Business Process Reengineering driven by customer value: a support for undertaking decisions under uncertainty conditions

Yuri Borgianni [a,b,*], Gaetano Cascini [c], Federico Rotini [a]

[a] Dipartimento di Ingegneria Industriale, Università degli Studi di Firenze, Via di S. Marta, 3, 50139 Florence, Italy
[b] Faculty of Science and Technology, Free University of Bolzano/Bozen, Piazza Università, 5—Universitätsplatz, 5, 39100 Bolzano, Italy
[c] Dipartimento di Meccanica, Politecnico di Milano, Via Lambruschini, 4, 20156 Milan, Italy

Received 5 December 2013
Received in revised form 27 November 2014
Accepted 6 January 2015
Available online 9 February 2015

1. Introduction

In rapid changing and highly competitive marketplaces, industries face the challenge of continuously improving their offer in terms of products and services. The demand for innovation rebounds on the industrial environment and affects the business processes, which require continuous and controlled updates. On the one hand, companies are asked to enhance the quality of products and services, so as to fulfil the growing expectations of customers and stakeholders. On the other hand, firms strive to curb costs and, generally speaking, any other channelled resource. In this sense, a paramount importance is attributed to all those initiatives aimed at strategically redesigning industrial processes in order to accomplish significantly higher performances and that are ascribable to the field of business process reengineering (BPR). The literature witnesses considerable advantages arisen by BPR initiatives and describes textbook success stories. However, plenty of contributions from different periods (e.g. [1,2]) point out a high percentage of unsatisfactory results concerning BPR practical implementations, causing therefore diffused scepticism in the field. Recent studies provide greater understanding about the success factors and major effects of BPR initiatives, thus advancing guidelines to generate benefits for the enterprises to the greatest extent [3–6]. The reasons of unmet expectations can be related to disparate causes. Among them, the literature recognizes the complexity and the nondeterministic behaviour of business models [7], as well as the overwhelming focus on the minimization of costs [8], with the consequent disregard of workforce interests and customer preferences.

Abbreviations: API, Active Pharmaceutical Ingredient; AT, Attractive; BPR, Business Process Reengineering; CD, Customer Dissatisfaction; CR, Customer Requirement; CRM, Customer Relationship Management; CS, Customer Satisfaction; DSS, Decision Support System; IDEF, Integrated Definition; MB, Must-be; OD, One-dimensional; OS, Overall Satisfaction; OV, Overall Value; POV, Phase Overall Value; PVA, Process Value Analysis; QFD, Quality Function Deployment; VAC, Value Assessment Chart; VE, Value for Exciting requirements; VN, Value for Needed requirements; VoC, Voice of the Customer.

* Corresponding author at: Free University of Bolzano/Bozen, Faculty of Science and Technology, 39100 Bolzano, Italy. Tel.: +39 0 471 017821; fax: +39 0 471 017009.

E-mail addresses: yuri.borgianni@unibz.it (Y. Borgianni), gaetano.cascini@polimi.it (G. Cascini), federico.rotini@unifi.it (F. Rotini).

Besides, customer-oriented approaches are largely diffused within New Product Development tasks. In this context, Quality Function Deployment (QFD) plays a central role within BPR, with the intended purpose of linking together customer needs and product design [9]. QFD is aimed at maximizing the perceived satisfaction of potential clients, on the basis of Voice of the Customer (VoC) techniques, and indicates through quantitative metrics the most favourable mix of technical performances. However, few QFD applications have been experienced to relate product innovation directions to practical recommendations for carrying out the redesign of the business processes at the operational level.

In such a context, companies encounter difficulties to select the most beneficial innovation strategy to be undertaken and the most suitable BPR tool for its implementation. Particular problems are experienced by small enterprises with limited investments dedicated to R&D activities. SMEs would certainly benefit of reliable and easy-to-use Decision Support Systems (DSSs), capable to support the identification of the major process criticalities and the definition of valuable redesign strategies. With the purpose of overcoming such problems, the paper proposes a system for supporting decisions, whose methodological framework has been implemented in a popular computing environment (MATLAB R2012b). The system individuates the main weaknesses of a business process and highlights the most effective directions for process innovation. The proposed procedure is achieved by radically upgrading and extending a methodological roadmap [10], namely Process Value Analysis (PVA), swivelling on the role played by business process phases in fulfilling customer require-ments. More in particular, the basic method has been further developed to deal with uncertainties management and to assess the reliability of the outputs. The objective of the enhancements is to strengthen the approach for undertaking decisions concerning the choice of the most favourable BPR initiatives.

The manuscript is organized as follows. The next section presents a state of the art analysis focused on systems supporting decisions about reengineering activities. Section 3 better explains the starting point for the development of the proposal and clarifies the methodological objectives to be pursued. Section 4 presents the designed methodological framework and its computer implementation. Section 5 shows two applications of the methodology. The former is an illustrative case study treating a manufacturing process from the pharmaceutical field, carried out by a sample of 27 MS Engineering students. The purpose of this example is to show the impact of divergent opinions between process analysts with adequate scientific rigour. The latter is a real case study from the footwear industry, for which 16 individuals have analysed the whole business process of a small Italian firm within a project of national interest. The section further discusses the emerging outcomes of the experiments. Eventually, Section 6 draws the final considerations and depicts the planned future activities.

2. Related art

This Section aims at elucidating how the literature treats a wide variety of topics related to industrial innovation practices. According to the authors' understanding, process- and product-oriented approaches separately show complementary benefits with regards to several aspects. Moreover, in the complex network of existing support systems, a difficult task is represented by weighing up the efforts dedicated to improve the quality of products and to stem the costs of industrial processes. The following Sections debate the above recalled aspects and outline an initial set of requirements to define an ideal DSS for process reengineering, thus posing the methodological objectives of the paper.

2.1. Overview of DSSs for process reengineering

2.1.1. General features of DSSs to support BPR

BPR initiatives represent complex multidisciplinary tasks, dealing with multiple sources of risk [11] and a wide range of aspects regarding different fields of expertise [12]. Furthermore, reengineering issues are directed towards complex business and industrial processes, which are characterized by not deterministic behaviours and require dynamic time-dependant models. The uncertainty regarding the model and the parameters governing the business process affects the outputs of BPR tasks. As a consequence, firms tend to take extremely risky decisions intuitively rather than through a systematic analysis. It follows that consistent research efforts have been dedicated to the development of DSSs, modelling instruments and simulation techniques aimed at increasing the effectiveness of industrial processes [13] by individuating major inefficiencies [14].

On the other hand, failures of BPR initiatives can be explained by strategies oriented on redesigning just the features pertaining the internal processes [15]. With a particular insight into process rethinking, it has been argued [8] that numerous BPR applications have been focused mainly on resources savings. Such practices, with the purpose of achieving lean processes by imitating past experiences, have frequently underestimated the relevance of the value delivered to customers [16], conversely seen as a determi-nant for the success of BPR initiatives [17].

The documented decision supports that have considered the supply side for process enhancement have been mostly aimed at aligning business strategies towards Customer Relationship Management (CRM) [18–22]. In this sense, rather than customer-oriented BPR approaches, such DSSs represent methodologies addressed at improving a particular area of business and industrial management. Eventually, recent contributions exploit customer feedbacks and demands to redesign the business process. However, these proposals are restricted to specific industrial domains, such as electronic items assembling [23] and servicing [24].

2.1.2. Accounting of uncertainty issues within BPR systems

Like any decision-making activity, the redesign and planning of business processes is associated with uncertain inputs and risk. With reference to such a problem Lambert et al. [25] take into account relevant risky factors starting from the modelling phase by representing such additional information through tailored IDEF (Integrated Definition) frameworks.

Many research efforts have been carried out about DSSs dealing with the uncertainty that characterizes a business process. Min et al. [26] developed a DSS suitable for the banking industry, assessing appropriate BPR tasks under multi-criteria analysis and present constraints. Williams et al. [27] deal with risk and uncertainties associated with BPR initiatives, focusing on organizational hurdles and providing guidelines for pursuing incremental or radical changes with reference to expected benefits and available investments. Wang and Lin [28] introduced genetic algorithms to efficiently schedule industrial processes for a make-to-order manufacturing firm. Their research and application is tailored for resource allocation decisions in an environment characterized by time pressure with regards to delivery dates. By exploiting simulation techniques, Mahdavi et al. [29] built a model meant to dynamically control the production activities of a flexible job-shop, whereas manufacturing processes are characterized by stochastic events.

Still with regards to intelligent decision making within industrial processes affected by uncertainty, Gregoriades and Sutcliffe [30] developed a decision-based system capable to evaluate the advantages of introducing and managing a new candidate business process, whose characteristics are known. The system simulates the business process, by taking into account industrial performance and human factors, and assesses oppor-tunities and risks on the basis of the generated scenarios. Besides, the problem of working with nondeterministic and uncertain models is compounded by the presence of qualitative parameters. In such a context, recent contributions introduce measurable parameters to deal with uncertainty issues within relevant aspects related to business processes, i.e. customer relationship [20] and purchasing management [31].

Overall, the heterogeneous aims of these contributions either enhance specific aspects of industrial strategies, or are tailored to support specific categories of firms. In this sense, they mostly lack a general and versatile approach, capable to fit the exigencies of differentindustrialdomainsandencounteredproblems.

2.2. QFD as a decision support to address the development of products

2.2.1. Employment of QFD within reengineering tasks

As already mentioned in the Introduction, QFD represents the main reference for product development initiatives stimulated by customer value. The employment of quantitative variables eases the displaying and the interpretation of the arising outcomes, thus facilitates decision making. Further on, QFD shows a robust link with Kano model [32], thanks to its focus on products features in the perspective of achieving customer satisfaction. The matching of QFD and Kano heuristics allows considering the different impacts of the relevant competing factors on the perceived value [33,34].

QFD basic principles have been exploited also to support process redesign. In [35], a modified QFD method replaces engineering featureswiththefactorscharacterizingthemanufacturingprocess, by directly relating the latter with customer requirements. The main achievement of the system is the disclosure of potential conflicts between disparate aspects concerning the business process, rather than practical hints to support decisions about the reengineering activitiestobeundertaken.

Ultimately, besides claiming to support a wide range of reengineering activities, the positive influence of QFD on the improvementofindustrialprocessesisquestionable[36].Its function within BPR predominantly consists in supporting the strategic positioning in the market by analysing and assessing the product performances[37]andchoosingthemostappropriate manufacturing meansforthedesignedartefacts[38].

2.2.2. The management of uncertainties

Furthermore, a considerable drawback of QFD is represented by diffused uncertainty affecting the inputs and the outputs of the methodological framework.

Fung et al. surveyed QFD models [39] to analyse the reasons of uncertainty introduction, revealing how a major role is played by the relationships between customer requirements and engineering characteristics.Inaddition,theirresearchsurveystheeffectiveness of linear programming models with fuzzy coefficients to correctly estimatetheextentofsuchrelationships.

The employment of fuzzy set theory represents the most diffused approach in the literature for managing the uncertainties and the dynamics of the inputs in QFD: Kahraman et al. [40] proposed a critical review of these applications. Experiences dealing with uncertainty carried out by means of fuzzy set theory regard also the Kano model [41,42], as well as its conjoint utilization with QFD [43].

