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Tailoring performance evaluation to specific industrial contexts – application to sustainable mass customisation enterprises

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This paper proposes an approach for measuring performance improvement through prioritising and aggregating performance indicators (PIs). The proposed approach helps practitioners build, in a formal way, their performance measurement systems. The novelty of the methodology lies in: (i) adapting PIs to specific industrial contexts according to companies concerns and (ii) supporting the decision-making process by providing a holistic and limited number of aggregated PIs. The context considered in the current research is sustainable mass customisation (SMC). Accordingly, a set of SMC indicators are used to illustrate the applicability of the methodology. The implementation and illustration with a real case showed some evidence of its usefulness and pointed out several improvement rooms.

Keywords: performance measures; sustainable manufacturing; mass customization; analytical hierarchy process; simulation

1. Introduction

The increasing pressure of customers, governments and non-governmental organisations urges enterprises to take serious steps towards sustainable and mass customised products, processes and supply chains. Sustainable development means meeting 'the needs of the present without compromising the ability of future generations to meet their own needs' (WCED 1987).

Sustainable mass customisation (SMC) is a new paradigm promoted, in particular, by the European project S-MC-S (S-MC-S Consortium 2013). Starting from Pine's definition (Pine 1993), SMC can be defined as the strategy aiming to satisfy individual customer needs with near mass production efficiency while ensuring sustainable development. The current research falls under the following question: how can one push forward mass customising enterprises towards sustainability? We propose to use performance measurement as a mean for evaluating and improving mass customising enterprises sustainability. As such, heterogeneity of aspects related to sustainability (e.g. CO_2 emissions, costs, working hours, etc.) and mass customisation (i.e. number of variants, etc.) needs to be dealt with in order to allow for a more straightforward decision-making process. This raises the question: how to provide support for the decision-making process based on heterogeneous indicators?

How to address this question is the subject of this paper. To do so, Section 2 gives an overview of the performance measurement in general and in the context of SMC. Section 3 describes the proposition. The context considered for illustrating the applicability of the proposed approach is SMC. Section 4 addresses the implementation and describes a case study in the kitchen furnishings and equipment sector. Discussion and concluding remarks are presented in Section 5 and Section 6, respectively (Figure 1).

2. State of the art

2.1 *Performance measurement*

Performance measurement aims at reaching predefined goals that derive from the company's strategic objectives, using performance indicators (PIs). A PI quantitatively expresses the effectiveness and/or efficiency of a system against a given norm or target (Lohman, Fortuin, and Wouters 2004). According to The Association for Operations Management (APICS) dictionary, a PI is an index of business activities: a financial or non-financial measure, either tactical or strategic, that is linked to specific strategic goals and objectives (APICS 2013). The development of a performance measurement system may be conceptually separated into: design, implementation and use phases (Braz, Scavarda, and

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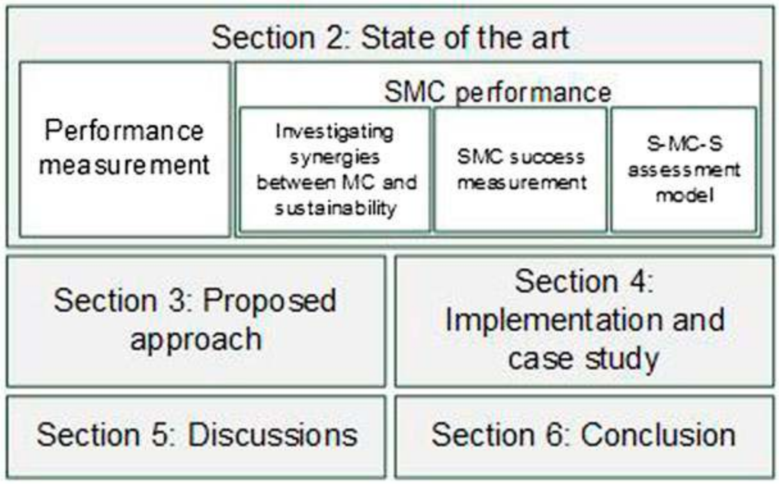

Figure 1. Graphical abstract.

Martins 2011). The design phase focuses on defining objectives and indicators. During the implementation phase, systems and procedures are put in place to collect and process the data so that measurements can be made regularly. In the use phase, the results are reviewed in order to assess the operations and possibly challenge the already defined indicators (Braz, Scavarda, and Martins 2011). The performance measurement system should be able to translate enterprise strategies into concrete goals and monitor the delivery of the strategy. Moreover, Indicators need to capture the relevant characteristics of the underlying operational processes (Lohman, Fortuin, and Wouters 2004). However, in performance measurement literature, methodological aspects are not as much addressed as structural aspects (the way of structuring indicators, for instance) (Folan and Browne 2005). The structure and methodological guidance are two complementary aspects of a performance measurement system; they need both to be considered when developing this later. Moreover, authors such as Ageron, Gunasekaran, and Spalanzani (2012) pointed out the lack of a clear framework for PIs at strategic, tactical and operational levels. The challenge is, thus, how to take into consideration enterprise priorities when measuring performance, especially when indicators are heterogeneous as in a sustainability and mass customisation context.

2.2 *SMC performance*

2.2.1 *Investigating synergies between MC and sustainability*

For the manufacturing enterprises, sustainability can be defined as the 'creation of manufactured products that use processes that minimise negative environmental impacts, conserve energy and natural resources, safe for employees, communities and consumers and economically sound' (Jayal et al. 2010). SMC refers to jointly deploying sustainability and mass customisation. Mass customisation can be seen as a trade-off between pure personalisation and mass production. The former means considering each customer preferences individually and may lead to adapting production system to fulfil each specific need. Such a phenomenon can be seen in the case of some luxury kitchen manufacturers: each single customer order may require tailoring production processes. This can be explained by the fact that each customer seeks uniqueness of his product, which induces additional costs and time for the company to fulfil such personalised kitchen. Moreover, production processes are likely to generate more wastes and environmental impact cannot be easily controlled. Conversely, mass customisation aims to take advantage of economy of scale by standardising processes (Pine 1993; Duray 2011; Fogliatto, da Silveira, and Borenstein 2012), increasing components commonality (Jiao and Tseng 2000; Daaboul et al. 2011) and forwarding customer order decoupling point upstream (CODP) (Davila and Wouters 2007). CODP can be defined as the 'point in the value chain for a product, where the product is linked to a specific customer order' (Olhager 2010). Mass customisation is likely to move supply chains from 'push' to 'pull' configurations, allowing for providing customer with exactly what he needs. It is likely to reduce wastes caused by unused products (and thus environmental impact) since a customised product is supposed to fit specific customer needs (Brunoe et al. 2013). As such, mass customisation can be seen as engine for at least environmental and economic sustainability (Bernard et al. 2012; Medini, Da Cunha, and Bernard 2012). However, a recent empirical study carried out by Pourabdollahian, Taisch, and Piller (2014) revealed that according to several experts from academia and industry, postponement does not have a specific impact on environmental sustainability. The study indicated that there is no agreement on the impact of mass customisation enablers on sustainability, in particular product modularity, robust process design, postponement and delivery at point of sale. Brunoe et al. (2013) argued that modular products foster the closed loop strategies (e.g. reuse, remanufacturing), thus lowering environmental impact. However, the production of this kind of products requires more material and energy, than traditional ones, thereby having a negative impact on environmental sustainability. The same figure holds for process variety which implies more flexibility and thus more material and energy consumption.

Although mass customisation may have the potential to improve enterprises sustainability performance, current research does not focus on the question whether these concepts are correlated. It rather aims to outline a methodology supporting the decision-making process based on several indicators. This is typically the characteristic of sustainability and SMC performance measurement.

