Classification of performance and quality indicators in manufacturing

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Abstract: A critical aspect in operations management is to represent the firm goals properly. This is usually done by translating the organisational results and objectives in 'performance measurements'. The scientific literature shows many applications in different fields such as quality, production, logistics, marketing, etc. Nevertheless, a general theory formalising basic and application concepts is still lacking. This paper shows a classification of 'performance indicators' in manufacturing, providing a mathematical structure to the concept of 'indicator'. This approach is based on the formalism of the *Representation Theory*. All the mentioned concepts are explained and discussed through practical examples.

Keywords: indicators; metrics; performance measurement; quality indicators; performance indicators; process representation; manufacturing.

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1 Introduction

Currently, in the scientific literature, the concept of 'metric' in operations management is widely studied. Terms such as 'metric', 'performance measure' and 'performance indicator' are usually used as synonyms for quality indicators (Evans, 2004; Gosselin, 2005; Melnyk et al., 2004, 2005; Sousa et al., 2005; Tangen, 2004).

Metrics are utilised for a variety of purposes. A few authors suggested many performance measures for the analysis and the design of manufacturing systems (Tapinos et al., 2005). The most commonly used are throughput, product defectiveness, product quality, material flow smoothness, due date attainment, output variability and flexibility (Galbraith and Greene, 1995; Galbraith et al., 1991). Metrics such as market share, sales increase, margins and customer satisfaction surveys help firms to individuate their market position and to plan for their future (Hauser and Katz, 1998).

Logistics and manufacturing functions are two of the first factory functions to be concerned with the use of performance indicators. Caplice and Sheffi (1994) suggested a set of evaluation criteria for individual logistics performance metrics as well as a preliminary taxonomy of the existing ones.

The concept of a performance measure/indicator is not a new one in Quality Management (Juran, 1988; Lalla et al., 2003). In recent years, there is a widespread interest in this area. This phenomenon is mostly related to the new edition of ISO 9000 standards, which emphasise the concepts of 'Quality Measurement' and 'Customer Satisfaction Measurement' (ISO 9000:2000; ISO 9001:2000).

Metrics are also used in various sectors vary from business domain. Indicators are used for determining the final score of athletes (or teams) in sport competitions; for example, think of decathlon score or artistic gymnastics or Formula 1 car racings and so on (Lins et al., 2003).

In recent years, a few literature studies focused on the development, implementation, management, use and effects of metrics in the operations management area or in the supply chain (Babu et al., 2003; Bourne et al., 2003; Neely et al., 1995). Many authors tried to address their studies towards the definition of basic rules to assist practitioners in metrics definition (Denton, 2005; Kaplan and Norton, 2003; Lohman et al., 2004; Rathore and Andrabi, 2004; Robson, 2005).

A few authors assert that every metric, whether it is used explicitly to influence behaviour, to evaluate future strategies, or simply to take stocks, will affect actions and decisions. This is empirically demonstrated by a series of 'on-field' studies (Evans, 2004; Hauser and Katz, 1998; Holloway, 2001; Tapinos et al., 2005). The concept is quite intuitive. If in a firm a few particular aspects are observed, for example, absenteeism, telephone charges and employee productivity, then managers (and the whole organisation) will pay more attention to these aspects, rather than others. This mechanism follows a rapid escalation, which now and then drives the firm to 'become what it measures' (Hauser and Katz, 1998). Metrics gain the control of the enterprise with the risk that, if they lead to counter-productive decisions and actions, the result would be deleterious.

The advantages and disadvantages of performance measurement are emphasised by Melnyk et al. (2004). Having the aim of giving a few initial theoretical grounding for the metrics research topic, those authors provide a general definition for metric, and a first classification based on their 'focus' (quality, manufacturing, operational, financial, etc.) and their 'tense' (i.e. how the metrics are intended to be used: for outcome analysis, prediction, comparison among competitors, etc.).

If there is no doubt about the metrics importance, a general theory, which is able to model metrics from a formal point of view, is still lacking. In the literature, a few preliminary attempts to provide a mathematical structure to the concept of an indicator have been presented (Franceschini et al., 2005b; Melnyk et al., 2004).