Geng et al. [44] introduce a fuzzy model for QFD, taking into account, beyond product characteristics, those requirements involved in services delivery and pertaining the manufacturing process. Jia and Bai [45] propose a fuzzy-QFD model tailored for manufacturingprocesses,whosemainfeaturesareevaluatedby four industrydomainexperts;theapplicationofthetoolfinally depictsthe effects of uncertain inputs in a modified House of Quality [46]. The surveyedcontributionsarehoweveraffectedby thearguedefficacyof fuzzy sets within the management of uncertainties for decisions undertaking [47]. Furthermore, the relentless difficulties in employing such complex mathematical models hinder a wide diffusionofsuchDSSswithinalargeamount ofindustrialcontexts.

2.3. Approaches for choosing the most advantageous BPR activities

According to the above overview, the field of decision support for BPRappearsasanextremelypopulatedsetoftoolsand methodologies. Inthisperspective,aconsiderablesupportforthe companieswouldbe represented by systems capable of individu-ating the aspects of the wholebusinessrequiringthemost beneficialreengineeringactivities.

Insuchacontext,themostfavourabledirectionsforBPR initiatives areaddressedbyseveraldecisionsupports,thatapply howeverjustto peculiarfeaturesofthebusinessstrategy,suchas thetechnicalaspects of the process [48] or single units of the enterprise [49]. Reijers and Mansar [50] provide a framework of best practices for BPR tasks accordingtothefocusofredesign efforts.Heetal.[51]havedevelopeda Fuzzy Analytical Hierarchy Process to support the choice among different alternatives of possible BPR initiatives. Eventually, Cho and Lee [52] develop a web-based tool for choosing the most suitable approach for Business Process Management, according to the evaluation criteria dictated by the characteristics of the firm under investigation.

Amethodological approach, namely Process Value Analysis (PVA) [10], has been developed in the perspective of individuating the business segments needing major reengineering efforts. The methodology characterizes the main phases of an industrial process by quantitatively determining their contribution to avoid dissatisfactionandtoprovideunexpectedvalueforcustomers.It takes into account also the resources spent to fulfil the planned customer requirements. This allows highlighting the value bottle-necks of the businessprocess,soastoaddressthereengineering priorities.Anakin objective is pursued through the methodology proposed by Jammernegg and Kischka [53], that focuses never-theless just on the enhancement of a peculiar segment of the business processes, i.e. supplychains.

The PVA simulates the interplay between QFD and Kano model, although the phases constituting the business process are considered instead of engineering requirements. The methodology differs also from the already cited proposal advanced by Jagdev et al. [35], because it investigates the single constituent activities and phases of a business process instead of global characteristics.

2.4. Summary of the survey and individuation of the main lacks within DSSs for BPR

Table 1 provides an assessment of the examined approaches with respect to a set of desirable characteristics for an ideal DSS, gathered from the above survey. The table highlights, besides the primary scope of the different proposals, the level at which such characteristics are achieved according to the authors' opinion.

With reference to Table 1, the scenario of proposals for supporting BPR includes tools to prioritize aspects for product redesign, criteria to individuate weaknesses concerning the

Table 1
Strengths and weaknesses of the existing decision supports for Business Process Reengineering.

Kind of contribution to support decision making	Main aim	Kind of output to support the decisions (quantitative or qualitative)	Consideration of the customer sphere	Consideration of internal demands	Flexibility according to different industrial fields	Addressed section of the business process	Capability to account of uncertainty issues
Traditional BPR approaches [1,2,11,12]	Restructuring industrial processes by suppressing low-valued activities	Diffusedly qualitative	Moderate	Very careful	Modest (due to standard solutions)	Whole	Limited
BPR approaches swivelled on CRM [18–22]	Aligning strategies towards CRM	Diffusedly qualitative	High	Varying	Varying	Just partially	Varying
BPR systems exploiting customer feedbacks [23,24]	Reengineering business processes according to inputs from the customer sphere	Diffusedly qualitative	High	Limited	Very limited	Whole	Not relevant
Qualitative BPR approaches considering uncertainties [25–30]	Varying according to the single proposals	Qualitative	Moderate	Varying	Diffusedly low	Diffusedly just partially	Foreseen
Quantitative BPR approaches considering uncertainties [20,31]	Reengineering strategic segments of a business process	Quantitative	Moderate	Foreseen	Limited	Just partially	Foreseen
QFD (+Kano) [33–35]	Aligning product profiles to maximize the customer satisfaction	Quantitative	Very careful	Limited	Good	Diffusedly just the product redesign	Absent
Fuzzy QFD (+Kano) [40,43–45]	Aligning product profiles to maximize the customer satisfaction	Quantitative	Very careful	Diffusedly absent	Good, but complex to be applied (especially in small contexts)	Just the product redesign (in most cases)	Foreseen
Systems to choose the most valuable BPR tool [48–52]	Selecting which BPR methodologies can result the most advantageous	Mostly qualitative	Moderate	Careful	Diffusedly good	Mainly just a part of the business process	Diffusedly limited
Process Value Analysis [10]	Identifying the priorities for BPR according to value bottlenecks	Quantitative	Careful	Careful	Good	All the phases composing the whole business process	Absent

current process and practical instruments to carry out transformations at the operational level. Such tools result poorly linked with each other and the fulfilment of DSSs capable to guide the enterprises in the whole reengineering process still represents a severe challenge. The ideal result would be a system capable of individuating the aspects and the areas of the business process needing major changes and translating these inputs into practical suggestions to redesign the involved industrial activities. According to this objective, the initial step of a targeted research activity would be the achievement of a DSS module in charge of supervising the business process and remarking its main weaknesses, complying with the features illustrated in Table 1.

Such outcome may be accomplished by extending the existing contributions (with a specific reference to those closer to the ultimate goal) beyond the limitations highlighted in the survey. According to the authors' vision, three alternative paths can be followed:

- extending the purpose of BPR instruments based on customers' opinion;
- improving QFD-like tools tailored to investigate industrial processes;
- developing the Process Value Analysis further.

Table 2 summarizes the pros and cons envisioned for the above alternatives. In detail, the first hypothesis regards the extension of the BPR tools swivelling on customer feedbacks, leading to a method capable to work in different industrial contexts. Such a method would indicate the most favourable redesign actions according also to the amount of resources requested to the firm for

Table 2
Methodological opportunities to achieve the first module of a DSS meant to supervise the business process and highlight the value bottlenecks: pros and cons.

Candidate strategy to obtain a DSS module to highlight process weaknesses	Main advantages concerning its development	Hurdles to overcome in the design phase of a corresponding method
Extension of BPR tools based on customer feedbacks	Orientation towards practical measures to be undertaken (ease of linking with subsequent DSS modules)	Penalty for firms without efficient customer services
Enhancement of QFD approaches tailored to industrial processes	Developed capabilities to manage uncertainty issues	Arguable possibility to blend different methodologies Complexity of systems based on Fuzzy Sets
Further development of Process Value Analysis	Proper accounting of the resources spent by the industrial process Existence of preliminary indications about reengineering directions	Diffused employment of subjective evaluations

Table 3
Inputs of the PVA procedure and steps in which they are employed, so as to generate partial results which characterize the treated industrial process (column outcomes).

PVA step	Task to be carried out	Outcomes	Required inputs
1	Information gathering	Process model, individuation of the attributes that characterize the business, sizing of expenditures relevant to each phase	List of phases; list of customer requirements (CRs)
2	Evaluating the reasons of satisfaction and discontentment	Characterization of the CRs according to their orientation in determining expected or exciting quality	Kano categories
3	Estimating the role played by product and service attributes	Characterization of the CRs according to their impact within the commercial offer; consequent determination of their share in terms of customer (dis)satisfaction	Relevance indexes *R*; CS/CD terms
4	Relating the internal sphere of the process with the business outputs	Estimation of the contribution provided by process phase in fulfilling the CRs	Correlation coefficients k_{ij}
5	Measuring the phases expenditures	Extent of employed resources, emerging harmful effects, auxiliary functions, costs and time necessary to carry out the process phases	Phases resource indexes

their pursuance. The advantage of this development strategy would stand in a quick link with the subsequent module of the DSS, since the existing BPR methods are considerably oriented to the practical measures for the transformation of the process. On the other hand, the resulting DSS would suffer from scarce usability for firms without developed client services, since the feedbacks of a restricted amount of customers would result in poorly reliable indications.

The second development strategy aims at employing the existing QFD-based approaches, with a particular reference to those tools involving also manufacturing and business processes and already capable to manage uncertainties. A consistent direction for the development strategy of QFD-oriented systems should regard a reliable computation of costs and resources in charge of the enterprise. Since the surveyed proposals quite differ in terms of the fulfilment of the expected characteristics for a future DSS, an opportunity (to be however verified) is represented by blending a set of QFD-oriented methods, attempting to combine the benefits of single contributions. Disadvantages would concern the complexity accounted to systems exploiting fuzzy sets and the lack of an appropriate strategy to manage uncertainty.

Eventually, the third alternative concerns the extension of the Process Value Analysis, whose intended purpose fits the expected objectives concerning the recalled initial module of a more articulated DSS. Moreover, an insightful analysis of the approach reveals that its outputs include preliminary indications about the most proper BPR practices to be implemented in order to beneficially follow the emerging reengineering directions. According to the above discussion, the main limitation of this methodology consists in the disregard of uncertainty issues in view of a not negligible quantity of subjective evaluations about the process. An upgraded version of the PVA, capable to manage uncertainties, would require an intense testing campaign in order to assess its actual reliability.

Despite the above hurdles, the authors decided to follow the development strategy based on the extension of PVA. This option potentially allows obtaining a tool for intelligent decision making to be employed without necessarily resorting to costly and time-consuming customer surveys. The consequent methodological objectives to be pursued, better clarified in the following Section, stand in the upgrade of the system in terms of accounting for uncertainty issues, striving to safeguard the intuitiveness of the original PVA framework.

3. Methodological background and research objectives

In order to clarify the measures proposed in the present paper to develop a DSS with the enunciated scopes, a more detailed overview of the Process Value Analysis is hereby provided. Tables 3 and 4 summarize its methodological roadmap, illustrating the steps for the determination of the inputs and the computation of the outputs, respectively. Said inputs and outputs represent the terms that symbolize the performances of the business process, its segments and deliverables. All the steps are featured by an outcome, i.e. the methodological requirements to be attained, which besides can be deemed useful to qualitatively describe the industrial process and its nuances. The following Subsection shows with greater detail the original structure of the methodology in a stepwise fashion.

3.1. Description of the reference methodology

The first stage of the PVA procedure concerns the gathering of the information related to the business process under investigation. Customized IDEF0 models are suitable to represent the flows of information and materials along the process phases, as well as the employed technology, machinery, human skills. Complementary data are collected to map the expenditures and the timing of each activity. The overall model helps individuating the Customer Requirements (CRs) that are intended to be delivered and the organizational and/or manufacturing phases that compose the business process.

The next step of the methodology regards the investigation of the customer requirements that have been identified. According to authors' experience, in order to perform reliable analyses, a comparable detail level has to concern the schematization of the process into phases and the representation of the products and services through said customer requirements. Each product/service attribute is at first characterized in terms of the Kano categories contributing to deliver customer value (One-dimensional, Attractive, Must-be). Additionally, as within the applications of the House of Quality, relevance indexes are assigned to these attributes,

Table 4
Outputs of the PVA procedure and steps in which they come out; the column Outcomes illustrates the kind of obtained results in terms of the characterization of the treated industrial process.