2.2.2 *SMC success measurement*

The success towards SMC or sustainability of mass customising enterprises can be measured through PIs (Garbie 2014; Mani et al. 2014). The literature of sustainability assessment is rich in indicator systems and methods, but its three dimensions (i.e. economic, environmental and social) are unequally addressed (Global Reporting Initiative 2002; Rebitzer et al. 2004; Dreyer, Hauschild, and Schierbeck 2010). Furthermore, authors such as Dahl (2012) argue that most of existing sustainability indicators fall short of ensuring sustainability. Indicators are mainly intended for reporting purposes and they do not take companies specificities into account. This raises the need to adapt indicators development to their users. Moreover, a complete shape of the sustainability performance requires a big number of indicators, which in turn impedes the decision-making process. In this sense, integrating several metrics turns out to be very useful for decision makers especially in the context of sustainability, which is by nature a holistic concept (Garbie 2014). However, the success of SMC also requires taking mass customisation into account in the development of performance measurement system. This gives rise to another dimension (in addition to sustainability three dimensions), that is mass customisation. Several evaluation frameworks and metrics are available in literature and can be used for this purpose. For instance, Jiao and Tseng (2000) proposed metrics to measure the commonality of product family and process used to produce customised products. The aim is to provide practitioners with more insight into product family design and its manufacturability. Blecker et al. (2006) and more recently, Daaboul et al. (2011) analysed the interdependencies of several mass customisation and economic indexes and built a system to control the complexity of supply chains in the mass customisation context. Recently, Nielsen et al. (2014) proposed a comprehensive set of mass customisation metrics and discussed their applicability for mass customisation companies. A well-established review of performance measurement tools with a focus on mass customisation can be found in (Storbjerg, Brunoe, and Nielsen 2014). In the next section, the focus will be brought to S-MC-S assessment model (Bettoni et al. 2013; Boër et al. 2013).

2.2.3 *S-MC-S assessment model*

The S-MC-S evaluation model integrates product, production process and supply chain in a life-cycle perspective. According to the United Nations Environment Programme (UNEP, 2009), life cycle thinking is about going beyond the traditional focus on production sites and manufacturing processes so that the environmental, social and economic impact of a product over its entire life cycle, including the consumption and end of life phase, is taken into account. Life-cycle perspective provides more reliable information about product impact by broadening the scope of evaluation. Unlike most of the existing evaluation frameworks, S-MC-S assessment model covers the three sustainability pillars: environmental, social and economic. The rationale of S-MC-S model lies in the development of a holistic set of indicators for assessing the sustainability of a customised solution space (Boër et al. 2013; Bettoni et al. 2013). The solution space clearly delineates the offer by determining what universe of benefits, an offer, is intended to provide to customers and then within that universe what specific permutations of functionality can be provided (Piller and Tseng 2009; Paul and Piller 2014). A wide literature review and analysis of existing indicators systems and databases in the field of sustainability and mass customisation resulted in a draft list that have been filtered according to several criteria such as measurability and understandability. A subset of these indicators is presented in Tables 1–4, adapted from Bettoni et al. (2013).

SMC needs to be deployed in a smooth way at operational levels and practitioners require the help of a methodological support to select suitable indicators with regard to their strategies and contexts. In other words, a methodological guidance needs to be provided to the companies in order to select indicators and measure and improve their performances while taking into account their strategies. Next section describes a methodology for measuring manufacturing enterprises performance in the context of SMC.

Table 1. Economic indicators.

Indicator	Unit of measure	Definition
UVPC – Unitary Production Cost	€	The UVPC indicator measures the direct costs (deducting overheads and taxes) related to the manufacturing of one product unit, calculated as the average one weighted on the expected product mix
PLT – Production Lead Time	h	Total time required to manufacture an item, including order preparation time, queue time, setup time, run time, move time, inspection time, and put-away time
VPLT – Variability of Production Lead Time	Dimensionless	The VPLT indicator measures how much the actual production lead times differ from the mean value as its coefficient of variation
VAT – Value Added Time	%	The VAT indicator measures the percentage of the production lead time spent for operations that increase the value of the product
TR – Throughput Rate	h^{-1}	The TR indicator measures the number of units the production system can process in a given time
CUR – Capacity Utilisation Rate	%	The CUR indicator measures the capability of the production system to exploit available capacity
UEGP –Unitary Expected Gross Profit	€	The UEGP indicator measures the difference between the revenues obtained by the yearly product sales (calculated on an expected volume and product mix) and the related costs, before deducting overhead, payroll, taxation, and interest payments
PLC – Product Lifecycle Cost	€	The PLC indicator measures the total costs the customer has to afford during the product lifecycle (price plus usage, maintenance, repair and end of life costs)
RDII – R&D Investments Intensity	€	The RDII indicator measures the company R&D investments allocating them on the solution space

Table 2. Environmental indicators.

Indicator	Unit of measure	Definition
GWP – Global Warming Potential	kg eq. CO_2	The GWP indicator measures the contribution to the global warming caused by the emission of greenhouse gases in the atmosphere
POCP – Photochemical Ozone Creation Potential	g eq. C_2H_4	The POCP indicator calculates the potential creation of tropospheric ozone ('summer smog' or 'photochemical oxidation') caused by the release of those gases which will become oxidants in the low atmosphere under the action of the solar radiation
EP – Eutrophication Potential	g eq. PO_4^{3-}	The EP indicator measures the contribution to the water eutrophication (enrichment in nutritive elements) of lakes and marine waters caused by the release of polluting substances in the water
ODP – Stratospheric Ozone Depletion Potential	g eq. CFC-11	The ODP indicator measures the contribution to the depletion of the stratospheric ozone layer caused by gas emissions
AP – Acidification Potential	g eq. H^+	The AP indicator measures the contribution to the air acidification caused by gas emissions in the atmosphere
TP – Toxicity Potential	kg eq. 1,4-DCB	The TP is indeed a set of six indicators that measures the relative impact of the emitted substances on specific impact categories (freshwater aquatic environment (FAETP), marine aquatic environment (MAETP), freshwater sediment environment (FSETP), marine sediment environment (MSETP) and terrestrial environment (TETP)) due to emission to environmental compartments (air, fresh water, sea water, agricultural and industrial soil)
NRD – Natural Resources Depletion	kg antimony eq.	The NRD indicator measures the depletion of non-renewable abiotic natural resources
WD – Water Depletion	m^3	The WD indicator measures the water of any quality (drinkable, industrial ...) consumed during the whole life cycle of the product. Water used in a closed loop processes are not taken into account
ED – Energy Depletion	kwh	The ED indicator measures the energy consumed during the whole life cycle of the product distinguishing between renewable and non-renewable sources
WP – Waste Production	kg	The WP indicator calculates the quantity of waste produced during the whole life cycle of the product
PRP – Product Recycling Potential	%	The PRP indicator calculates the percentage in weight of the product that could be recycled using the current best recycling techniques

Table 3. Social indicators.

