterion associated to *i*.

With the same methodology adopted in step 2, after the assignment of the relative importance for grouping criteria and performances, we got two CR values. Considering the case of the Consumer products manufacturer as example, the following results were obtained: CR_1: 0,0782 for the Maintenance Manager and CR_2:0,0352 for the Product Costing Manager. Likewise, the other case of Business products manufacturer obtained the consistency of the analysis also at this step, and for the respective managers.

The partial weight of *p*, related to the grouping criterion *c* and to the competitive priority *i,* is then computed as:

$$X_{ip} = X_{ic} * X_{cp} \qquad (1)$$

Considering the weights of the competitive priorities X_i calculated at step 2, the global weight GW_p can be calculated as:

$$GW_p = X_i * X_{ip} \qquad (2)$$

Step 5: measurement of the support to the manufacturing strategy of the plant

Two scores, an internal and an external score, are used to measure the support to the SMS of the plant:

$$IS = \sum_p^m WI_p \qquad (3)$$

$$ES = \sum_p^m WE_p \qquad (4)$$

where:

- m is the number of the performances considered by the company
- WI_p is the internal score for the performance p weighted by the global weight: $WI_p = IS_p * GW_p$ (5)
- WE_p is the external score for the performance p weighted by the global weight: $WE_p = ES_p * GW_p$ (6)

According to the scale used for self-positioning, the meanings of the overall scores are the followings:

– IS = 0 (ES = 0) indicates that the manufacturing plant, in comparison with the internal (external) benchmark, does not provide any contribution to the sustainable strategy of the company;
– IS = 0,5 (ES = 0,5) indicates that the manufacturing plant, in comparison with the internal (external) benchmark, provides a similar contribution to the sustainable strategy of the company;
– IS = 1 (ES = 1) indicates that the manufacturing plant, in comparison with the internal (external) benchmark, provides a regularly better contribution to the sustainable strategy of the company.

With the purpose to define a reference value independent from the weights of performances, the mean of the IS_p and ES_p is also computed with respect to the number of performances.

$$ISM = {\sum_p^m IS_p}/{m} \qquad (7)$$

$$ESM = {\sum_p^m ES_p}/{m} \qquad (8)$$

The comparison of IS/ES and ISM/ESM allows to highlight the efforts and resources of the company planned according to the strategy. The following remark can be raised:

- IS (ES) < ISM (ESM) is the case when the efforts and resources are not properly planned. It occurs in case of high scores of IS_p (ES_p) in those performances that have low weight of importance and/or of low scores of IS_p (ES_p) in performances that have a high weight of importance;
- IS (ES) > ISM (ESM) is the case when the efforts and resources are properly planned. It occurs in case of high scores of IS_p (ES_p) in those performances that have high weight of importance and/or of low scores of IS_p (ES_p) in performances that have a low weight of importance.

It is worth remarking that IS and ES incorporate not only a perception of how the plant is performing with respect to selected benchmarks. In addition, these values consider also the importance of the different elements used to characterize the SMS of the plant under assessment – i.e., competitive priorities, grouping criteria and performances – as perceived by the business functions. This is mainly due to the research questions, aimed at providing a measure with the purpose to characterize the evolution of a company towards a SM strategy, while verifying the alignment of the business functions in the industrial organization.

Step 6: analysis of the overall information collected through the model

This is the core step where the empirical evidences from the cases are analyzed. It relies on all the information collected in previous steps of the analysis process.

5. Empirical evidences

5.1 Results of the analysis

The working protocol and the AHP analysis were conducted in two plants. The first one producing white appliances (Consumer products), the second producing industrial and civil elevators (Business products), the analysis resulted in the values shown in table 5.

Table 5 – Measurement of the support to the Manufacturing Strategy

Manufacturer	**Target**	**IS**	**ISM**	**ES**	**ESM**
Consumer products	Product costing manager	0.61	0.62	0.56	0.6
	Maintenance manager	0.54		0.54	
Business products	Production manager	0.63	0.62	0.63	0.61
	Lean production manager	0.65		0.65	

Some remarks can be made based on these first outcomes.