The aim of this paper is to classify the different categories of indicators, providing formal definitions and descriptions of them. Concepts of an *indicator* and a *set* of indicators are discussed in detail. Furthermore, indicators are classified as *subjective*, *objective*, *basic* and *derived* using the typical formalism of the Representation Theory (Finkelstein, 2003).

2 Theoretical considerations

To understand the definition of an indicator, the concept of measurement must be reminded. According to the Representation Theory of Measurement, a measurement is a 'mapping' from an empirical relational system (the 'real world') onto a representational relational system (usually, a numerical system) (Roberts, 1979). The definition of measurement is strictly related to the notion of *representation-target*. A representation-target is the operation aimed to make an empirical system, or part of it, 'tangible' to perform evaluations, make comparisons, formulate predictions, take decisions, etc. In a given process, one or more different representation-targets can be defined. For example, if a system is the 'logistic process' of a company, the two possible representation-targets are 'the efficiency of suppliers' and the 'management of the manufactured goods inventory'. Usually, different *dimensions* of a process can be observed. Each dimension corresponds to a system aspect to represent.

Given a representation-target, we define A as the set of all the possible empirical manifestations of a process, $A = \{a_1,\ldots, a_i,\ldots\}$ and R as the family of empirical relations (i.e. equivalence, order, composition, etc.) among the elements of A, $R = \{R_1,\ldots,R_m\}$, then the empirical system E can be defined as $E = \langle A, R\rangle$.

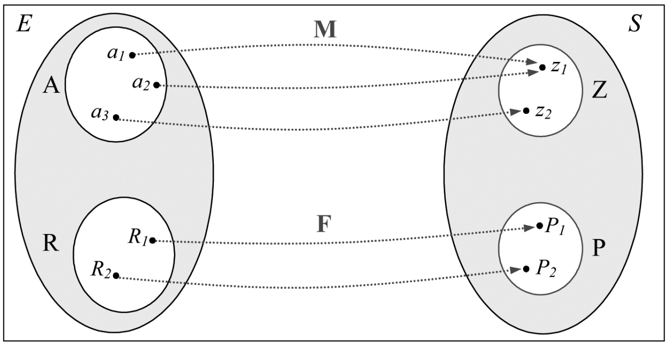
Analogously, if Z is a set of symbols $Z = \{z_1,\ldots,z_i,\ldots\}$ and P is a family of relations among the elements of Z, $P = \{P_1,\ldots,P_m\}$, then the symbolic system S can be defined as $S = \langle Z, P\rangle$.

Generally, a measurement is an objective empirical function, which maps A onto Z and R onto P (Finkelstein, 2003). Therefore, the two mappings are defined as follows (see Figure 1):

$M: A \rightarrow Z$ homomorphism (this mapping is not one-to-one). Separate but not distinguishable manifestations, according to the representation-target, are mapped onto the same symbol.

$F: R \rightarrow P$ isomorphism (the mapping between the empirical and the symbolic relations is one-to-one).

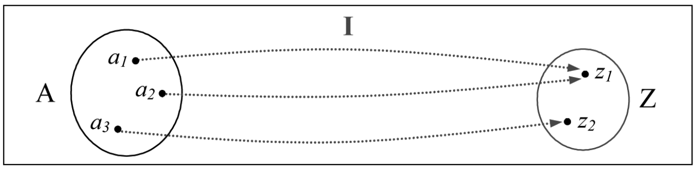
Figure 1 Schematic representation of the concept of measurement



Note: It should be noted that the homomorphical mapping *M* is not one-to-one. Separate but indistinguishable manifestations, according to the representation-target, are mapped onto the same symbol. In this figure, two indistinguishable manifestations – a_1 e a_2 – are mapped onto the same symbol z_1.

According to a representation-target and referring to the Representation Theory, an indicator '*I*' can be considered as a homomorphical mapping from the manifestations of an empirical system onto the manifestations of a symbolic system. In other words, an indicator operationalises the concept of representation-target. However, the isomorphical mapping between the empirical and symbolic relations, unlike measurement, is not required (see Figure 2).

Figure 2 Schematic representation of the concept of indicator from the *Representation Theory* point of view



Note: An indicator (*I*) homomorphically maps a set of real empirical manifestations (*A*) onto a set of symbolic manifestations (*Z*). In formal terms $I: A \rightarrow Z$.