Indicator	Unit of measure	Definition
II – Injuries Intensity	Dimensionless	The II indicator measures the number of yearly work related injuries, diseases and fatalities occurred in the company allocating them on the solution space
HTP- Human Toxicity Potential	kg eq. 1,4-DCB	HTP measures the relative impact of the emitted substances on humans
SEI – Safety Expenditures Intensity	€	The SEI indicator measures the company safety expenditures allocating them on the solution space
WTI – Workforce Turnover Intensity	Dimensionless	The WTI indicator measures the employees leaving the company allocating them on the solution space
MSO – Multi Skilled Operators	%	The MSO indicator measures the percentage of the multi skilled workers within the solution space
SDI – Staff Development Investments	%	The SDI indicator measures the percentage of the company investments in staff development within the solution space
ID – Income Distribution	Dimensionless	The ID indicator measures the equity of the employee wage distribution within the solution space
IL – Income Level	Dimensionless	The IL measures the average annual income per employee divided by the average income per person in the country where the company is located
WH – Worked Hours	h	The WH indicator measures the number of worked hours per employee per week
CL – Child Labour	%	The CL indicator measures the percentage of suppliers within the solution space using child labour
CCI – Charitable Contributions Intensity	€	The CCI indicator measures the expenditures and charitable contributions in favour of the local community allocating them on the solution space
LS – Local Supply	%	The LS indicator measures the percentage of the purchasing expenditures made to buy items from local suppliers

Table 4. Mass customization indicators.

Indicator	Unit of measure	Definition
NCF – Average Number of Customizable Features	Dimensionless	The NCF indicator measures the number of customizable features of each type (aesthetics, functional or fitting) offered within the solution space
OCF – average number of Options per Customizable Feature	Dimensionless	The OCF indicator measures the average number of options of each type of customizable feature (aesthetics, functional or fitting) and their distribution among five classes of number of options
DLT – Delivery Lead Time	h	The DLT indicator measures the interval time between the placement of an order and the receipt of the corresponding goods ordered

3. Proposed approach

3.1 *Used tools*

3.1.1 *Interviews*

The proposed methodology relies on interviews with experts and/or managers from the case company. Such a choice of the interviewees is motivated by the need to start from a strategic vision in order to build the performance measurement system of the company. The rationale of the proposed methodology is to address the above mentioned research question in the context of small and medium-sized enterprises (SMEs). For such companies, we assume that only one interview with the CEO is enough for the methodology. In fact, in an SME, the manager is usually the one who sets company strategies and supervises their deployment. Notwithstanding, data for evaluating different improvement scenarios, such as product bill of material, production processes, etc. are gathered with the help of production staff. In order to leave the interviewee with the required time for familiarising with the different concepts, interviews supporting documents need to be available with him/her few days before having the interview. The aim is to clarify all concepts and methodological aspect of the proposed approach. These documents include description of: (1) goals of the interview, (2) performance aspects and (3) PIs. During the interview, decision-maker (i.e. interviewee) has only to choose among available options for pair-wise comparisons. He/she is guided throughout this task as some clarifications are often needed, and also to make sure the pair-wise comparisons are performed properly. This guidance consists mainly on providing a relative verbal appreciation to the decision-maker to identify which criterion dominates the other, for instance (e.g. is A much more important than B? is it

Table 5. Saaty scale.

a_{ij}: Value of the preference of i over j	Intensity of preference
1	i and j are equally important
3	i is slightly more important than j
5	i is more important than j
7	i is significantly more important than j
9	i is absolutely more important than j
2, 4, 5, 8	Intermediate values when compromise is needed

Table 6. Random consistency index.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

equal? Do you consider that A has no importance compared to B, etc.). Thus, interview forms are jointly filled out by interviewer and interviewee.

3.1.2 *Analytic Hierarchal Process*

The interviews output is processed using AHP to come up with indicators' weights. The AHP steps can be summarised as: structuring the hierarchy from top level (ultimate objective) to lower levels such as decision criteria and alternatives. Afterwards, the priorities of the criteria are derived based on pair-wise comparisons with respect to the goal. These are performed in terms of which element dominates the other. Table 5 shows Saaty scale which defines preference values Saaty (2008).

For n criteria, $n \times n$ comparisons are required resulting in an $n \times n$ judgment matrix and D is formed by comparing row elements to column elements. Priorities are governed by following rules: $a_{ij} > 0, a_{ji} = 1/a_{ji}, a_{ii} = 1$, for all $i \in \{1 \ldots n\}$. Thus, D is a positive reciprocal judgment matrix. Once priorities a_{ij} are calculated, weights are obtained by normalising columns of D and then calculating average values of the rows, as shown in Equation (1). $\omega_i, i \in \{1 \ldots n\}$ form the so called Eigen vector.

$$\omega_i = \frac{\sum_{j=1}^{n}\left(\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}\right)}{n}, \quad i \in \{1 \ldots n\} \tag{1}$$

As priorities are the results of human judgment, their consistency needs to be verified. To do so the so-called consistency ratio (CR) is calculated as follows:

$$\mathrm{CR} = \frac{\frac{\lambda_{max-n}}{n-1}}{\mathrm{RI}} \tag{2}$$

where λ_{max} is the maximum Eigen value, such that: $\lambda_{max} = \sum_{k=1}^{n}(\sum_{i=1}^{n} a_{ik}) \times \omega_k$. RI is the random consistency index. Table 6 shows RI values for different numbers of criteria.

3.2 ***Rationale of the methodology***

The interviews are articulated around three points: (1) definition of the goals and enablers, (2) prioritisation of the performance aspects and (3) prioritisation of the PIs (Figure 2). The second and third steps require a reference pool of performance aspects and indicators. As the methodology is intended to be deployed in SMC context, S-MC-S assessment model will be used as a reference (Bettoni et al. 2013). Such a model addresses many areas of sustainability and mass customisation. Since the proposed methodology aims to tailor performance measurement to specific industrial contexts, the choice of a reference framework is not restricted to S-MC-S. Other frameworks can be used according to the context in which the methodology is applied, i.e. company strategy and concerns. A major motivation for using S-MC-S indicators to validate the proposed approach is the reliability (due to the connection with Ecoinvent database) and ease of calculation (ensured by a product, process and supply chain editors) (Pedrazzoli et al. 2012). These characteristics are