1- Both the business functions of the Business products manufacturer consider that the support to the MS is better than the benchmarks (as the scores IS and ES are between 0,63 and 0,65). The perception is different in the case of the Consumer products manufacturer. Only the product costing manager thinks that the support to the MS is better than just the internal benchmark (IS equal to 0,61). In other cases, just a slight better contribution is perceived (IS and ES between 0,54 and 0,56).

2- Efforts and resources of the company appear more aligned to the strategy for the business products manufacturer, as both IS and ES are higher than ISM and ESM. An opposite situation occurs in the case of the consumer products manufacturer (as both IS and ES are lower than ISM and ESM).

With these findings, the following evidence can be argued.

Evidence #1: the consumer products manufacturer has in general a lower satisfaction in its strategy in comparison with the business products manufacturer.

Figure 5 reports the weights of the competitive priorities X_i for both manufacturers.

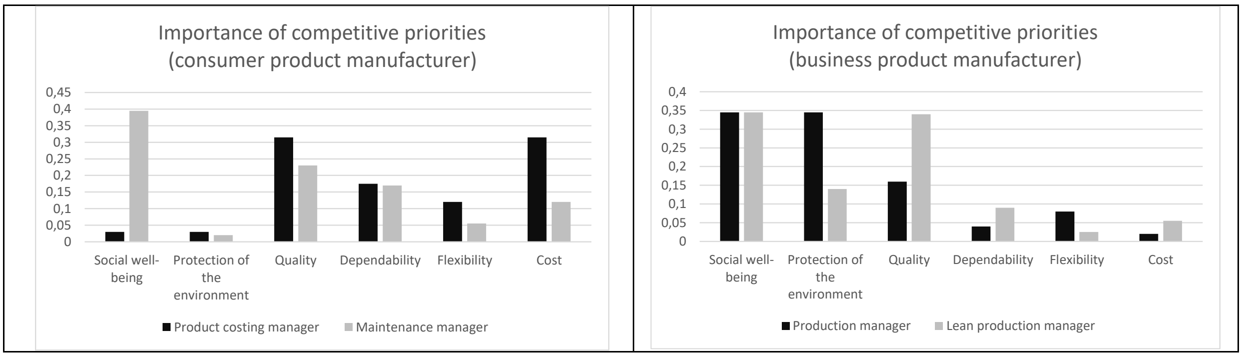


Figure 5 - Relative importance of competitive priorities according to the targets of interview

Concerning the consumer products manufacturer:

1- the highest competitive priority is the only difference between the two business functions: *social well-being* is in the first place for the maintenance manager. As it could be expected, *cost* is the most important competitive priority for the product costing manager, even if *quality* – in the second place – is comparable with a very close score;

2- except for the first place, the relative order of importance is the same for both the business functions: *quality* is in the second place and *dependability* in the third place of the ranking;

3- *protection of environment* resulted to have the worst position within the rankings of competitive priorities for both business functions.

Concerning the business products manufacturer:

1- *social well-being* and *protection of the environment* resulted relevant for both functions: they are almost equivalent competitive priorities for the production manager, while the lean production manager shares the highest importance of *social well-being* with *quality*, being the *protection of environment* in the third place;

2- the most important competitive priorities – *social well-being*, *protection of environment*, *quality* – are common to both functions.

Based on the previous findings, we may state the second evidence of this study.

Evidence #2: The consumer products manufacturer is oriented to a more "traditional" strategy, generally based on quality and dependability, joined with specific functional competitive priorities – thus dependent on the business functions – that may be costs or social well-being. In contrast, the business functions within the business products manufacturer are sharing the same competitive priorities, both oriented to quality, with a novel attention towards the social and environmental dimensions. This last consideration provides clear signs of introduction of a more holistic support to the sustainability concept.