As a result, the concept of an indicator includes the concept of measurement, but vice versa is not true. On the basis of the *Representation Theory*, measurements can be considered as a subset of indicators (Franceschini et al., 2005b).

We note that, for measurements alone, relationships among the empirical manifestations (equivalence, order, composition, etc.) are isomorphically linked to the relationships among the symbolic manifestations. In other words, the relations among symbolic manifestations reproduce the relations among the real manifestations. This is not true with indicators.

Consider, for example, the representation-target 'inventory of the machines of a manufacturing company', implemented by the indicator 'name of the machine'. This indicator associates each machine (empirical manifestation) to the corresponding name (symbolic manifestation). Naturally, there is no order relation among the empirical manifestations (machines), which corresponds to the alphabetical ordering relation among the symbolic manifestations (names of the machines). So, the 'name of the machine' is only an indicator, not a measurement. The order relation among the symbolic manifestations does not correspond to the any existing relation among the real manifestations.

Furthermore, a complex representation-target can be split up into different dimensions. Each dimension can be described using one or more indicators. Consequently, to represent and to operationalise a complex representation-target, we may use a *set* of indicators (each indicator referring to a specific dimension):

$$S = \{I_i\}$$

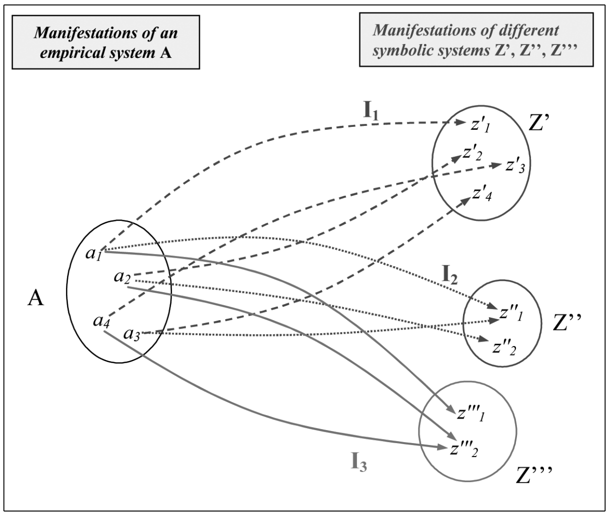
where $i = 1, 2, \ldots, n$ and $n \in N$.

2.1 The condition of 'uniqueness' of representation

Given a representation-target, we cannot conceive a tool that algorithmically generates a set of associated indicators. Such a tool should generate a chain of operations normally carried out by a 'modeller', such as: the definition for a set of indicators, which are assumed to be proper; test and verification; correction of the model; further verification (Roy and Bouyssou, 1993).

It can be shown that, given a specific representation-target, the related indicator (or indicators) is not univocally defined (see Figure 3) (Franceschini et al., 2005b). The most evident consequence is that we may have at least two different ways to describe the same representation-target. In addition, given two sets of indicators for a specified representation-target, the existence of mathematical transformations linking them is not always guaranteed. This entails that similar representation-targets may not be comparable if represented by different indicators.

Figure 3 Schematic illustration of the condition of *non-uniqueness* of representation



Note: *Non-uniqueness*: the same representation-target is operationalised by three different indicators (I_1, I_2, I_3). A few empirical manifestations are not distinguishable, following one indicator, but can be distinguished by another (e.g. the manifestations a_2 and a_4 are not distinguished by the indicator I_3, but they are by said I_1).

As different possible sets of indicators may be found, to represent the same representation-target, some questions may arise: 'What is the best way of selecting?' and 'Are we sure that the representation is complete?'. In this paper, we present a taxonomy of indicators and discuss their main properties.

2.2 Local and global performance

As already explained, a complex representation-target can be split up into different dimensions. For each dimension one or more indicators can be used. As a result, a complex representation-target can be operationalised by a set of indicators.

Generally, for a system modelled by indicators we may define two kinds of performances.