PVA step	Task to be carried out	Outcomes	Procedure outputs
6	Measuring the process outputs from customer viewpoint	Benefits delivered by each phase in terms of avoided dissatisfaction and customer contentment	PCS and PCD coefficients
7	Comparing the delivered benefits and the internal expenditures	Ratio between the terms expressing satisfaction and the phase consumed resources	VN and VE coefficients
8	Summarizing the results	Comparison of phases value, highlighting of the bottlenecks	Value Assessment Chart graph

expressed with R, meant as the relative importance of the customer requirements within the bundle of benefits provided by the business process. Such coefficients are expressed with natural numbers through a Likert-type scale, ranging from 1 to 5 in previous PVA applications. Both the Kano categories and the relevance indexes are established through customers' interviews or stated by business experts, whereas opinions of the clientele are unavailable or considered untrustworthy in the perspective of reengineering tasks.

The introduction of all Kano categories and importance coefficients allows to establish the extent of customer satisfaction CS (dissatisfaction CD) that is generated (prevented). Attractive and One-dimensional attributes contribute (to the extent of their relevance R) to the CS term. Must-be and One-dimensional features contribute (still according to their relevance R) to the CD term. The following formulas clarify the way CS and CD of the ith CR are calculated:

$$\mathrm{CS}_i = \frac{(a_i + o_i)}{\sum R_k}; \tag{1}$$

$$\mathrm{CD}_i = \frac{(m_i + o_i)}{\sum R_k}; \tag{2}$$

whereas o_i, a_i and m_i hold Ri if the customer requirement is classified as One-dimensional, Attractive or Must-be, respectively, 0 otherwise. The denominator stands for the sum of relevance indexes ascribed to all the attributes.

The following phase consists in identifying, on the basis of business experts' evaluation, the correlation coefficients k_{ij} $(0 \le k_{ij} \le 1)$ that link the phase j to each attribute i in terms of the accounted relative contribution of each process stage to fulfil the customer requirements (see Fig. 1 for a better comprehension). These parameters allow establishing a quantitative link among the process steps and the arisen benefits. It follows that each phase is assessed with respect to its role in both providing unexpected benefits perceived in the marketplace (Phase Customer Satisfaction, PCS) and avoiding user discontent (Phase Customer Dissatisfaction, PCD), according to the following mathematical expressions:

$$\mathrm{PCS}_j = \sum_i k_{ij} \times CS_i; \tag{3}$$

$$\mathrm{PCD}_j = \sum_i k_{ij} \times CD_i. \tag{4}$$

The extent of employed resources, emerging harmful effects, costs and time necessary to carry out the process phases (globally indicated as RESj for the share of the jth phase) are compared with the terms expressing the customer satisfaction (PCS and PCD). Thus, the phases are estimated in terms of their capability to provide both basic quality and unexpected features, according to their consumption, throughout the terms Value for Exciting requirements (VE_j) and the Value for Needed requirements (VN_j), as follows:

$$\mathrm{VE}_j = \frac{\mathrm{PCS}_j}{\mathrm{RES}_j}; \tag{5}$$

$$\mathrm{VN}_j = \frac{\mathrm{PCD}_j}{\mathrm{RES}_j} \tag{6}$$

The outcomes of the analysis (normalized VE_j and VN_j) are summarized in a diagram, namely Value Assessment Chart (VAC), standing in a scheme with four quadrants that represent different performance areas for process phases according to VE_j and VN_j indexes (Fig. 2). More specifically, the quadrants represent:

- Area of Low Value (low VE_j and VN_j, e.g. Phases 2 and 5 in Fig. 2): the employed resources do not guarantee an adequate product/service appreciation level and their extent is excessive with respect to the share of consumer dissatisfaction they are capable to avoid. Consequently, reengineering actions should massively regard the phases falling in such a quadrant. Said phases are demanded to deliver novel functions and should be radically restructured in order to drop their resources consumption or even trimmed and substituted by existing process segments.
- Area of Basic Value (low VE_j and high VN_j, e.g. Phase 4 in Fig. 2): the employed resources do not provide perceivable product/service unexpected benefits, but they are well spent to avoid

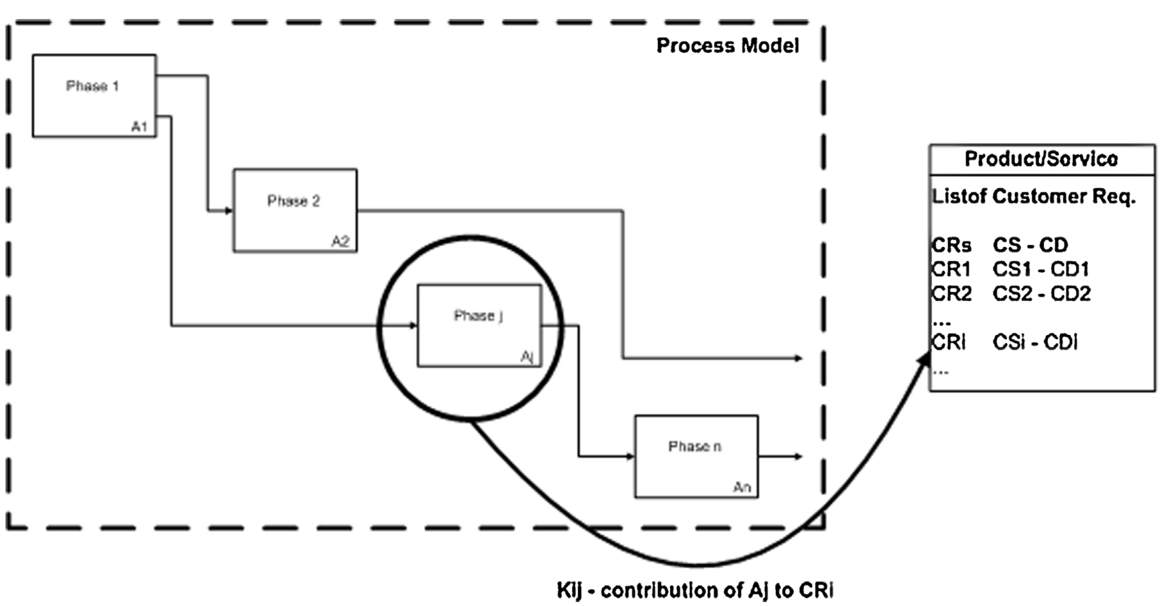

Fig. 1. Meaning of the coefficients k_{ij}, representing the contribution of the jth phase to the fulfilment of the ith customer requirement [10].

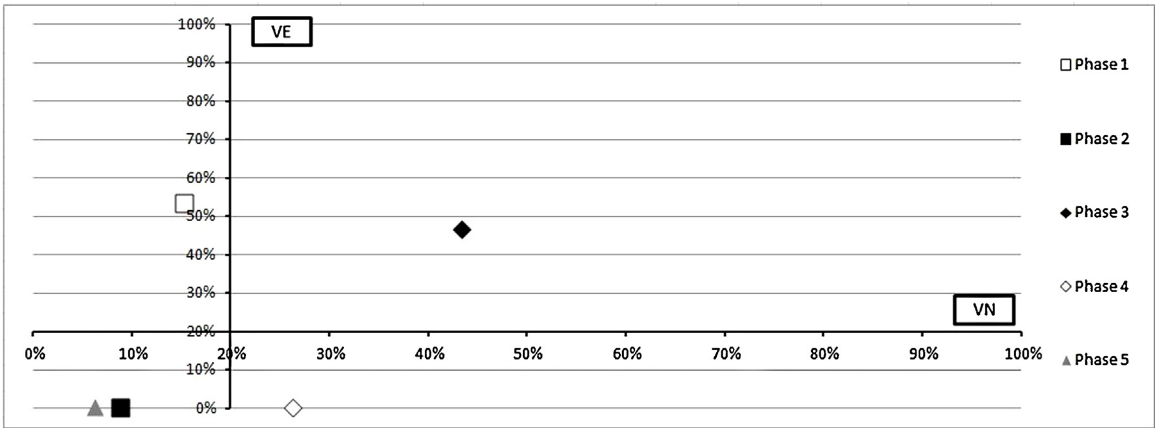

Fig. 2. Illustrative example of the four-quadrant scheme named Value Assessment Chart.

consumer dissatisfaction; typically, the phases falling in this quadrant are oriented to fulfil the fundamental attributes and do not necessarily require investments.

- Area of Exciting Value (high VE_j and low VN_j, e.g. Phase 1 in Fig. 2): in this case, the employed resources play an evident role to produce a good product/service appreciation level, but they do not contribute to avoid consumer dissatisfaction; the phases falling in this Area are worth of investments in order to maximize their generated benefits; their success is a key to let the product/service differentiate from the competitors.
- Area of High Value (high VE_j and VN_j, e.g. Phase 3 in Fig. 2): this quadrant is characterized by phases capable to provide well perceivable benefits, still maintaining an extreme efficiency for fulfilling basic needs; the phases belonging to this Area are to be safeguarded.

3.2. *Deficiencies of the original methodology*

The first industrial applications of the PVA showed its capability to orientate decisions concerning BPR. However, as assessed by the developers of the methodology, consistent limitations of the methodology concern subjective evaluations about its input parameters [54]. The outputs, resulting by the application of the procedure, are likely to suffer from imprecision and variability which are currently not monitored.

The uncertainties may regard the classification and the relevance of customer requirements, the rates of process phases in fulfilling the aforementioned attributes, the amount of resources spent by each industrial activity when not directly measurable through monetary expenditures. Besides, the list of phases and the attributes through which the business process is schematized can differ according to single analysts.

Given the above considerations, the different estimations can be imputed to the absence of a deterministic model for the analysis of the system and by diverging evaluations of the process parameters according to experts' role (e.g. by considering the perspective of account executives and industrial production managers). Consequently, within the inputs of PVA model, epistemic uncertainty (i.e. related to the lack of knowledge or caused by measurement errors) is supposed to be more impacting than aleatoric uncertainty (i.e. provoked by the variability of the involved parameters), although the latter is not negligible.

3.3. *Expected enhancements and methodological requirements*

The methodological objective of the present paper is therefore to improve the decision support provided by the PVA, through the adoption of an upgraded model capable to manage uncertainties. Table 5 summarizes the main differences between the original algorithm and the new proposal, as well as the expected achievements in the industrial practice through the consideration of uncertainty.

As highlighted in Table 5, the new system is meant to work when multiple users analyse an industrial process by means of PVA, thus revealing the extent and the nature of divergences. Since subjectivity primarily affects the inputs of the original methodology (as already recalled in Section 3.2), the variability of said parameters has to be taken into account. The variability of the outputs originated from a plurality of PVA applications could be easily managed by means of descriptive statistics, but such a strategy is unsuitable in light of likely high sensitivity from the inputs. Eventually, a particular attention has to be dedicated towards employing techniques tailored to deal with the kind of uncertainty that characterizes the methodology.

4. Methodological approach for the development of an enhanced PVA

On the basis of the above discussion, the development of the PVA has to include the exploitation of data gathered from multiple sources, thus taking into account process uncertainties and estimating their impact with reference to the end results.