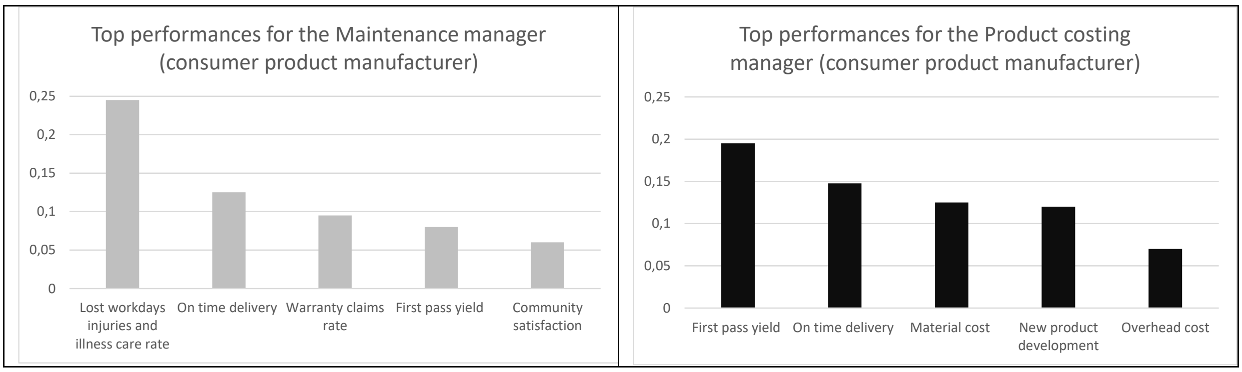
As a further investigation, we strived in pointing out the difference in the scope of performance measures selected as content of the MS; it is measured, for each competitive priority, as the number of selected performances over the number of total performances (see Table 6).

Table 6 - Percentage of performances selected from the checklist.

Manufacturer	**Social well-being**	**Protection of the environment**	**Quality**	**Dependability**	**Flexibility**	**Cost**
Consumer products	25%	21%	50%	30%	13%	75%
Business products	69%	50%	70%	90%	88%	83%

Out of the 70 performances submitted with the model in step 1, the percentage of selected performances is systematically higher in the case of the Business products manufacturer, for all competitive priorities. Conversely, the Consumer products manufacturer majorly focuses its attention – as major percentages of performances of interest – to two traditional competitive priorities, i.e. cost and quality.

Amongst the selected performances, the global weight GW_p of each performance allows a better specification of the importance of the competitive priorities. Hence, figure 6 reports an extract of the rankings of the selected performances according to each business function.



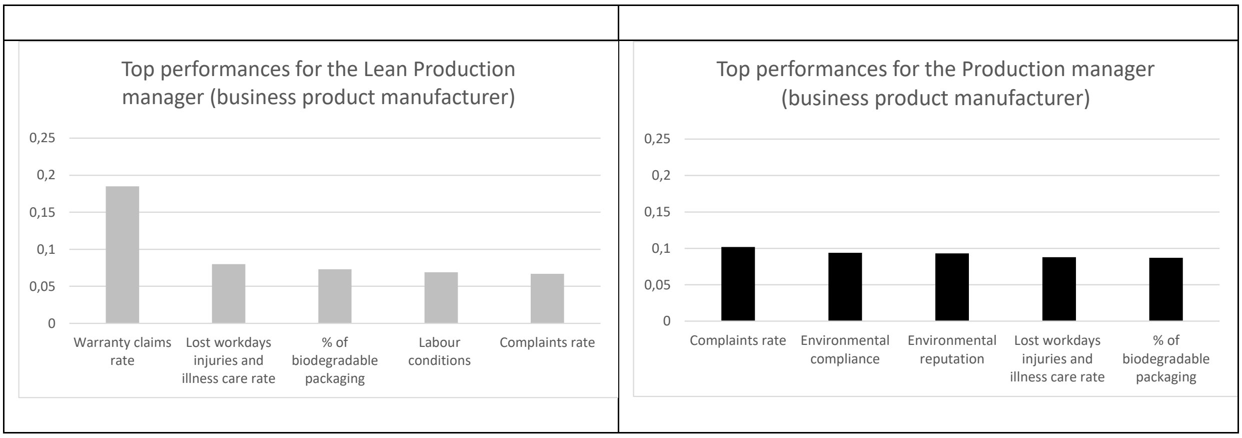


Figure 6 - Rankings of performances based on the global weights GW_p
(the rankings are limited to the performances at the highest rank order)

Some findings may emerge in this portion of the analysis concerning the consumer products manufacturer:

1- the most important performance for the maintenance manager – i.e. the *lost workdays injuries and illness care rate* – expresses his particular attention to workers' safety, thus clearing out the main focus of the competitive priority *social well-being*;
2- the maintenance manager does not discriminate much the importance of performances relative to the other competitive priorities, as he indicates at almost the same place *on time delivery* for *dependability*, *warranty claims rate* and *first pass yield* for *quality*;
3- the importance of *quality* and *dependability* is definitely confirmed by the top performances indicated by the product costing manager, which are respectively *first pass yield* and *on time delivery*; such performances are preferred to others;
4- *material cost* and *overhead cost* achieve the highest importance for the product costing manager within the competitive priority *cost* (respectively, first and second place in the rank order within this competitive priority).

Some evidences emerge concerning the business products manufacturer.

1- The production manager builds his competitive priorities on multiple performances featuring similar high importance. Namely, for *social well-being* the rank order is *lost workdays injuries and illness care rate* and *labour conditions*; this last performance is at the 6th position in the ranking, thus it is very close to the top five performances. For *protection of the environment* the rank order is *environmental compliance*, *environmental reputation* and *% of biodegradable packaging*, for *quality* the *complaints rate*.
2- Differences and similarities emerge for the competitive priorities indicated by the lean production manager. A different important performance is considered for *quality* (*warranty claims rate*). The least competitive priority – *protection of the environment* – confirms some of the performances already indicated by the production manager as top ones (the first place is for *% of biodegradable packaging*). Moreover, the lean production manager focuses on the same important performances for *social well-being*, in the same rank order as the production manager, i.e. *lost workdays injuries and illness care rate* and *labour conditions*.
3- A difference is noteworthy also on the pattern in relative importance, that is closer to the ones observed for the business functions of the consumer products manufacturer, even if smoother. Hence, also in this case, the lean production manager identifies one performance with higher relevance than others, i.e. *warranty claims rate*.
4- In terms of grouping criteria, for the model of figure 2 and, correspondingly, the checklist of performances organized in criteria in annex 1, it is worth remarking that the two business functions are both focused – in terms of *social well-being* – to the *workers* criterion, while – in terms of *protection of the environment* – to the *factory green image* and *products* criteria.

Considering these last evidences, together with the highest percentages of selected performances (Table 4), it is apparent that the Business products manufacturer is considering a wider scope of performances of interest for the MS, while many performances are perceived with a similar importance.

These last findings may give us the possibility to raise the last evidence of this study.

Evidence #3: a better alignment emerges in the case of the business products manufacturer, as the top priority – social well-being – is guided by the same criteria and performances, while some overlap exists also for the protection of the environment. In the case of the consumer products manufacturer, concerning the common competitive priorities – quality and dependability – even if some performances are shared, the degree of discrimination between relevant ones is different. Moreover, it is apparent that the consumer products manufacturer drives its decisions by focusing its scope especially on a few traditional competitive priorities and related performances, while the business products manufacturer has an enlarged focus, which may be considered as symptomatic of a holistic view across different competitive priorities.

5.2 Discussions and implications

The analysis provided a view on how sustainability is supported in the MS, enabling to investigate whether the manufacturing plants, in the two cases under comparison, are evolving towards a SMS or not. The feedbacks from the interviews and the AHP analysis gave a tangible evidence on how economic, environmental and social dimensions are actually integrated in the SMS. Based on the evidences, the two cases appear to be representative of two potential situations.

The Business products manufacturer is the case more oriented on supporting sustainability in the MS. From this first case, the following two implications can be argued.

- Besides the higher perception of a good overall performance as well as of an adequate effort and resource planning with respect to the benchmarks, both the business functions appear to integrate the environmental and social dimension in their competitive priorities and reference performances.
- The behavior of the business functions is expected to be consistently driven by what required by the SMS. In fact, to this end, it is worth noting that multiple performances are adopted and a good number amongst them is shared between the business functions. Moreover, the importance of competitive priorities is also aligned within the related criteria – *workers* for the *social well-being* and *factory green image* and *products* for the *protection of the environment*, all relevant for different target stakeholders. Overall, these multiple and shared viewpoints can be considered favourable for the holistic management that is typically required by the sustainability concept.