Definition 1: *Local performance is the performance of a process, from the point of view of a single indicator (single dimension of the representation-target).*

Definition 2: *Global performance is a more general performance, which considers more dimensions of the representation-target. It is based on a full of local performances. If the process studied is complex, local performances cannot always be summarised by single information. Frequently, the criteria to synthesise the local performances can be questionable and are based on 'dangerous' simplifications (Franceschini et al., 2005c).*

3 Indicators classification

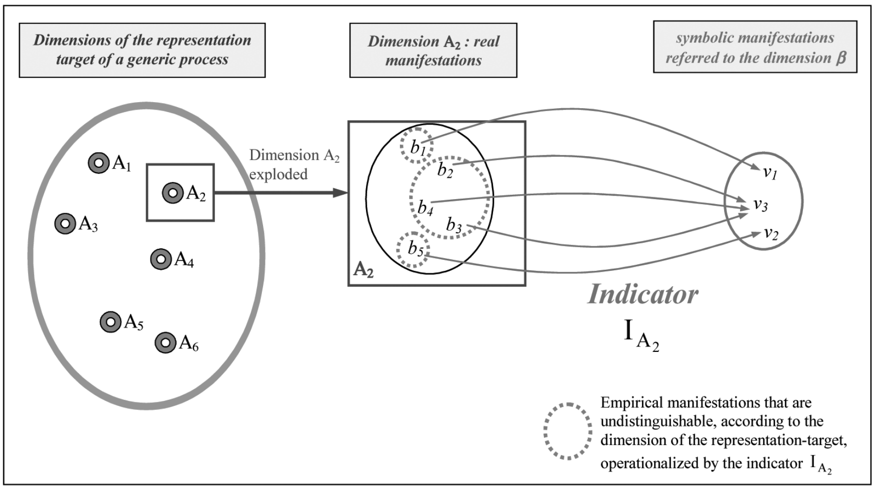
A complex process can be represented by many indicators. Even if the information available is much, the number of indicators must not be too large, to avoid the complication in the representation of the system (Melnyk et al., 2004). As a result, two questions may arise: 'How to know the number of indicators needed?' and 'How to select and handle the different indicators?' Before dealing with these problems, it is reasonable to classify the main typologies of indicators and describe their peculiarities. For this reason, the existing literature has been examined.

While several indicators are used and described, there are relatively a few studies that focus on a general classification of them. This paper proposes a general classification, without entering into the specific fields of application. In the following sections, the fundamental categories of indicators (*subjective*, *objective*, *basic* and *derived* indicators) are examined and discussed.

3.1 Set of indicators

In the representation of a generic process, selected indicators make up a set or a family. Generally, each indicator represents a dimension, which is a distinguishing aspect of the process studied. The concept of a set of indicators is schematically represented in Figure 4.

Figure 4 Schematic representation of the concept of set of indicators



Note: Each of the schematised dimensions of the representation-target (A_1, A_2, A_3, A_4,…) is represented by one or more indicators. All the indicators make up a set or a family. Indicator I_{A_2} represents the dimension A_2.

Additionally, in some specific situations, it is possible to define an aggregated indicator that summarises the performance of the set of indicators.

3.2 Objective and subjective indicators

Having identified the empirical and the symbolic systems of the process studied (with the respective manifestations and relations), indicators are classified into two main categories: *objective* and *subjective*.

Definition 3: *Objective indicators objectively associate the manifestations of the empirical system to the manifestations of the symbolic system. The mapping does not depend on the subject performing it.*

Consider, for example, the indicator: ‘number of goods produced in a plant during a defined period of time’. The empirical manifestation (production of the plant) can objectively be connected to the symbolic manifestation (number of products). Different subjects (or automatic devices even) determine the same final number, by counting the units produced.

Definition 4: *Subjective indicators map subjectively empirical manifestations onto symbolic manifestations, on the basis of subjective perceptions or opinions. The result is that distinct individuals can map the same empirical manifestation onto different symbolic manifestations.*

For example, indicators such as ‘the customer satisfaction for a specific product’ or ‘the personal opinion on the style of a car’ are usually confined to personal perceptions or opinions. In this case, empirical manifestations are mapped onto symbolic manifestations, depending on the subjective evaluation scale for everyone.

3.3 Basic and derived indicators

Indicators can also be classified into two more categories: *basic* and *derived*.