Table 5
Main differences between the new proposal and the previous reference.

Feature	Original PVA	Upgraded design of the PVA
Way of working	Post-processing of process analysis performed by a single industrial expert	Post-processing of process analyses performed by multiple subjects
Provided information	Potentially unreliable picture of process bottlenecks and strengths	Picture of the most probable process bottlenecks and strengths
Use	Determination of the most urgent BPR measures to be undertaken	Determination of the most urgent BPR measures to be undertaken; consideration of the risk associated with redesigning the structure of industrial processes

Since PVA follows an algorithmic logic, transforming variables initially introduced into characteristic values for the process phases, uncertainty about said inputs has to be considered in order to provide a full spectrum of possible outputs. On these premises, Monte Carlo simulation method represents an acknowledged opportunity for dealing with the uncertainty of inputs within complex mathematical models [55,56]. Monte Carlo method is a widespread technique tailored to support decisions, due to its capability to generate scenarios according to many varying and uncertain inputs. Its employment is widely witnessed in numerous domains, including engineering [57], product development [58], business [59] and project management [60]. With a particular focus on engineering applications, the method is tailored, as assessed by Kreinovich et al. [61], to deal with both epistemic and aleatoric uncertainty.

At this stage, the objective is therefore replicating a large quantity of inputs based on the data that have been introduced by a limited number of industrial experts applying the PVA on the same business process. The application of Monte Carlo method to PVA, by involving the whole range of potential values for each input (i.e. number of phases and customer requirements, Kano categories, relevance extents, correlation indexes k_{ij}, amount of resources), would result merely in a sensitivity analysis measuring the overall potential impact on the outputs, thus out of the scope of the present research. Willing to constrain the simulation with respect to specific inputs, the common approach is to replicate each input variable according to an attributed probability distribution function, which best fits previously gathered data.

An explanation is given in the following Subsections about the choices performed to carry out the simulation.

4.1. Simulation problems

4.1.1. Problems with diverging sets of phases and customer requirements

It is expected that experts of a given business activity share a common vision about how the industrial process is organized and which outputs are offered to the customer in terms of product and service attributes. Proper modelling techniques, like IDEF0, are appraised to provide a schematic picture of the process and thus to rapidly find a consensus about the system boundaries, the phases and their outcomes.

However, discordances about the determination of the phases and the list of customer requirements could still emerge. Such mismatches determine consistent problems in the simulation task that would be better performed starting from homogeneous systems of phases and outputs valuable for the customer. In order to address such an issue, the schema of an overall industrial process is favourably represented by including all the phases and requirements that have been individuated by the analysts. With reference to the missing phases or attributes of each individual analysis, the following strategy can be followed:

- all the correlation indexes and resource ratios concerning the phases that are not represented by analysts will be assigned the null value; in this way such phases do not play any role in delivering customer value, nor do they impact process expenditures;
- the relevance extents of the customer requirements that are not judged impacting by analysts will assume the null value, thus providing no contribution in the determination of customer value.

4.1.2. Problems with the simulation of nominal variables (Kano categories)

Within PVA, Kano categories inputs are nominal variables, for which Monte Carlo method is not applicable. Conversely, the simulation of categorical variables is usually addressed through resampling techniques. In particular, the bootstrapping method is capable to replace sophisticated mathematical procedures thanks to the growing computational power of calculators [62] and is tailored for experiments characterized by small pilot samples [63]. The major shortcoming of such a technique stands in the impossibility to replicate nominal variables that have not been indicated by any analyst [64].

In order to overcome the problem, complex statistical tools can improve resampling applications otherwise biased by the absence of some, although scarcely likely, nominal values [65]. This approach does not fit however the scope of building an easily usable system. As a consequence, the authors opted to simulate CS/CD variables, which contain the information provided by Kano categories, i.e. the kind of customer perception about a specific product requirement.

4.2. Simulation choices

4.2.1. Simulating CS/CD indexes

As clarified in Section 4.1.2, it is necessary to simulate CS/CD indexes for each surveyed product attribute. CS/CD coefficients range, by definition, in the [0 1] interval and can be therefore supposed to follow a beta distribution, for which Monte Carlo simulation is applicable [66,67]. Since two shape parameters are required for the utilization of the beta probability density function, these coefficients can be calculated by exploiting the mean and the variance of the sample data (i.e. CS/CD indexes emerging from individual PVA analyses), as in [68].

The determination of the scale parameters allows therefore drawing, for each customer requirement, an array of simulations following a suitable beta distribution. The size of the array depends on the previously established number of simulations that will be indicated with *nsim* in the followings.

4.2.2. Simulating correlation indexes

The k_{ij} coefficients that express the role of the phases in fulfilling each customer requirement are positive uncertain variables with a fixed sum, i.e. 1. According to the authors' experience, the analysts of industrial processes employing PVA individuate for each product attribute one influential phase playing a major role for the fulfilment of the attribute itself. The influence of the residual phases is established with respect to the key one. By observing this characteristic behaviour, the authors have chosen a specific simulation strategy for k_{ij} variables.

A single reference phase is individuated for each product attribute, by selecting the one with the maximum average k_{ij} within the process analyses. Subsequently, for each analysis, the procedure requires to compute the ratios (indicated with k'_{ij} in the followings) between each individual k_{ij} and the values concerning the key phase. Such ratios are, by definition, positive or null variables. Their mean and variance have to be subsequently calculated. k'_{ij} ratios showing non-null variance (at least the reference phase has not this feature) are supposed to follow a gamma distribution (being they positive or null), which allows the application of the Monte Carlo simulation method [66]. The definition of the gamma probability density function requires the knowledge of two parameters (shape and scale), that can be deducted by mean and variance also for simulation purposes, as in [69]. Hence, the varying k'_{ij} are simulated *nsim* times, while the constant ones are simply repeated in the same quantity. Subsequently, arrays of k_{ij} simulated coefficients are determined by turning the emerged proportions into shares summing to 1. For any given customer requirement and with reference to a specific simulation, such an outcome can be trivially obtained by dividing each set of ratios for its sum.

4.2.3. Simulating resources shares

As seen for k_{ij} coefficients, resource shares are uncertain variables whose sum equals to 1. If any probability distribution is established for each share, the presence of the fixed sum makes the simulation problem over-constrained. With respect to resource shares, no roundabout strategy can be applied, since analysts employ substantially different criteria to determine the impact of phases on overall process expenditures and operation times.

Such a kind of problem has been however faced in the literature, by exploiting conditional probability theory [70,71]. By assuming a normal distribution for the treated variables, it is possible to exploit available simulation strategies suitable for implementation through specific programming languages. The authors have then partially adopted the logic and the commands suggested by an Internet resource supporting the development of scripts in MATLAB[1]. The means and the variances of the sample data are required to carry out the simulation, giving rise to *nsim*-sized arrays of resource ratios regarding each individuated process phase.

4.3. Stepwise guided methodology and software application

This Subsection provides a stepwise guide to apply the proposed methodology, as illustrated in Fig. 3. In addition to the sequence of the steps, the figure highlights the intervals to be considered for carrying out each operation. The illustration is organized in three sub-diagrams (delimited by rectangles with dotted lines), standing for the "Gathering of individual analyses", the "Elaboration of obtained data" and the "Simulation process leading to display the final results"; hereinafter, they are described in detail.

4.3.1. Gathering of individual analyses

With respect to the activities included in this sub-diagram, the user has to collect the complete list of individuated business process phases and customer requirements, thus building an overall schema of the system under investigation. Missing data as a result of disregarded phases and product characteristics are introduced, as described in Section 4.1.1.

4.3.2. Elaboration of obtained data

Once the individual analyses are gathered, the obtained data should be organized as follows (the numbers of the following items correspond to those reported in Fig. 3 on the arrows featuring different streams of data elaboration):

(1) CS/CD indexes are calculated for each listed customer requirement and each individual PVA analysis through the expressions (1) and (2); their mean and variance are calculated for each customer requirement, so as to determine shape parameters for fitting a beta distribution;
(2) an array of the assigned correlation indexes k_{ij} has to be built for each listed customer requirement, process phase and PVA analysis; the data are then divided for the value of k_{ij} showing the maximum mean for each customer requirement, so determining k'_{ij} indexes; means and variances of k'_{ij} variables are calculated and consequently shape and scale parameters are computed for fitting a gamma distribution;
(3) an array of the attributed resource ratios has to be arranged for each listed process phase; their means and variances are subsequently calculated.

In order to run the operations recalled in the third sub-diagram, the number of the steps of the simulation has to be planned (usually some thousands), by taking into account the expected reliability of the Monte Carlo method outcomes [72]. Then, on the basis of the inputs resulting from the second sub-diagram, the simulation is performed according to the attributed probability density functions, as described in Section 4.2. This allows drawing *nsim*-sized arrays of resource ratios, CS/CD indexes and k_{ij} shares (which are calculated after the simulation of k'_{ij} values). The data are then used for simulating *nsim* PVA analyses, leading to the same quantity of VE/VN pairs, by means of formulas (3)–(6). The emerging data are used to assess uncertainties about the performances of the phases in the examined industrial process. Such uncertainties can be graphically represented in a modified VAC diagram, which replaces single points symbolizing phases performances with sets of the most likely VE/VN values.

4.3.3. Simulation process leading to display the final results

This sub-diagram represents the portion of the algorithm that can be automatically executed by exploiting the built MATLAB script, freely downloadable as an open-source web resource[2]. Such a computer application helps carrying out the methodology especially in those parts that require greater computational efforts. The residual steps can be easily performed manually or through diffused software tools, such as spreadsheets, since they require just trivial mathematical operations (multiplications, divisions, determination of means and variances). Then, data obtained in the initial steps (the first two sub-diagrams of Fig. 3) have to be properly introduced in the MATLAB script in order to correctly run the simulation, as specified in the description of the routine at the indicated webpage. The software application includes a main part, devoted to carry out the simulation and to compute the performance of the phases, and a conclusive block to extrapolate the VAC diagram.

Such a module displays process performance through actual simulated data, creating for each phase a broken line that delimitates the most populated area of the graph in terms of VE/VN values.

5. Description of the experiments and discussion of the results

The performed tests have been designed to check the applicability of the methodology and of the software tool, as well as the reliability of the outputs.

A first experiment has involved people with poor experience in the industrial domain (pharmaceutics) of the examined business process. The provided information was however sufficient for each experimenter to sketch an analysis through the PVA. Said process regards well established manufacturing practices and technologies, whose evolutions are known. The emerging results, in terms of decisions dictated by the VAC diagram and phases uncertainties, were therefore compared with the real observed transformations of the investigated process.

People with greater knowledge of the industry then conducted a second experiment. The analysed industrial process regards the current activities of a SME producing women's shoes, involved in a research project together with the Institution of some of the authors. The sample of testers included some member of the management of the shoe factory and volunteer students with a good level of knowledge about the analysed industry and firm's practices. The outcomes of the application of the proposed methodology were then illustrated to the factory's direction in order to elaborate more conscious decisions about process reengineering.

[1] www.mathworks.it/matlabcentral/newsreader/view_thread/304141.

[2] http://www.mathworks.com/matlabcentral/fileexchange/44594-pva-simulation-with-monte-carlo.