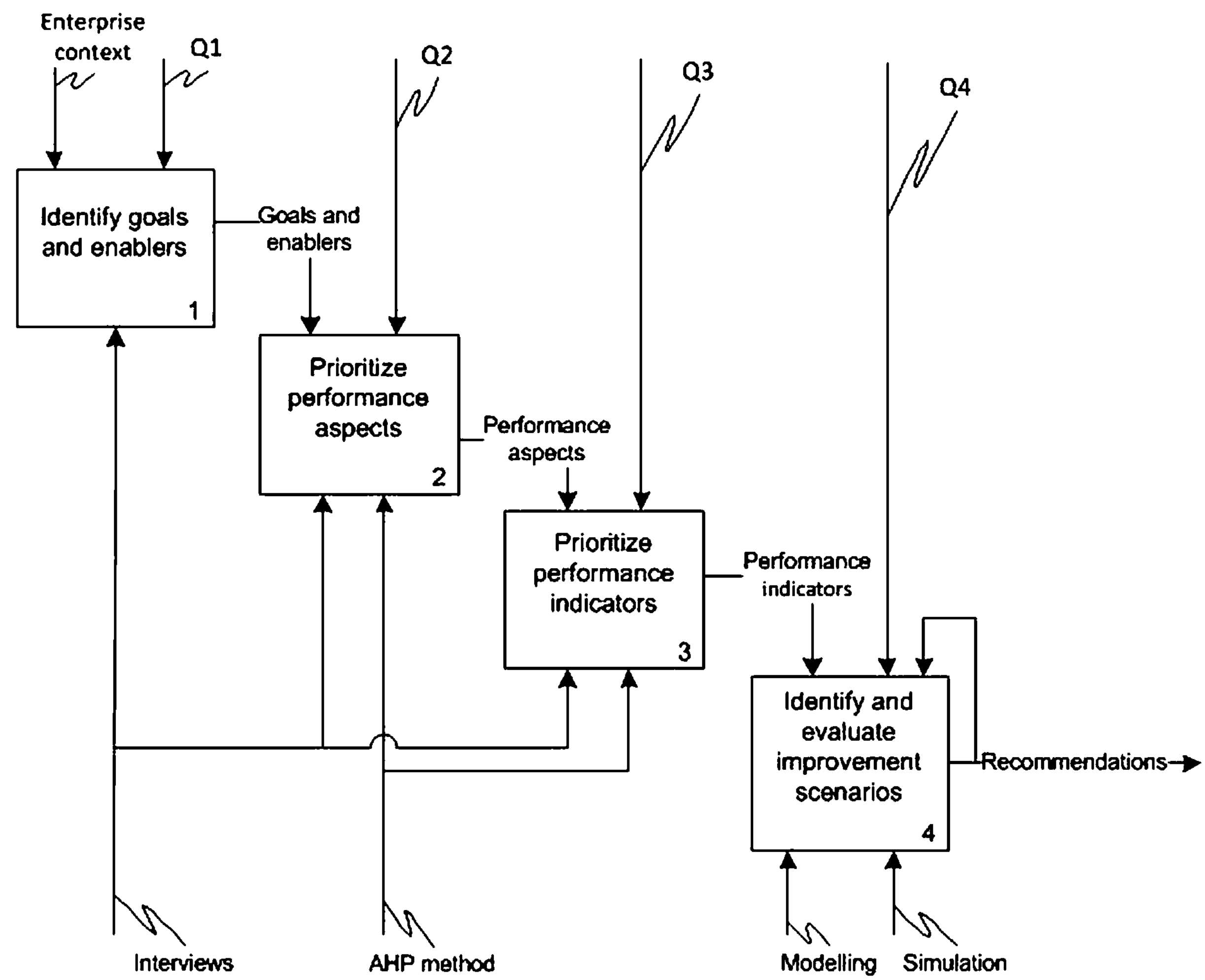

Figure 2. Steps of the proposed methodology.

not satisfied by many of other existing assessment frameworks importantly because of the lack of consolidated sustainability information bases at company and industry levels (Mani et al. 2014). Last step of the methodology is focused on the identification and evaluation of improvement scenarios using modelling and simulation along with the indicators and weights calculated in step three.

While first step is based on manager's perception of sustainability and mass customisation goals, the inputs of second step are performance aspects identified in (Bettoni et al. 2013). These are: emissions, resources use, wastes, efficiency, profitability, investments in technologies and competencies, working conditions, local communities, customisation level and service level. The input of third step is indicators presented in Tables 1–4. Each of these indicators falls under one of the performance aspects. Ultimate goal is to provide support for the decision makers so as to measure the progress towards SMC through economic, environmental, social and mass customisation shifts. Figure 3 depicts the hierarchy of the decision-making problem. PA and PI stand for performance aspect and PIs, respectively.

3.2.1 *Step 1: Define goals*

The purpose of this step is to define the strategic goals of the company and break them down into sub-goals (SG_i) to clearly describe the vision of the company, and identify enablers (E_j) to achieve them. The rationale of this step can be summarised in Q1: what do we want to achieve and how can we achieve it?

The answer to the first sub-question forms the goals (and sub-goals) whilst the second sub-question deals with enablers to reach these goals. This step helps interviewees in clarifying the enterprise priorities regarding sustainability and mass customisation. Thus, it facilitates the prioritisation of the performance aspects.

3.2.2 *Step2: Identify/prioritise performance aspects*

This step consists of comparing the performance aspects in order to calculate their weights by applying the AHP method. The rationale of this step can be summarised in the following question Q2: what are the areas of success in my company? This part of the interview consists on asking interviewee to perform a pair-wise comparison of the performance aspects. The output of this interview is the judgmental matrix P. formed by the pair-wise comparisons of the performance aspects. The size of P is $n \times n$, where n is the number of performance aspects. $\propto_{ij}$ is the relative importance of the performance aspect i over the performance aspect j (Equation (3)).

For all $i,j \in \{1 \ldots n\}$, $\propto_{ji} = 1/\propto_{ij}$. Thus, interviewee has only to define upper part of P, that is $\propto_{ij}$ such that $i,j \in \{1 \ldots n\}$ and $j > i$.

The relative weights of the performance aspects are $\varphi_i, i \in \{1 \ldots n\}$ calculated according to Equation (4).

$$P = \begin{pmatrix} \propto_{11} & \cdots & \propto_{1n} \\ \vdots & \ddots & \vdots \\ \propto_{n1} & \cdots & \propto_{nn} \end{pmatrix}, \quad \propto_{ij} \in]0,9] \tag{3}$$

$$\varphi_i = \frac{\sum_{j=1}^{n} \left(\frac{\propto_{ij}}{\sum_{i=1}^{n} \propto_{ij}} \right)}{n}, \quad i \in N, i \in \{1 \ldots n\} \tag{4}$$

Judgments are verified by calculating the consistency ratio according to Equation (2).

3.2.3 *Step3: Identify/prioritise PIs*

This step follows the same principle as the previous as it also relies on the interviews and the results are processed using AHP. At this point, interviewee is asked to perform a pair-wise comparison of PIs according to their relevance to the performance aspects.

The output of such comparison for a given performance aspect k is the Q_k matrix. $\beta_{ij,k}$ represents the relative importance of the PI i over the PI j with respect to the performance aspect k (Equation (5)). n_k is the number of indicators falling under performance aspect k. Local priorities of the indicators are δ_{ik} calculated according to Equation (6). For each of the performance aspects, judgments are verified by calculating the consistency ratio according to Equation (2). Indicators' weights ω_i are calculated according to Equation (7) where φ_k is the weight of performance aspect k under which falls indicator i.

$$Q_k = \begin{pmatrix} \beta_{11,k} & \cdots & \beta_{1n_k,k} \\ \vdots & \ddots & \vdots \\ \beta_{n_k1,k} & \cdots & \beta_{n_kn_k,k} \end{pmatrix}, \quad \beta_{ij,k} \in]0,9], i,j \in \{1 \ldots n_k\}, \quad k \in \{1 \ldots n\} \tag{5}$$

$$\delta_{ik} = \frac{\sum_{i=1}^{n_k} \left(\frac{\beta_{ij,k}}{\sum_{i=1}^{n_k} \beta_{ij,k}} \right)}{n}, \quad i,k \in \{1 \ldots n_k, 1 \ldots n\} \tag{6}$$

$$\omega_{ik} = \varphi_k \times \delta_{ik} \tag{7}$$

The rationale of this step lies in the following question Q3: what are the most suitable indicators for given areas of success?

These steps result in a list of weighted PIs according to the enterprise priorities. This would help manager, for instance, in pointing out critical improvement areas, thus making decisions more easily.

3.2.4 *Step4: Identify and evaluate improvement scenarios*

This step consists of evaluating current situation, identifying improvement scenario(s), evaluating them and then analysing shifts. For a given indicator i, the shift is calculated according to Equation (8) where $asIs_i$ and $toBe_i$ are the current and future values of i, respectively. γ_i is an operator that takes 1 if the increase of i is appreciated (e.g. Profit) and -1 (e.g. GWP) otherwise.