  The implications regarding the Consumer products manufacturer are mainly related to the matter of fact that it is less oriented to the support of sustainability in the MS. In particular, the following implications can be argued.
- Besides the lower satisfaction in terms of overall performance as well as of effort and resource planning with respect to the benchmarks, evidences bring signs of a more traditional approach to business needs, through differences in competitive priorities and reference performances (i.e. related to cost and quality). In this context, social dimension is only partly motivated by the functional role played in the company, as it appears the interest of the maintenance manager. Yet, the environmental dimension appears to be poorly addressed.
- We guess that the behavior of different business functions within this case seems addressed to an approach driven either by what expected by the functional objective, or by specific personal attitudes and competence. In contrast, it seems to miss some strategic needs required at a corporate or manufacturing strategy level. This issue was partly noted at the validating step of the working protocol (see table 5) with the head of the unit. At that step, a misalignment was noted in regard to the fact that no performance related to costs resulted within the top priorities of the maintenance manager function. In that portion of the study we experienced that this was not properly fitting the strategy needs of the head of unit.
- Surprisingly, for this case environmental dimension was not considered in the competitive priorities. We guess that it may be due to the perceptual nature of the respondents and to the fact that this kind of respondents may view sustainability as addressed to the internal production and safety issues, rather than in terms of *protection of the environment* relevant to external stakeholders. The fact that the head of the unit validated the result let us deduce that this limited, internal viewpoint was acceptable at higher – corporate or manufacturing – level.

Starting from the evidences raised within the analysis, and the relative implications, the following remarks can be derived to answer the research questions.

1. *(RQ #1)* The relative importance of competitive priorities and performances for the sustainability of the manufacturing strategy, inclusive of the all dimensions of sustainability – economic, social, and

environmental one, has enabled the discovery of different traits, which can be a help to identify diversity in archetypes along the "journey" towards a SMS.

2. *(RQ #2)* The alignment of different business functions appear to be related to these archetypes. The hypothesis that is apparent from the study can be stated as: "the more a company is showing traits of an archetype that is advanced along the "journey" towards a SMS, the higher is the expectation of aligned behaviors as expected by the SMS". Indeed, this is the case of the business products manufacturer that has been discussed in this study.

Due to the nature of the study, these remarks might be useful to build hypotheses for future investigations.

6. Future implications and conclusions

The general aim that stimulated this work was to enrich the scientific debate on sustainable manufacturing by means of a perspective built on theories of manufacturing strategy. Therefore, the competitive priorities and performances of a manufacturing plant were the main theoretical content used to enable an overall assessment of the achievements of sustainability concepts in a manufacturing plant.
The analysis presented in the paper showed the evidences gathered through a model and analysis process built on top of an AHP-based measurement method. The evidences enabled reflecting on different strategies and the correspondent behaviours in different business functions.
The approach was tested in two different firms producing i) low-cost and highly standardized products and ii) high-cost and highly customized products. This provided an evidence of adoption of the assessment method in different production contexts showing different manufacturing strategies. The results obtained confirmed the applicability of the methodology, fostering room for future usability by means of practitioners and academics. Policy-makers could be also interested. Therefore, the perspective of different stakeholders can be discussed for future implications.

- Practitioners have the possibility to verify the sustainability of the internal strategies of a firm in view of the implementation of Environmental Management Systems according to the ISO 14001 Standard and other standards covering the Social dimension; indeed, the implementation of processes and approaches according to extant standards could be verified, thus checking and revising the sustainability of production management choices. In particular, the proposed methodology could be used by companies to assess how sustainability is supported in the MS and whether the manufacturing plants are evolving towards a SMS or not: the feedbacks from the interviews and the AHP analysis give a tangible evidence on how economic, environmental and social dimensions are integrated in the SMS, this could be helpful in order to activate a review of the extant strategy.
- Academics may be interested in the results of this study to think of future verification in the sustainability of different manufacturing strategies. Through the two applications of this research, we demonstrate that the methodology is applicable to any general manufacturing organization, independently to its industrial environment; this could be interesting for future researches run at a larger scale, involving companies in different industrial sectors. A special emphasis may regard how sustainability of the MS vary according to the different size and different production context of the firms.
- The research outcomes are also relevant for policy makers that could evaluate the proposed approach as an assessment tool helpful in order to guide the orientation of manufacturing companies towards the 12th Sustainable Development Goal, i.e. responsible production and consumption.