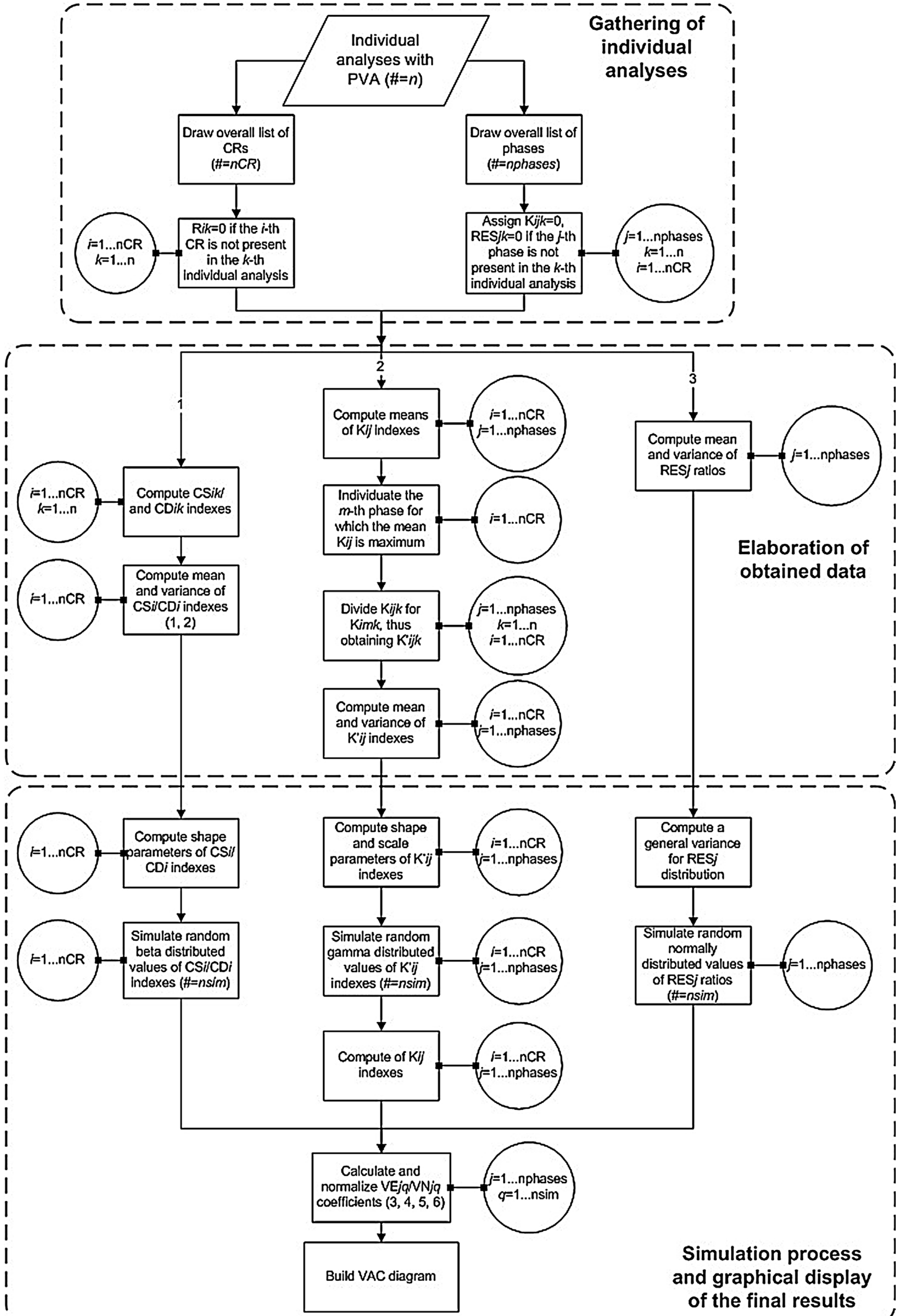

Fig. 3. Overview of the simulation process concerning the whole sample of customer requirements and process segments; full-line circles indicate the interval in which to contain the data employed in the connected methodological steps; the bottom dotted-line quadrant individuates the part of the algorithm supported by the developed MATLAB script.

Ultimately, the two tests are supposed to provide complementary results. Whereas the former aims at checking the applicability of the methodology and the reliability of the outputs, the latter can be exploited to evaluate its capability to support decisions in industrial environments. The tests are described in the following subsections.

5.1. Pilot experiment

The Section illustrates an experiment about the application of the original PVA, carried out by a sample of convenience constituted by 27 volunteer MS Engineering students, attending the course "Methods and Tools for Systematic Innovation" at Politecnico di Milano (Italy). The students performed the testing activity by compiling a tailored spreadsheet, which automatically computes the main outcomes and graphically displays the outputs of the methodology throughout the original VAC diagram.

The case study, extracted from a real industrial project, regards a well-established process for treating pharmaceutical powders in order to enhance the manufacturability of tablets, i.e. high-speed granulation. More in detail, the objective of the analysed process stands in the transformation of Active Pharmaceutical Ingredients (APIs) and excipients, commonly delivered in a powder state, into grains. Such grains have to show a good level of flowability to be easily compressed for the manufacturing of tablets. The technique consists in a prior mixing of water, API and excipient powders in order to obtain a doughy compound. The subsequent phase consists in chipping the dough (a sort of extrusion) into filaments. Such formed products are, in turn, dried before being submitted to a further cracking so to obtain structures with the requested size of the grains. The obtained grains are subsequently sifted to select a sufficiently homogeneous output showing the required characteristics of flowability.

The involved process is characterized by consistent information about its effective evolution, obtained throughout experts involvement in the research partially described in Becattini et al. [73]. More specifically, actual process developments, and hence expected indications provided by methodology stand in:

- the reduction of channelled resources for the mixing phase;
- the removal of the phases devoted to reduce the size of the pharmaceutical material (as observed in the fluidized-bed technology) or their integration with other process phases (like it is performed with the spry-drying technology);
- the key attention paid to the drying phase or to alternative activities aimed at maintaining a well-defined extent of humidity;
- a technological change for the sifting process, with the objective of strongly reducing the employed resources.

The description of the process provided to the experimenters reports the available information about the granulation technology, so as to allow the schematization of the industrial system and extract the knowledge relevant for PVA tasks.

On the basis of the process description, all the 27 testers individuated the same process phases, consisting in the mixing, dough extrusion, drying, filaments chipping and sifting operations. Each student described the outputs of the technical system by means of a number of Customer Requirements ranging from 6 to 10. The whole sample of CRs, that takes into account all the individuated features mentioned in the complete analysis, includes 10 items, further on named CR1 to CR10: dosage homogeneity, density and porosity, flowability, size, relative humidity, reduced volatility and contamination, mechanical characteristics, hardness, smoothness and aesthetic properties, colour homogeneity.

The application of the methodology exploited a different VAC representation to avoid overlapping lines. The new illustration (see Fig. 4) makes use of Parzen windowing [74], a widespread non-parametric probability density distribution.

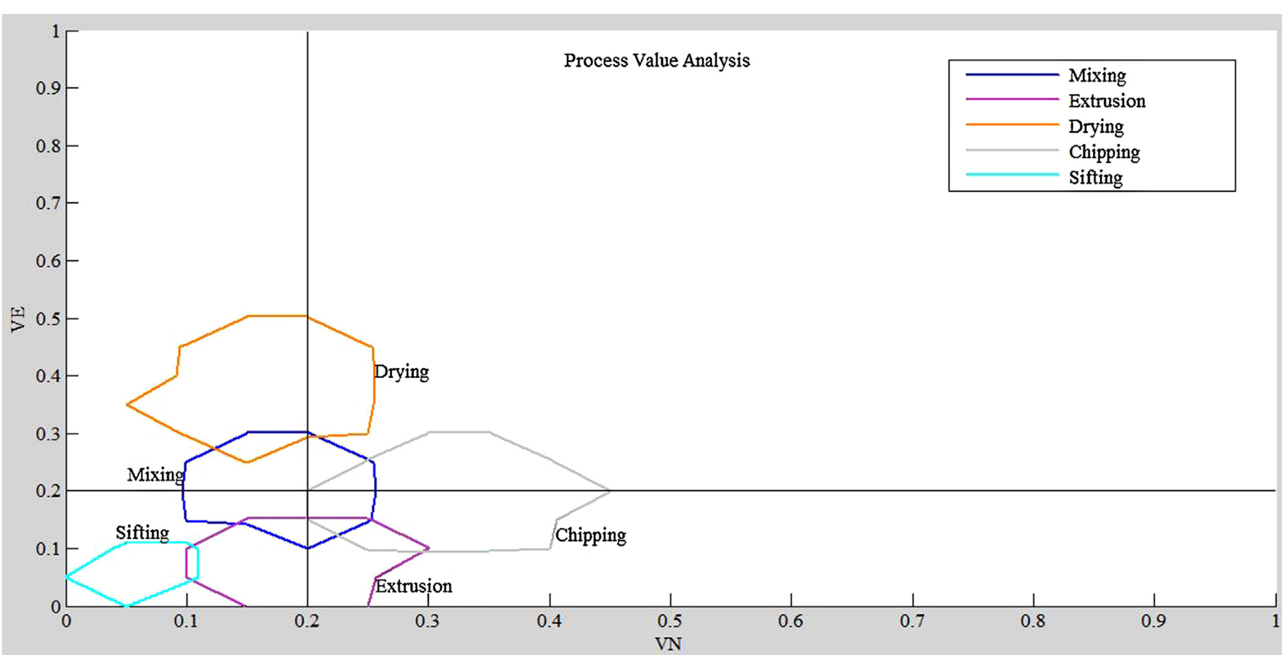

Fig. 4. Representation of uncertainties through the modified VAC diagram with reference to the granulation process of pharmaceutical powders: Parzen windowing is employed for the scopes of the representation.

In order to perform such a type of representation, the final block of the MATLAB *script* was substituted by an alternative routine[3], whose drafting benefitted from an available Internet resource[4]. In detail, the standard deviation of the samples was exploited for the scopes of building Parzen windows, according to the common normal distribution approximation. Parzen windowing is supposed to clearly identify the most proper areas of the VAC diagram concerning each phase for the specific case study.

With respect to the present experiment, the emerging results schematized in Fig. 4, show that:

- the main process value bottleneck, consisting in the sifting phase, is individuated without relevant uncertainty;
- also the dough extrusion phase is supposed to poorly contribute to customer satisfaction according to the consumed resources, since a not negligible amount of VE/VN pairs is included in the Low Value area of the VAC;
- the operations regarding the drying and the filaments chipping phases result the most value adding; while the former is particularly oriented towards the fulfilment of less expected characteristics, the latter is mostly addressed at delivering the basic properties of the granulation process;
- uncertainties about the mixing phase do not allow to suggest any suitable direction for undertaking BPR tasks.

Although affected by uncertainty, the results provide useful information for decision making. According to the general indications provided by the PVA method, the phases that represent value bottlenecks should be submitted to the most severe transformations within the technological development of the granulation process.

The poor value emerging by the sifting phase suggests technical changes with respect to the grain separation; as a matter of fact, less consuming pneumatic sieving are used in pharmaceutical industry, gradually replacing mechanical devices. With respect to the phase concerning the dough extrusion, also showing limited contribution to customer value, major changes should be expected. As well, the most diffused alternative wet granulation technique, i.e. fluidized bed, recurs to a single phase for determining the right size of the grains, thus avoiding the preliminary volume reduction of the pharmaceutical mix. Furthermore, the key role played by the drying phase is remarked by the outcomes.