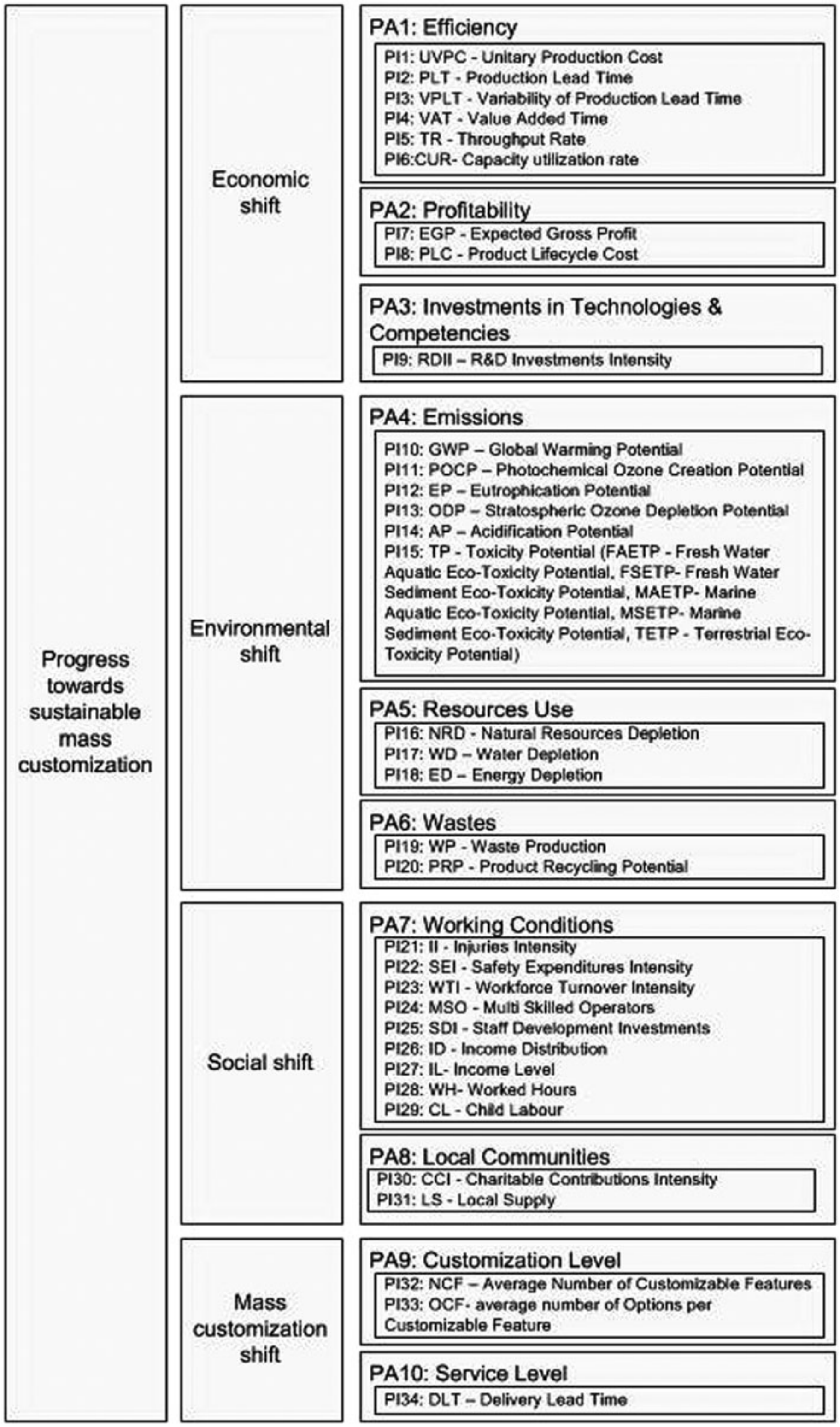

Figure 3. Sustainable mass customization.

$$Shift_i = \gamma_i \times \frac{toBe_i - asIs_i}{asIs_i}, \quad \gamma_i \in \{1, -1\} \tag{8}$$

More global shifts can be calculated in order to come up with aggregated values measuring the changes that happen within mass customisation and sustainability dimensions. It is calculated according to Equation (9), where p refers to one of the followings: economic sustainability, environmental sustainability, social sustainability and mass customisation. W_i is the weight of indicator i and I_p is the set of indicators falling under p.

$$Shift_p = \sum_{i \in I_p} Shift_i \times W_i \tag{9}$$

This step allows answering the following question Q4: what is the impact of a given scenario on the overall performance?

In fact, improvement scenarios need to be checked before implementing them in real life. As a result, the company will not need to carry out corrective measures, in the event of the scenarios not being economically, environmentally or socially viable. This requires modelling and simulating different scenarios while calculating the indicators' values for current and future situations. More details on the implementation will be given in the next section along with an illustration with a case study.

4. Implementation and case study

4.1 *Implementation*

In order to show how the method works in practice, the steps are implemented in a demonstrator developed in JAVA code on the Eclipse[1] platform. The demonstrator is a part of a more complete system whose architecture is shown in Figure 4. The already existing tools and interfaces which have been developed within the framework of the S-MC-S project are in white. The developments made by authors are coloured in grey. The demonstrator functionalities are the following:

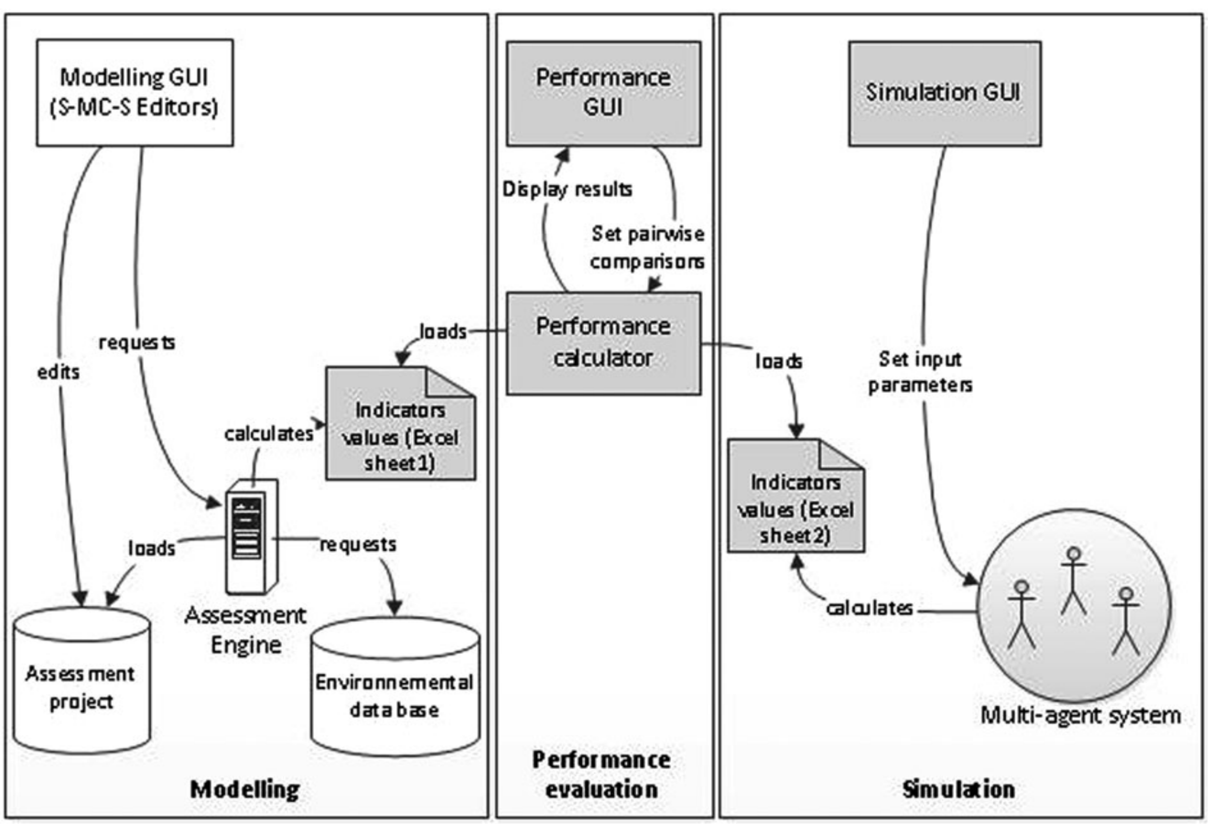

Figure 4. System architecture.