  Further developments can be directly expected in the future research:
- *(development #1)* the archetypes of behaviours of the business functions emerged as evidences through this research should be verified by means of a larger data/observations set;
- *(development #2)* the AHP-based measurement of the SMS of a plant may also allow understanding how a company is giving prominence to sustainability in its plant(s), benchmarking with others; therefore, the method could be also considered for future benchmarking studies; this development is synergic with *development #1*.

  These developments will require the adaptation of the analysis process in order to be used as a base-ground for a survey at large scale. This considers a current limit of the assessment method – implemented for case studies –, which require at least an automatic procedure in order to run the working protocol in an efficient way. Moreover, some standardization effort will be required, to standardize reports, graphs and diagrams resulting from the assessment method, and usable for the discussion with different types of stakeholders.

Moreover, other new research ideas may be indirectly derived. We consider the followings as most relevant:

- *(development #3)* the AHP-based measurement of the SMS of a plant could be usable for specific action research, in order to aid companies mastering the strategy formulation and long term planning towards the implementation of an approach of sustainable manufacturing based on Triple Bottom Line assessment;
- *(development #4)* the assessment of the relative importance of the competitive priorities for different business functions within the industrial organization of a company could be used for the selection of the most relevant performances in the Performance Measurement System and for the alignment of behaviors of different business functions with the strategy.

These other developments are a follow-up inherently embedded in the current assessment method. The major caveat for application in the future regards the update of the performance measures under concern for different competitive priorities, both considering the requirements released from standards and the needs emergent from specific companies and sectors.

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Annex 1 – Checklist of performance measures

The checklist is organized according to the following indenture levels:

- Competitive priority
  - Grouping criterion
    - Performance

- Protection of environment

- Energy and material use
  - Freshwater consumption
  - % of freshwater recycle and/or reused
  - Material used
  - % of material recycled and/or reused
  - Energy use
  - % of energy from renewable resources
- Emissions to natural environment (including human health)
  - Kg of waste generated before recycling
  - Global warming potential
  - Acidification potential
  - Kg of persistent bioaccumulative and toxic (PBT) chemical used
  - Land used
- Products
  - Land used
  - % of product designed for disassembly, reuse or recycling
  - % of biodegradable packaging
  - % of product with take-back policies in place
- Factory green image
  - Environmental compliance
  - Environmental reputation

- Social well-being
  - Community development and social justice
    - Community spending and charitable contributions
    - # of employees per unit of product/dollar sales
    - # of community-company partnerships
    - Community satisfaction
    - Social compliance
  - Workers
    - Lost workdays injuries and illness care rate
    - Labour conditions
    - Number of safety events
    - Turnover rate
    - Absence rate

- Cost
    - Material cost
    - Labour cost
    - Overhead cost
    - Quality inspection cost
    - Rework / scrap cost
    - Warranty cost
    - Compliance cost
    - Delay/penalty cost
    - Inventory cost
    - Capacity utilization
    - Setup cost
    - Maintenance cost

- Quality
  - Conformance to specification
    - First pass yield
    - Defect/rework ratios

        - Scrap rate
        - Inspection rate
        - Rationalization degree
    - Customer response
        - % of repeat sales
        - % of unfulfilled customer order
        - After sales service
        - Complaints rate
        - Warranty claims rate

- Dependability
    - Delivery Performance
        - On time delivery
        - Delivery reliability
        - Delivery lead time
        - Delivery speed
        - Average delay
        - Cycle time
        - Schedule attainment rate
    - Material and system availability
        - Inventory level
        - WIP level
        - Equipment availability

- Flexibility
    - Production Flexibility
        - Volume flexibility
        - Cross training of personnel
        - Handling variations in customer schedule
        - Process and technology flexibility
        - Expansion flexibility
        - Lot sizes-setup times
    - Product Flexibility
        - Customization degree- product variety
        - New product development