Besides, the urgency of lowering the required resources for the mixing phase is not identified, due to high uncertainty. In addition, the filaments chipping does not emerge as a phase expected to be overcome, since it shows good performances.

5.2. Industrial application

The second experiment deals with an industrial case study from the footwear sector and shows the capability of the methodology to orientate decisions in industrial contexts. More in detail, the proposed method has been applied to analyse the design and manufacturing of shoes for a factory that has participated to the project "ICT4SHOES", funded by Tuscany Region, Italy. The project aims at introducing new ICT solutions for the production and the management of business processes in the footwear industry. The accomplishment of the task firstly requires a deep knowledge of industrial processes in order to generate tailored computer supports. The proposed methodology has been considered a reference for analysing processes and determining the main bottlenecks, hence individuating the firm activities requiring major redesign.

The main production of the firm consists in summer women's fashion shoes, characterized by remarkable lightness and flexibility. Experts who analyse fashion trends firstly plan the style of the collections. The design sketches have to be subsequently transformed into physical prototypes and tested in order to check if the shoes satisfy aesthetics and comfort expectations. Once the prototypes have been refined after the test, sales start by participating to sector fairs and entrusting the commercial promotion of the items to salesmen, who operate worldwide. New customers can even purchase shoes and perform orders through a web platform. As sales progress, the management of the factory and the commercial unit acquires orders. On this basis, they plan the manufacturing of the orders, supervise the stock of materials (mainly the leather) and semi-finished products (such as heels, soles and accessories). The organization of the production involves also the choice of contracting firms that are in charge of developing the initial models to allow the creation of various sizes, manufacturing the dies, cutting the leather and making shoe uppers by sewing leather parts. The warehousing unit of the factory is in charge of receiving and sending to the other parties all the materials, semi-finished products and working instruments. Once shoe uppers and all the remaining components are available, the shoe factory initiates the assembling phase or supervises this activity if carried out by third parties. The manufactured shoes are then finished, checked and packaged, so as to allow the shipment of the ordered items in the requested quantity and typology.

The authors schematized a model of the business process, including phases and fulfilled customer requirements. The model was inspected and modified by the firm's management up to the determination of a framework comprising 12 process segments and 17 product attributes. Additional information was acquired in order to achieve sufficient knowledge for applying the PVA. The debate with the production manager led to a reference version of PVA for the investigated industrial process. Overall, 13 volunteer MS Engineering students, attending the course "Product Development and Engineering Design" at University of Florence (Italy), took part of the experiment. They were introduced to the logic of the PVA, taught about the fundamentals of footwear industry and put into contact with the shoe factory in order to obtain any information they judged relevant to correctly perform the analysis of the given process. The students were urged to acquire independently further information, thus providing added value for the scope of the analysis of the industrial process. At the end of the procedure, the students and 3 other members of the enterprise's management were asked to modify the reference framework according to their viewpoint on the market of the shoes, the process and its mechanisms that enable the accomplishment of the product attributes.

The whole sample of 16 examinations through the PVA performed by individuals with a not negligible knowledge in the field represented the starting point for carrying out the simulation. The data were then grouped and organized in order to execute the simulation with the proposed MATLAB tool[5].

Given the great quantity of phases that characterize the industrial application, it was evaluated that a separate graphical output for each process segment was preferable. The standard representation with broken lines was kept, but the possibility to introduce different thresholds was introduced. The strategy

[3] The script can be downloaded from the webpage: http://www.mathworks.com/matlabcentral/fileexchange/44595-parzen-representation-of-pva-simulations. The part of the main block to be substituted is introduced by the disclaimer "% THE FOLLOWING MODULE IS AIMED AT BUILDING GRAPHICS".

[4] http://stackoverflow.com/questions/9134014/contour-plot-coloured-by-clustering-of-points-matlab.

[5] The data employed to perform the simulation are available in the first comment concerning the file exchange page of MATLAB, where the script is reported.

exploited a second alternative MATLAB block[6], substituting the final part of the main script.

The diagram shown in Fig. 5 is a result of the computerized procedure regarding the phase entrusted to determine the style of collections. Although the extent of uncertainties is considerable for this phase, the definition of the style can be considered a well performing activity (in the context of the analyzed process), being its corresponding VE/VN pairs majorly positioned in the High Value area of the VAC. Other phases characterized by significant uncertainties face a situation for which no quadrant of the VAC is predominant and decisions can be hardly taken, e.g. testing of prototypes, which is schematized in Fig. 6.

For the scope of tackling reengineering initiatives in the shoe factory, the core of the analysis stands in the individuation of value bottlenecks. Before the application of the methodology, the enterprise had already individuated the need to update the technologies employed for warehousing activities. Fig. 7, showing the diagram related to such a phase, partially confirms this choice, being VE/VN pairs concerning warehousing diffusedly placed in the Low Value area. Anyway, other quadrants are rather populated, especially Basic Value area. On the other hand, several manufacturing phases clearly represent process bottlenecks, since, although uncertainties are present, very few VE/VN pairs lie outside of the Low Value area. Figs. 8–10 schematize the performances of leather cutting, leather sewing and shoes assembling, respectively. It can be additionally underlined how representative areas with thresholds set at 75% and 95% of the whole simulation of VE/VN values widely overlap, especially in Figs. 8 and 9. Therefore, the measures of the phases performance are highly concentrated and this lessens the risks about the decisions to be undertaken.

The application of the methodology convinced the shoe factory to rethink its plans for process reengineering, considering to include also manufacturing activities within the bundle of tasks to be redesigned in order to enhance firm's business outcomes.

6. Discussion and conclusions

Despite different methodological options should be tested (such as systems for BPR evolution, process-oriented QFD, as discussed at the end of Section 2) in order to compare the efficacy of alternative approaches, the candidate module for a DSS reported in the paper has demonstrated its capabilities with respect to the objective of the present research. Indeed, the illustrated methodology, consisting in a radical rework of the PVA [10], supports the individuation of the main deficiencies pertaining the investigated industrial process towards the goal of delineating the reengineering priorities and consequently applying the most beneficial BPR tools. With respect to the posed requirements, the module pursues the double goal of taking into account the customer sphere and evaluating the risk associated with the decisions to be undertaken, according to the level of disagreement among the decision makers.

More in detail, the illustrated system works like those DSSs that integrate information pertaining the end user domain. Indeed, it uses said information to build quantitative value metrics and takes into consideration also the uncertainties concerning such issues in order to strengthen the reliability of the outputs. In the developed model, the assessment of uncertainties impact has been accomplished by integrating specific simulation tools within the original methodology. The proposed approach is suitable for supporting decision tasks in situations characterized by any of the following circumstances: superficial information concerning customer opinions; urgency of the decision such that it is not possible to collect exhaustive or reliable data; high variability of the context; diverging evaluations provided by sector experts.

The original methodology and a novel simulation module, meant to allow the handling of diverging inputs, are characterized by the ease of being exploited by means of diffused software applications (such as spreadsheets). The task is further simplified by employing MATLAB, thanks to a script published on the web, which automates the simulation procedure and additional routines to build suitable graphical representations. Consequently, such tools are suitable also for small-sized firms with limited resources and competences in statistics.

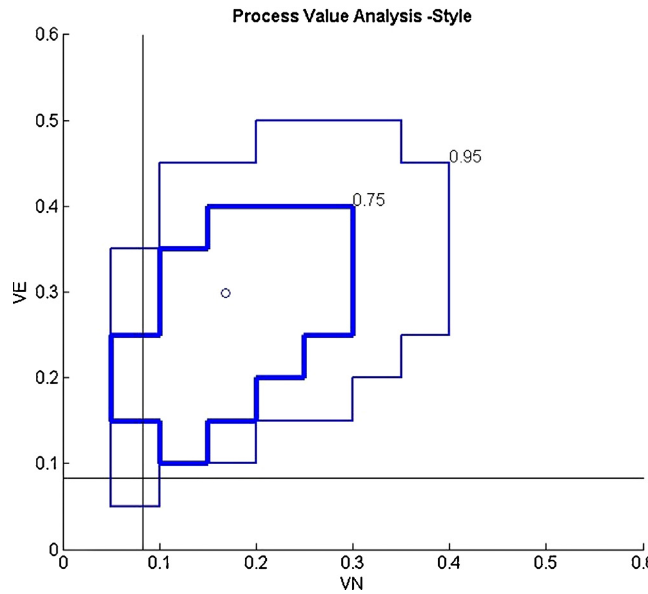

Fig. 5. Representation of uncertainties referred to the phase entrusted to determine the style of shoes in the footwear industry: contours of areas comprise at least 75/95% of VE/VN simulations, as indicated in the figure itself.

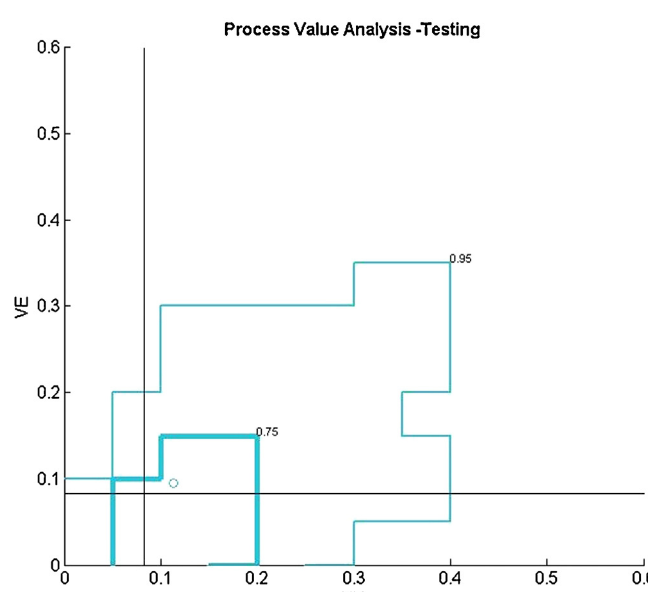

Fig. 6. Representation of uncertainties referred to the phase entrusted to test prototypes in the footwear industry: contours of areas comprise at least 75/95% of VE/VN simulations, as indicated in the figure itself.

[6] The script can be downloaded from the webpage: http://www.mathworks.com/matlabcentral/fileexchange/44596-single-vac-graphs-with-threshold-selection. The part of the main block to be substituted is introduced by the disclaimer "% THE FOLLOWING MODULE IS AIMED AT BUILDING GRAPHICS".