(1) *Calculation of indicators weights*: inputs are the pair-wise comparisons made by the user and gathered through performance GUI. Outputs are the indicators' weights.
(2) *Simulation of the current situation and improvement scenario(s)*: inputs are data about the product bill of material, production processes, suppliers and demand. These are entered by the user through simulation GUI. The simulation is ensured by a multi-agent system developed using Java Agent Development Framework. Outputs are the indicators' values evaluating current and future situations.
(3) *Calculation of the shifts*: input data are the indicators' values of the current and future situations. They are loaded from excel files. A part of the indicators, such as delivery lead time (DLT) and cost are calculated through simulation (i.e. excel sheet 2). The other part is calculated using S-MC-S editors which are linked to an environmental database (i.e. excel sheet 1). Outputs are mass customisation and sustainability shifts.

4.2 *Case company presentation and data collection*

The method was applied to a kitchen manufacturer which provides mass customised products and has a considerable share in the Swiss market. The company products range from basic lines to top quality lines and are sold through a network of resellers located throughout Switzerland. The production of kitchens is based on orders already received (i.e. Make to Order policy). The company is interested in SMC and aims to serve customers' highly varied needs while keeping sustainability as a priority. Figure 5 describes the supply chain of the company, where dashed and continuous arrows depict information and physical flows, respectively. The process begins with the customisation of a kitchen at the point of sale. Then kitchen drawings are transferred to the company headquarters where the designers and the factory are located. After receiving the raw materials, if needed (i.e. inventory is not enough), production is launched and then the customer order is delivered.

The steps performed for applying the methodology are detailed in the following. Let's note that interview forms have been filled in by the interviewer because manager is not familiar with the pair-wise comparison process and, in particular, the rating scale used. Interview consisted in asking manager questions about the importance of a criterion over another and providing him with verbal appreciations to help him with judgments. At the end of interview manager started to evaluate criteria importance using Saaty scale.

4.3 *Step1: Define goals and enablers*

The result of this step is shown in Figure 6. Goals have been identified based on open questions answered by the manager. Afterwards, they have been filtered (in order to remove duplication) and categorised into goals and sub-goals by

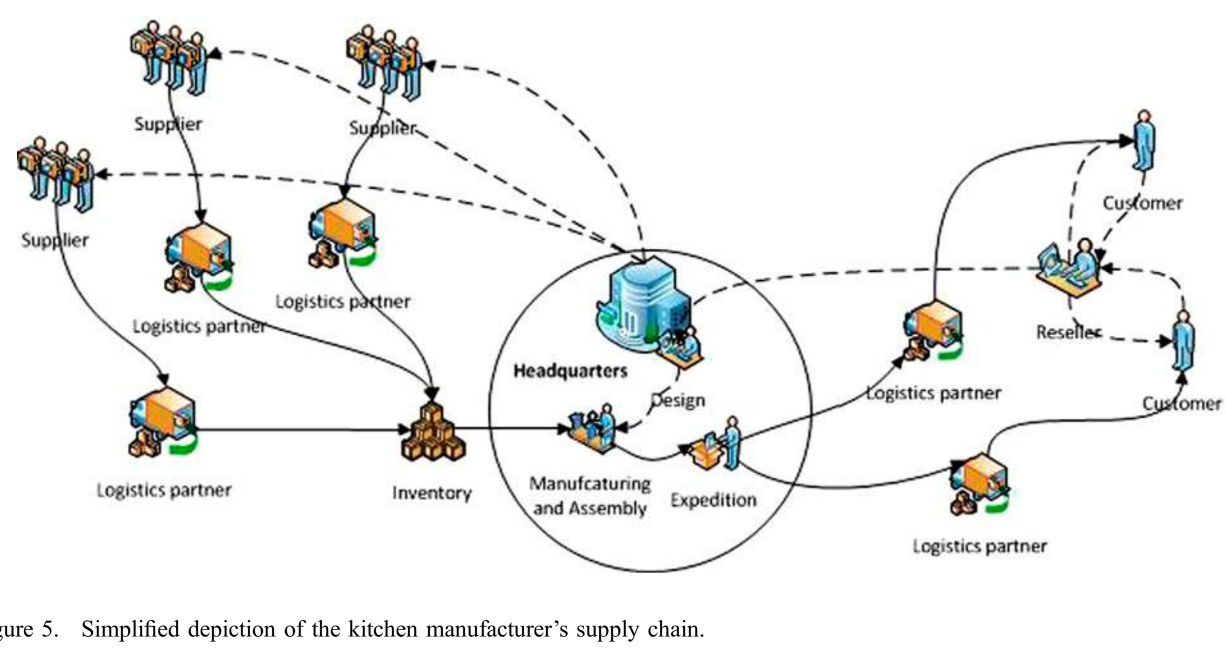

Figure 5. Simplified depiction of the kitchen manufacturer's supply chain.

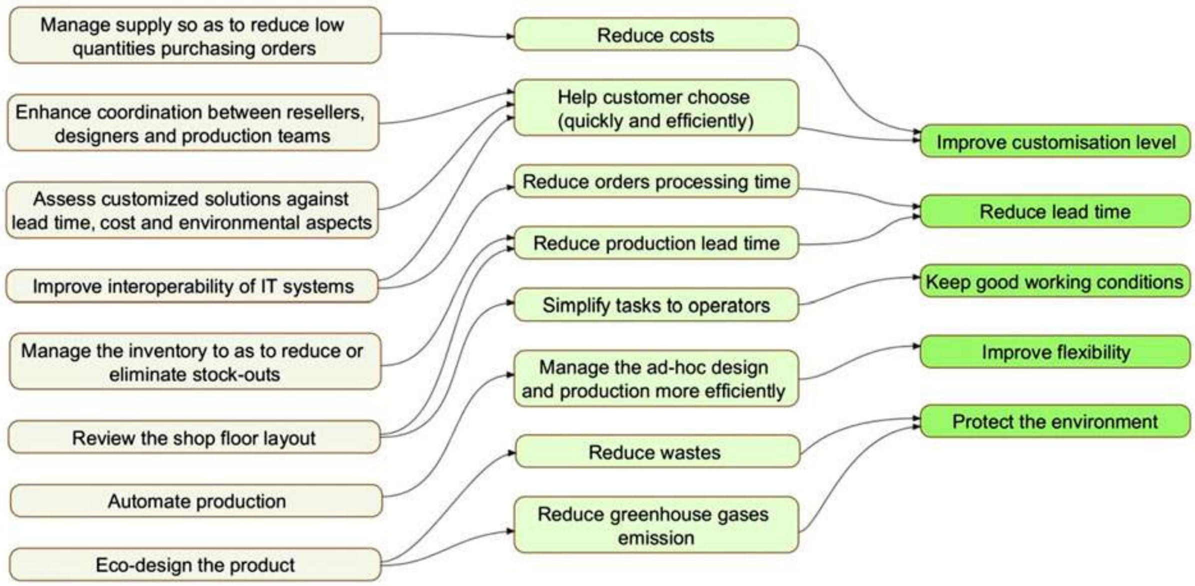

Figure 6. Goals and enablers.

authors (i.e. interviewer). The enablers are identified based on the knowledge authors got from analysing the company context (e.g. internal and external reports) and hearing from interviewee about critical issues the company is facing. In the end, it has been agreed upon the goals and enablers shown in Figure 6.

4.4 *Step2: Identify/prioritise performance aspects*

The results of the pair-wise comparisons of the performance aspects are represented in Table 7 whose last column represents the Eigen vector depicting their relative weights. $\lambda_{max} = 11.32$ and $n = 10$, subsequent consistency ratio (*CR*) calculated for these comparisons is $0.098 < 0.1$, thus, judgments are said to be acceptable.

4.5 *Step3: Identify/prioritise PIs*

Indicators' weights are presented in Table 8. The low values of the weights are explained by the high number of indicators considered in the case study. However, it can be said that DLT and unitary gross profit (UEGP) are the most important indicators for the company. Regarding environmental sustainability, the resources used (NRD, WD, and ED) and wastes (WP and PRP) are the most important indicators, whose cumulative weights amount to 0.0504 and 0.0563, respectively. Human toxicity potential (HTP) and child labour (CL) are the most important social indicators. Notwithstanding, all other indicators will be considered in the evaluation of the improvement scenarios so as to provide a holistic measure of all sustainability and mass customisation aspects whether they are important or not.

Table 9 shows the calculated consistency ratios for the judgments made at step 2. All values of *CR* are less than 0.1. The judgments are then acceptable.

Figure 7 depicts the distribution of the weights among sustainability dimensions and mass customisation. The economic dimension is still the most important for the company (48%). Mass customisation sustainability is also receiving more and more attention reflected by the 27%. Environmental sustainability is ranked third with 14% of the weights; this is due the fact that environmental sustainability is still seen from an economic point of view. In this sense, most important environmental criteria are the ones correlated with economic ones, such as resources use. Social sustainability represents only 11% of the total weights. This is partly explained by the fact that the company already made efforts to promote working conditions and moved to environmental sustainability where the focus is put now.

4.6 *Step 4: Identify and evaluate improvement scenarios*

Often, firms cannot control all of the indicators at once. As for the case company considered in this study, supply chain design and management is one of the key enablers likely to support the implementation of SMC. Moreover, both

Table 7. Performance aspects prioritisation.

	Efficiency	Profitability	Investments	Emissions	Resources use	Wastes	Working conditions	Local communities	Customization level	Service level	φ_i
Efficiency	1.00	1.00	5.00	5.00	7.00	3.00	5.00	5.00	1.00	1.00	0.18
Profitability	1.00	1.00	5.00	7.00	1/3	7.00	0.33	5.00	5.00	5.00	0.18
Investments	1/5	1/5	1.00	3.00	1/5	1.00	3.00	5.00	1.00	1.00	0.07
Emissions	1/5	1/7	1/3	1.00	1.00	1/3	1/5	1.00	1/5	1/7	0.02
Resources use	1/7	3.00	5.00	1.00	1.00	5.00	1/5	5.00	1/5	5.00	0.13
Wastes	1/3	1/7	1.00	3.00	1/5	1.00	1/5	1/5	1/5	1/7	0.03
Working conditions	1/5	3.00	1/3	5.00	5.00	5.00	1.00	5.00	1.00	1.00	0.12
Local communities	1/5	1/5	1/5	1.00	1/5	5.00	1/5	1.00	1/7	1/7	0.03
Customization level	1.00	1/5	1.00	5.00	5.00	5.00	1.00	7.00	1.00	1/5	0.11
Service level	1.00	1/5	1.00	7.00	1/5	7.00	1.00	7.00	5.00	1.00	0.13

Table 8. PIs weights.

Economic sustainability		Environmental sustainability		Social sustainability		Mass customization	
UPVC	0.0472	GWP	0.0018	II	0.0066	NCF	0.0504
PLT	0.0392	POCP	0.0013	SEI	0.0045	OCF	0.0504
VPLT	0.0233	EP	0.0041	WTI	0.0045	DLT	0.1674
VAT	0.0278	ODP	0.0016	MSO	0.0043		
UEGP	0.1882	AP	0.0036	SDII	0.0043		
PLC	0.0376	FAETP	0.0050	ID	0.0045		
TR	0.0110	FSETP	0.0050	IL	0.0045		
CUR	0.0110	MAETP	0.0050	WH	0.0045		
RDII	0.0895	MSETP	0.0050	CL	0.0281		
		TETP	0.0050	LS	0.0098		
		NRD	0.0058	CCI	0.0098		
		WD	0.0242	HTP	0.0273		
		ED	0.0204				
		WP	0.0507				
		PRP	0.0056				

Table 9. Consistency ratios for indicators comparisons.

Performance aspect (k)	$\lambda_{\max}$	n_k	Consistency ratio (CR)
Efficiency	6.33	6	0.053
Profitability	2	2	0
Investments	1	1	0
Emissions	10.99	10	0.074
Resources use	3.04	3	0.031
Wastes	2	2	0
Working conditions	11.17	10	0.097
Local communities	2	2	0
Customization level	2	2	0
Service level	1	1	0

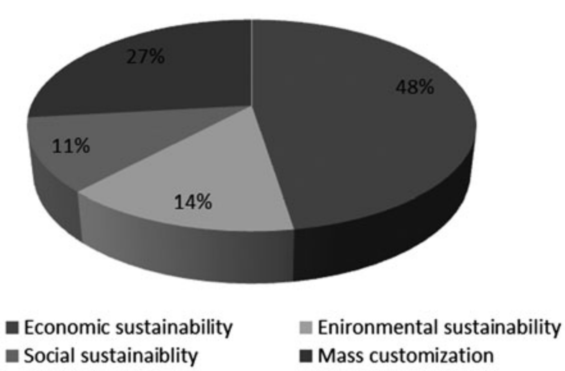

Figure 7. Weights of mass customization and sustainability dimensions.

product and process design have to be aligned with this goal by integrating practices such as the use of environmentally friendly materials, green technologies, etc. Considering the stock management issues within the case study and what it can do as improvement actions, the focus will be put on the kitchen boards' material selection and stock management. A more sustainable material would reduce the emissions and resources use indicators. Moreover, the reduction of safety stocks would decrease the stock holding costs but may increase the DLT while an increase of these stocks leads to an increase of the cost and decrease of the DLT. The subsequent scenarios are shown in Table 10.

Table 10. Scenarios.

Actions plan	Scenario1	Scenario 2
Use more sustainable material for the kitchen boards, for instance the Eurodekor®, already made available by one of the company suppliers	X	X
Increase the supplied materials by 100% from the supplier providing Eurodekor® and reducing them by 25% from the other supplier	X	X
Double safety stock	X	
Divide safety stock by 2		X

Assumptions underpinning the modelling and simulation are the following:

(1) Orders are already confirmed by the customer.
(2) Particular orders requiring pure personalisation efforts are not considered.

Following indicators are not calculated because of lack of data and/or limitations of the used software tools. They are VPLT, VAT, PLC, TR, CUR and LS. This, however, does not compromise the application of our method since only

Table 11. Evaluation results.