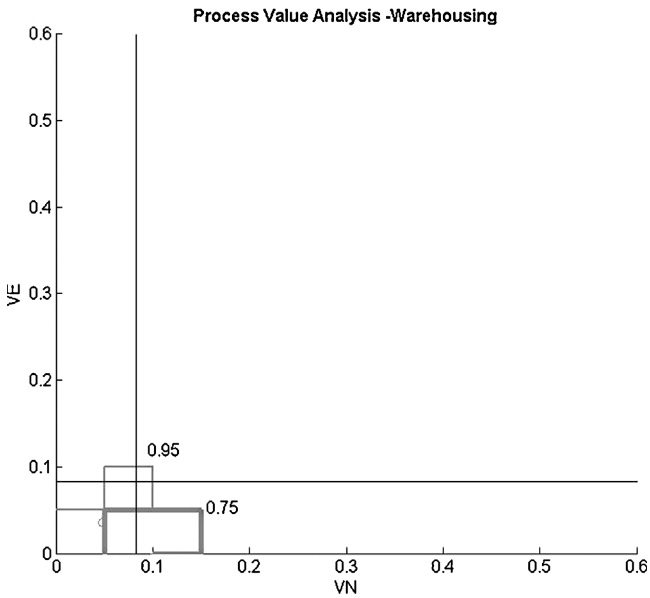

Fig. 7. Representation of uncertainties referred to the phase entrusted to warehouse materials and semifinished products in the footwear industry: contours of areas comprise at least 75/95% of VE/VN simulations, as indicated in the figure itself.

The results emerging from the first verification activity highlight that the value bottlenecks of a business process can be identified in cases characterized by diverging evaluations. Although great uncertainties, low-valued process phases were individuated for both the experiments illustrated in Section 5. At the same time, the presented methodology is capable to individuate process activities for which reengineering could result hazardous. Anyway, improvements are expected in light of the missed identification of advantageous reengineering activities, which have taken place in the pharmaceutics industry (Section 5.1). From this viewpoint, experiments carried out only by experts should highlight the role played by the limited domain knowledge in affecting the final outcomes of the proposed tool.

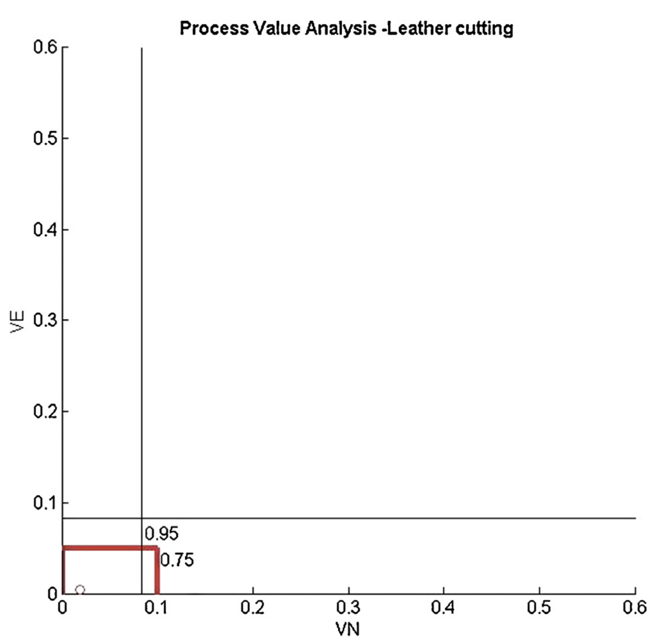

Fig. 8. Representation of uncertainties referred to the manufacturing phase entrusted to cut leather in the footwear industry: contours of areas comprise at least 75/95% of VE/VN simulations, as indicated in the figure itself.

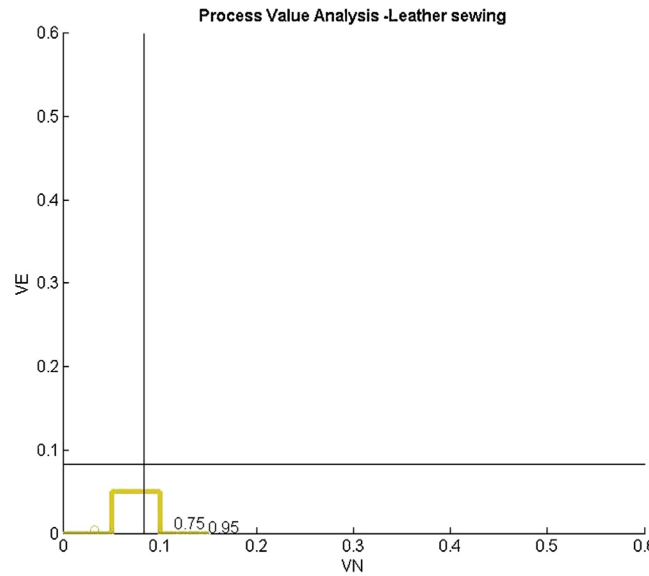

Fig. 9. Representation of uncertainties referred to the phase entrusted to sew leather in the footwear industry: contours of areas comprise at least 75/95% of VE/VN simulations, as indicated in the figure itself.

More in detail, the obtained results have highlighted that the proposed method:

- is capable to evaluate the impact that uncertainties have on the value indexes characterizing each phase;
- allows estimating the uncertainty of the provided outputs, hence the reliability of the consequent reengineering actions that decision makers might undertake;
- helps the users establishing which aspects of the business process (if any) result more fuzzy and, thus, which information elements require further investigations in order to reduce the uncertainty of the outputs.

However, current limitations of the methodology do not allow its application in particular cases, such as the situations that follow:

- processes markedly characterized by internal or management phases that do not provide value for customers to a considerable extent, but that are compulsory and cannot be trimmed (e.g.

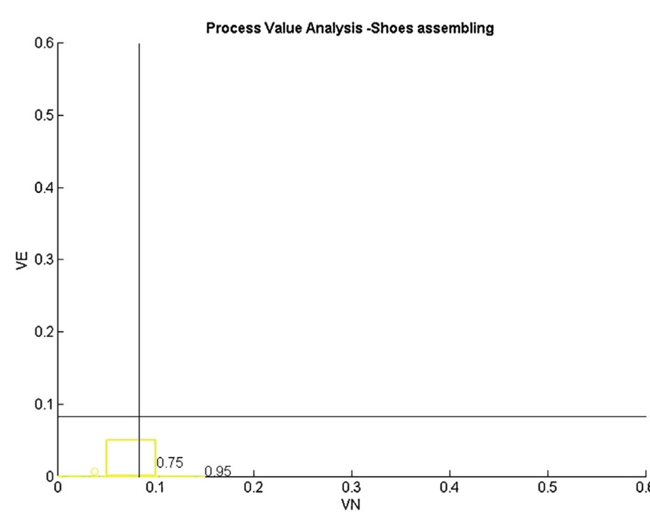

Fig. 10. Representation of uncertainties referred to the phase entrusted to assemble shoes in the footwear industry: contours of areas comprise at least 75/95% of VE/VN simulations, as indicated in the figure itself.

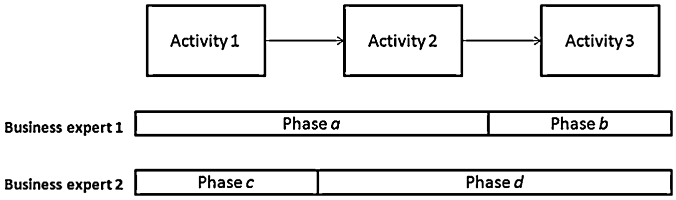

Fig. 11. Illustrative example of a particular case hindering the application of the presented methodology, because of the impossibility of representing the industrial process through a sequence of phases employing resources to participate to the fulfilment of customer requirements.

activities and controls to comply with norms, laws and other formalities);

- cases in which the companies operate with nested processes, that share phases and resources; in these circumstances, any industrial process bringing to well-defined deliverables can be analyzed, but the suggested reengineering actions can result of no utility (or even a pitfall) by potentially affecting other processes dedicated to offer different products or services;
- schematizations provided by business experts that do not allow a proper identification of the phases, by including activities and operations in diverse process segments, as shown in Fig. 11 with an illustrative purpose.

Eventually, the whole methodology has to be further developed with the aim of suggesting suitable guidelines for BPR, also in those cases that would manifest greater uncertainty degrees with regards to process bottlenecks. From the usability viewpoint, great benefits might be obtained through expanding the part of the methodology supported by the computer application. The expected developments of the research would arouse greater interest whereas the PVA-based module would result the most efficient alternative for supporting the initial steps of a multi-stage DSS, capable to guide the users up to the choice of the technologies and practices to be implemented for favourably reengineering business and manufacturing processes.

Any interested scholar or practitioner can contact the corresponding author to receive further details about the use of the software applications, files, data, suggestions and information required to repeat the experiments.

Acknowledgements

The authors appreciate the support of Niccolò Becattini and Walter D'Anna in carrying out the tests. Further on, they thank Fabio Piccioli for the suggestions given to compile the MATLAB script.

The research is partially supported by the project "Progetto di soluzioni ICT per supportare l'innovazione del valore nei processi aziendali del settore calzaturiero—ICT4SHOES", hence thanks to the decisive contribution of the Regional operational programme Objective "Regional competitiveness and employment" of the Tuscany Region (Italy), co-funded by the European Regional Development Fund for the period 2007–2013 (POR CReO FESR 2007–2013).

The work benefits also of the financial support provided by Ente Cassa di Risparmio di Firenze, that has funded the research activity of one of the authors.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version.