		Scenario 1 (%)		Scenario 2 (%)		Unit of measure
	Indicators	Values	Shifts (%)	Values	Shifts (%)	
Environmental indicators	GWP	19.88	−34.65	19.88	−34.65	$KgCO_2$
	POCP	0.0064	−8.57	0.0064	−8.57	gC_2H_4
	EP	0.027	17.39	0.027	17.39	gPO_4
	ODP	2.80E-06	−13.58	2.80E-06	−13.58	gCFC-11
	AP	0.12	0.00	0.12	0.00	$kgSO_2$
	FAETP	5.058	−4.75	5.058	−4.75	Kg1.4-DCB
	FSETP	11.18	−3.95	11.18	−3.95	Kg1.4-DCB
	MAETP	1723.13	−7.41	1723.13	−7.41	Kg1.4-DCB
	MSETP	1017.71	−7.53	1017.71	−7.53	Kg1.4-DCB
	TETP	0.023	−8.00	0.023	−8.00	Kg1.4-DCB
	NRD	0.198	−20.80	0.198	−20.80	KgSb
	WD	0.177	−11.50	0.177	−11.50	m^3
	ED	1389.93	−17.91	1389.93	−17.91	MJ
	WP	2.6	−6.81	2.6	−6.81	kg
	PRP	86.23	−1.89	86.23	−1.89	%
Economic indicators	UVPC	1018.75	+50.70	445.12	−34.15	€
	UEGP	1658.83	−16.60	2227	+11.97	€
	PLT	1.45	0.00	1.45	0.00	h
	RDII	8.474	−0.19	8.474	−0.19	€
Social indicators	II	5.79E-05	0.00	5.79E-05	0.00	Dimensionless
	SEI	0.078	0.00	0.078	0.00	€
	WTI	6.58E-05	−0.51	6.58E-05	−0.51	Dimensionless
	MSO	60	0.00	60	0.00	%
	SDII	0.669	−1.62	0.669	−1.62	€
	ID	2.095	−1.18	2.095	−1.18	Dimensionless
	IL	0.417	−7.33	0.417	−7.33	Dimensionless
	WH	18.05	−0.50	18.05	−0.50	h
	CL	0	0.00	0	0.00	%
	CCI	0	0.00	0	0.00	€
	HTP	20.27	−8.00	20.27	−8.00	Kg1.4-DCB
Mass customization	DLT	4.93	−6.98	5.58	+5.28	Days
	NCF	–	0.00	–	0.00	Dimensionless
	OCF	–	0.00	–	0.00	Dimensionless

Table 12. Global indicators.

Shifts	Values	
	Scenario 1 (%)	Scenario 2 (%)
Economic sustainability	−5.66	+3.72
Environmental sustainability	+1.28	+1.28
Social sustainability	+0.25	+0.25
Mass customization	+6.19	−4.69

variation of indicators is taken into account for calculating the shifts. The variation of these indicators can be accounted for as zero.

The modelling and simulation of current and future situations resulted in the shifts presented in Table 11.

First scenario led to an increase with 50% of the cost (UVPC) and a decrease of the profit (UEGP) with almost 17%. However, it allows reducing the DLT with 7%. Second scenario reduced the cost (UVPC) with 34% and led to an increase of the profit (UEGP) with 12% while increasing the DLT with 6.6%.

Both scenarios 1 and 2 have a positive impact on environmental indicators and a minor impact on social ones. The selection of the sustainable material, Eurodekor®, and the new distribution of the purchasing expenditures led to a decrease of 35, 21 and 18% of the GWP, NRD and ED indicators, respectively. However, minor change took place in social indicators values, in particular the HTP (8%) due to the selection of a more sustainable material for the boards.

Table 12 depicts the global shifts' values corresponding to the two scenarios and considering the weights of the indicators calculated in the previous step. Scenarios 1 and 2 resulted into shifts ranging between 0.25% and 6.19%. These low values are caused partly by the high number of indicators weighted and aggregated, and partly by the weights themselves which may decrease or increase the shift induced by a given indicator. Notwithstanding, having holistic shifts could help manager in choosing improvement actions by focusing not only on traditional economic indicators but on a complete SMC indicators system. From a global point of view, scenarios 1 and 2 have the same positive impact on environmental (+1.28) and social (+0.25) sustainability performances. However, Scenario 1 has a negative impact on economic sustainability reflected by the negative value of the shift, −5.66 while it allows improving mass customisation shift +6.19%. Scenario 2 improves economic sustainability (+3.72%) but has a negative impact on mass customisation (−4.69). These guidelines provide synthesised information about improvement alternatives contribution to the progress towards SMC.

5. Discussion

The proposed method is intended to be generic enough to be applied to several cases. Its originality lies in involving industrialists when ranking performance aspects, so that the final list of indicators is adapted to the company's context. The case study highlighted the major role of material selection in lowering environmental footprint of the customised product. This is witnessed by the reduction with approximately 35% of greenhouse gases emissions and about one quarter of the energy consumption. In the specific situation of the case study, material selection does not have a big impact on cost or lead time. This is explained by the fact that both traditional and substitute materials are provided by one of the company's suppliers and at similar cost. In addition, the inventory management turns out to be a key factor to improve the economic performance of a mass customisation production system. This is evident from the significant change in cost and lead time values among Scenarios 1 and 2. It should be noted, however, that improvement of one of these indicators is accompanied with regression of the other. This dilemma is partially solved by the combination of indicators values and weights resulting in the shifts (economic, environmental or social). In this way, the decision-making process is supported by both proposed method and decision-maker experience.

Nevertheless, the proposition still needs to be improved, in particular when it comes to the aggregation of indicators. Summing the weighted shifts may reduce the value of the global shift because of the high number of indicators and the weights given by user. Such an issue may be tackled by reducing the number of indicators to be prioritised so as to focus only on most relevant ones to a given sector. Moreover, further analysis could help identifying interrelationships between indicators and thus, modify the proposed hierarchy as in Figure 3. Decision-maker would compare all interrelated indicators with respect to a given objective. This would make the task more difficult for managers who are not much familiar with pair-wise comparisons. This difficulty can be mitigated through consistency evaluation; if judgments are not consistent, decision-maker should review his comparisons. For doing so, authors such as Saaty (2003) proposed formal ways to improve judgments matrix. An interesting research avenue could be to broaden the scope of the proposed approach by including the possibility of systematically improving judgments consistency.

While the use of S-MC-S model helped calculating aggregated sustainability and mass customisation indicators, it falls short of modelling interrelationships between these indicators. Consequently, it is not straightforward to analyse correlations between sustainability and mass customisation using this model as it is. One way to tackle this issue is by identifying and modelling performance drivers, their interrelationships and impacts on indicators. Causal loop diagrams can be used for this purpose. This would provide a reasonable foundation not only for correlations analysis but also performance monitoring. It would also help companies improve performance by showing how this can be done (Nielsen et al. 2014).

At a more technical level, modelling and simulation require additional efforts in order to integrate the used tools and facilitate the connection to company existing tools. This helps collecting the data for modelling and simulation and reduces the time needed for an evaluation project to be carried out. Furthermore, the amount and heterogeneity of data to be collected is the main reason of the industrialists' reluctance when applying the proposed approach, in particular at the modelling and simulation step. This means a more formalised data collection process would facilitate the implementation of the methodology. Such a process needs to be reinforced by a continuous capitalisation of knowledge about product, production process and supply chain so as to build a reference database accessed whenever evaluation is needed.

6. Conclusion

Performance measurement in general and of enterprises deploying SMC, in particular, requires not only traditional measurements but also a well-defined methodology and means to check relevance of the improvement scenario(s). The methodology presented within the limit of this paper addresses these issues and involves practitioners in the development process of the performance measurement system. It also puts together AHP modelling and simulation so as to check viability of given improvement scenarios with regards to economic, social and environmental sustainability and mass customisation. The illustration with an SME in the kitchen furniture sector shows some evidence of the applicability of the proposed methodology, whose added value is twofold. It captures manager's requirements through interviews and uses these requirements to put together heterogeneous indicators holistically, in order to support the decision-making process. By doing so, it helps decision makers to cope with heterogeneity of PIs, which is the prevailing figure in sustainability and mass customisation contexts. Accordingly, this promotes the operationalisation of sustainability and mass customisation in SMEs context.

In relation to sustainable mass customization, one interesting research avenue is to focus on the correlations between these concepts and its impact on supply chain sustainability and customer choices of the customised products. Furthermore, as the proposed methodology already exhibits some genericity, it would be interesting to explore its applicability to other contexts so as to promote trends shaping today's business world, such as product services systems.

Note

1. http://www.eclipse.org.

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