References

[1] D. Holland, S. Kumar, Getting past the obstacles to successful reengineering, Business Horizons 38 (1995) 79–85.
[2] Y. Ozcelik, Do business process reengineering projects payoff? Evidence from the United States, International Journal of Project Management 28 (2010) 7–13.
[3] A.A.A. Rostamy, M. Shaverdi, B. Amiri, F.B. Takanlou, Using fuzzy analytical hierarchy process to evaluate main dimensions of business process reengineering, Journal of Applied Operational Research 4 (2012) 69–77.
[4] N. Asika, O.D. Awolusi, Modelling critical success factors of business process reengineering and business performance of Nigerian oil and gas companies, International Journal of Financial Services Management 15 (2013) 28–43.
[5] T. Guimaraes, K. Paranjape, Testing success factors for manufacturing BPR project phases, International Journal of Advanced Manufacturing Technology 68 (2013) 1–11.
[6] G. Zellner, Towards a framework for identifying business process redesign patterns, Business Process Management Journal 19 (2013) 600–623.
[7] Z. Irani, V. Hlupic, L.P. Baldwin, P.E.D. Love, Re-engineering manufacturing processes through simulation modelling, Logistics Information Management 13 (2000) 7–13.
[8] D. Knights, H. Wilmott, The Reengineering Revolution?.: Critical Studies of Corporate Change, SAGE Publications Ltd, London, 2000.
[9] M. Rajala, T. Savolainen, H. Jagdev, Exploration methods in business process re-engineering, Computers in Industry 33 (1997) 367–385.
[10] Y. Borgianni, G. Cascini, F. Rotini, Process value analysis for business process re-engineering, Proceedings of the Institution of Mechanical Engineers, B: Journal of Engineering Manufacture 224 (2010) 305–327.
[11] D.Remenyi,A.Heafield,Businessprocessre-engineering:someaspectsofhowto evaluateandmanagetheriskexposure,InternationalJournalofProjectManage-ment 14(1996)349–357.
[12] S.L. Chan, C.F. Choi, A conceptual and analytical framework for business process reengineering, International Journal of Production Economics 50 (1997) 211–223.
[13] Y.Liu,H.Zhang,C.Li,R.J.Jiao,Workflowsimulationforoperationaldecision support usingeventgraphthroughprocessmining,DecisionSupportSystems52 (2012)685–697.
[14] L. Rao, G. Mansingh, K.M. Osei-Bryson, Building ontology based knowledge maps to assist business process re-engineering, Decision Support Systems 52 (2012) 577–589.
[15] R.B. Woodruff, Customer value: the next source for competitive advantage, Journal of the Academy of Marketing Science 25 (1997) 139–153.
[16] G. Hall, J. Rosenthal, J. Wade, How to make reengineering really work, Harvard Business Review 71 (1993) 35–50.
[17] M.Terziovski,P.Fitzpatrick,P.O'Neill,Successfulpredictorsofbusinessprocess reengineering(BPR)infinancialservices,InternationalJournalofProduction Economics84(2003)35–50.
[18] H.K.C. Chang, C. Hsiung, R. Tsai, The design and analyses of customer relationship management using ARIS technique, International Journal of Management and Enterprise Development 3 (2006) 1–18.
[19] H.S.Kim,Y.G.Kim,C.W.Park,Integrationoffirm'sresourceandcapabilityto implemententerpriseCRM:acasestudyofaretailbankinKorea,Decision Support Systems48(2010)313–322.
[20] M.R.Llamas-Alonso,A.I.Jiménez-Zarco,M.P.Martínez-Ruiz,J.Dawson,Designing a predictiveperformancemeasurementandcontrolsystemtomaximizecustom-er relationshipmanagementsuccess,JournalofMarketingChannels16(2009)1–41.
[21] A. Sen, A.P. Sinha, IT alignment strategies for customer relationship management, Decision Support Systems 51 (2011) 609–619.
[22] T.S.H. Teo, P. Devadoss, S.L. Pan, Towards a holistic perspective of customer relationship management (CRM) implementation: a case study of the Housing and Development Board, Singapore, Decision Support Systems 42 (2006) 1613–1627.
[23] D.M. Segura Velandia, A.A. West, P.P. Conway, A database system for decision support in low-volume electronics assembly, Proceedings of the Institution of Mechanical Engineers, B: Journal of Engineering Manufacture 225 (2011) 1411–1430.
[24] C.U.Pyon,J.Y.Woo,S.C.Park,Serviceimprovementbybusinessprocessmanage-ment usingcustomercomplaintsinfinancialserviceindustry,ExpertSystems with Applications38(2012)3267–3279.
[25] J.H.Lambert,R.K.Jennings,N.N.Joshi,Integrationofriskidentificationwith business processmodels,SystemsEngineering9(2006)187–198.
[26] D.M. Min, J.R. Kim, W.C. Kim, D. Min, S. Ku, Decision Support Systems 18 (1996) 97–105.
[27] A. Williams, J. Davidson, S. Waterworth, R. Partington, Total quality management versus business process re-engineering: a question of degree, Proceedings of the Institution of Mechanical Engineers, B: Journal of Engineering Manufacture 217 (2003) 1–10.
[28] K.J. Wang, Y.S. Lin, Resource allocation by genetic algorithm with fuzzy inference, Expert Systems with Applications 33 (2007) 1025–1035.
[29] I.Mahdavi,B.Shirazi,M.Solimanpur,Developmentofasimulation-baseddeci-sion supportsystemforcontrollingstochasticflexiblejobshopmanufacturing systems, SimulationModellingPracticeandTheory18(2010)768–786.
[30] A. Gregoriades, A. Sutcliffe, A socio-technical approach to business process simulation, Decision Support Systems 45 (2008) 1017–1030.
[31] A. Azadeh, S. Nassiri, M. Asadzadeh, Modeling and optimization of a purchasing system in uncertain environments by an integrated fuzzy business process

simulation and data envelopment analysis: a novel approach, in: Proceedings of the Spring Simulation Multi-conference, Society for Computer Simulation International, San Diego, CA, 2010, pp. 1–8.
[32] N. Kano, N. Seraku, F. Takahashi, S. Tsuji, Attractive quality and must-be quality, The Japanese Society for Quality Control 14 (1984) 39–48.
[33] K. Matzler, H.H. Hinterhuber, How to make product development projects more successful by integrating Kano's model of customer satisfaction into quality function deployment, Technovation 18 (1998) 25–38.
[34] K.C. Tan, X.X. Shen, Integrating Kano's model in the planning matrix of quality function deployment, Total Quality Management 11 (2000) 1141–1151.
[35] H. Jagdev, P. Bradley, O. Molloy, A QFD based performance measurement tool, Computers in Industry 33 (1997) 357–366.
[36] J.J. Cristiano, J.K. Liker, C.C. White III, Key factors in the successful application of quality function deployment (QFD), IEEE Transactions on Engineering Management 48 (2001) 81–95.
[37] Y. Zhou, Y. Chen, The analytic supporting tools for business reengineering with system integration design, IEEE Transactions on Systems, Man, and Cybernetics, A: Systems and Humans 40 (2010) 285–300.
[38] Y.Z. Mehrjerdi, Quality function deployment and its extensions, International Journal of Quality & Reliability Management 27 (2010) 616–640.
[39] R.Y.K. Fung, Y. Chen, J. Tang, Estimating the functional relationships for quality function deployment under uncertainties, Fuzzy Sets and Systems 157 (2006) 98–120.
[40] C. Kahraman, T. Ertay, G. Büyüközkan, A fuzzy optimization model for QFD planning process using analytic network approach, European Journal of Operational Research 171 (2006) 390–411.
[41] Y.C. Lee, S.Y. Huang, A new fuzzy concept approach for Kano's model, Expert Systems with Applications 36 (2009) 4479–4484.
[42] M. Wu, L. Wang, A continuous fuzzy Kano's model for customer requirements analysis in product development, Proceedings of the Institution of Mechanical Engineers, B: Journal of Engineering Manufacture 226 (2012) 535–546.
[43] L.H. Chen, W.C. Co, A fuzzy nonlinear model for quality function deployment considering Kano's concept, Mathematical and Computer Modelling 48 (2008) 581–593.
[44] X.Geng,X.Chu,D.Xue,Z.Zhang,Anintegratedapproachforratingengineering characteristics'finalimportanceinproduct–servicesystemdevelopment,Computers&IndustrialEngineering59(2010)585–594.
[45] G.Z. Jia, M. Bai, An approach for manufacturing strategy development based on fuzzy-QFD, Computers & Industrial Engineering 60 (2011) 445–454.
[46] J.R. Hauser, D. Clausing, The house of quality, Harvard Business Review 66 (1988) 63–73.
[47] D. Dubois, The role of fuzzy sets in decision sciences: old techniques and new directions, Fuzzy Sets and Systems 184 (2011) 3–28.
[48] T.A. Aldowaisan, L.K. Gaafar, A framework for a process reengineering decision support system, Computers & Industrial Engineering 31 (1996) 75–78.
[49] T.J. Crowe, K. Rathi, J.D. Rolfes, Selecting business process reengineering projects strategically, Computers & Industrial Engineering 33 (1997) 157–160.
[50] H.A. Reijers, S.L. Mansar, Best practices in business process redesign: an overview and qualitative evaluation of successful redesign heuristics, OMEGA—The International Journal of Management Science 33 (2005) 283–306.
[51] H.He,L.Jiang,B.Li,Businessprocessre-engineeringriskassessmentbasedona new improvedFAHP,in:Proceedingsofthe2009Asia-PacificConferenceon Information Processing,IEEEComputerSociety,Washington,2009,pp.278–281, vol.2.
[52] C. Cho, S. Lee, A study on process evaluation and selection model for business process management, Expert Systems with Applications 38 (2011) 6339–6350.
[53] W. Jammernegg, P. Kischka, Dynamic, customer-oriented improvement of supply networks, European Journal of Operational Research 167 (2005) 413–426.
[54] Y. Borgianni, G. Cascini, F. Rotini, Evaluating the effects of poorly performed product development phases on customer satisfaction, in: Interdisciplinary Design: Proceedings of the 21st CIRP Design Conference, CIRP—The International Academy for Production Engineering, Paris, 2011, pp. 108–115.
[55] I.M. Sobol, Global sensitivity indices for nonlinear mathematical models and their Monte Carlo estimates, Mathematics and Computers in Simulation 55 (2001) 271–280.
[56] D. Nash, M. Hannah, Using Monte-Carlo simulations and Bayesian Networks to quantify and demonstrate the impact of fertiliser best management practices, Environmental Modelling & Software 26 (2011) 1079–1088.
[57] N.Ivezic,J.H.GarrettJr.,Machinelearningforsimulation-basedsupportofearly collaborativedesign,ArtificialIntelligenceforEngineeringDesign,Analysis12 (1998) 123–139.
[58] G.Büyüközkan,O.Feyzioğlu,Anewapproachbasedonsoftcomputingto accelerate theselectionofnewproductideas,ComputersinIndustry54 (2004)151–167.
[59] F.C. Yuan, Simulation–optimization mechanism for expansion strategy using real option theory, Expert Systems with Applications 36 (2009) 829–837.
[60] K.B. Salling, S. Leleur, Transport appraisal and Monte Carlo simulation by use of the CBA-DK model, Transport Policy 18 (2011) 236–245.
[61] V. Kreinovich, J. Beck, C. Ferregut, A. Sanchez, G.R. Keller, M. Averill, S.A. Starks, Monte-Carlo-type techniques for processing interval uncertainty and their potential engineering applications, Reliable Computing 13 (2007) 25–69.
[62] B. Efron, R. Tibshirani, Statistical data analysis in the computer age, Science 253 (1991) 390–395.
[63] H.J. Adèr, G.J. Mellenbergh, D.J. Hand, Advising on Research Methods: A Consultant's Companion, Johannes van Kessel Publishing, Huizen, 2008.
[64] A. Alfons, S. Kraft, M. Templ, P. Filzmoser, Simulation of close-to-reality population data for household surveys with application to EU-SILC, Statistical Methods and Applications 20 (2011) 383–407.
[65] J. Simonoff, Analyzing Categorical Data, Springer, New York, NY, 2003.
[66] D.P. Kroese, T. Taimre, Z.I. Botev, Handbook of Monte Carlo Methods, 706, John Wiley & Sons, Hoboken, NJ, 2011.
[67] C. Alexander, G.M. Cordeiro, E.M. Ortega, J.M. Sarabia, Generalized beta-generated distributions, Computational Statistics & Data Analysis 56 (2012) 1880–1897.
[68] C.A. Czembor, W.K. Morris, B.A. Wintle, P.A. Vesk, Quantifying variance components in ecological models based on expert opinion, Journal of Applied Ecology 48 (2011) 736–745.
[69] I. Greenberg, A simple approximation for the simulation of continuous random variables, Simulation 49 (1987) 32–33.
[70] D.C. Myers, A.B. Yeh, Generating correlated random variables for a simulation model, Journal of the Operational Research Society 50 (1999) 183–186.
[71] P. Emberson, R. Stafford, R.I. Davis, Techniques for the synthesis of multiprocessor tasksets, in: First International Workshop on Analysis Tools and Methodologies for Embedded and Real-time Systems (WATERS), 2010.
[72] J. Mun, Real Options Analysis: Tools and Techniques for Valuing Strategic Investments and Decisions, John Wiley and Sons Inc., Hoboken, NJ, 2006.
[73] N. Becattini, G. Cascini, F. Rotini, Correlations between the evolution of contradictions and the law of identity increase, Procedia Engineering 9 (2011) 236–250.
[74] E. Parzen, On estimation of a probability density function and mode, The Annals of Mathematical Statistics 33 (1962) 1065–1076.