Definition 5: *Basic indicators are obtained as a direct observation of an empirical process (e.g. the 'number of defectives on a production line' or 'the cycle time of a manufacturing process').*

Definition 6: *Derived (or aggregated) indicators are obtained combining one or more indicators (basic or other derived). They represent the aggregation or the synthesis of several indicators.*

An example of a derived indicator in manufacturing processes is I_3: 'percentage of defectives on a production line', given by

$$I_3 = \frac{I_1}{I_2}$$

where I_1 is the number of defective units, I_2 is the total number of produced units and I_3 is the derived indicator, which aggregates the indicators I_1 and I_2.

Derived indicators are used in many application fields. An example of two different aggregated indicators for a unique representation-target is as follows. An environmental protection organisation asks two local agencies – A and B – to estimate the pollution level of the exhausted emissions that come out of a motor vehicle, on the basis of four pollutants' concentrations (measured as μg/m^3): $I_{\mathrm{NO_X}}$ is the concentration of nitrogen oxides NO_X, I_{HC} is the concentration of unburnt hydrocarbons, I_{CO} is the concentration of carbon monoxide CO and $I_{\mathrm{PM_{10}}}$ is the concentration of particulate matter (PM_{10}).

Agency A defines four corresponding derived indicators ($I'_{\mathrm{NO_X}}$, I'_{HC}, I'_{CO}, $I'_{\mathrm{PM_{10}}}$), which map each concentration into a three-level scale (one harmless; two acceptable and three unacceptable for the human health). Then, it defines an additional derived indicator, $I^{\mathrm{A}}_{\mathrm{TOT}}$, which aggregates the previous ones, assuming the maximum value of them (see Figure 5) (Franceschini et al., 2005a):

$$I^{\mathrm{A}}_{\mathrm{TOT}} = \max\left(I'_{\mathrm{NO_X}}, I'_{\mathrm{HC}}, I'_{\mathrm{CO}}, I'_{\mathrm{PM_{10}}}\right)$$

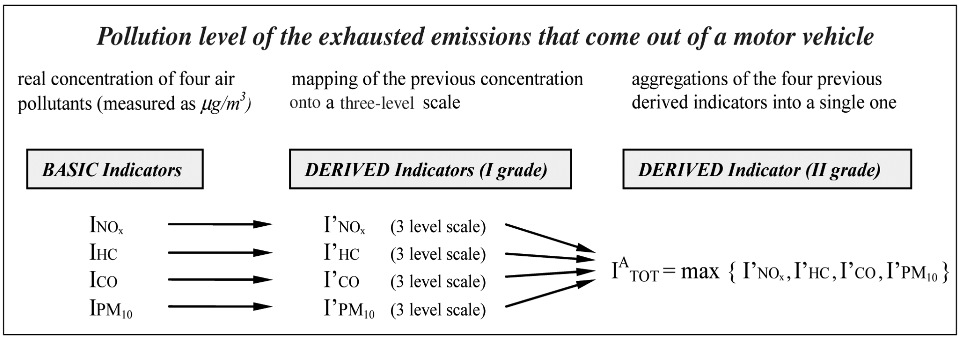
This final mapping represents the general effect of the air pollutants on the human health.

Agency B maps the concentration of each pollutant using a five-level scale and defines four corresponding derived indicators ($I''_{\mathrm{NO_X}}$, I''_{HC}, I''_{CO}, $I''_{\mathrm{PM_{10}}}$). Then, it defines an additional derived indicator, $I^{\mathrm{B}}_{\mathrm{TOT}}$, which aggregates the previous ones assuming the average value of them (Franceschini et al., 2005a):

$$I^{\mathrm{B}}_{\mathrm{TOT}} = \frac{(I''_{\mathrm{NO_X}} + I''_{\mathrm{HC}} + I''_{\mathrm{CO}} + I''_{\mathrm{PM_{10}}})}{4}$$

The two considered aggregation criteria differently model the effects of the polluting exhaust emissions on the human health. Furthermore, it is interesting to note that there is no mathematical transformation connecting the values of the two aggregated indicators ($I^{\mathrm{A}}_{\mathrm{TOT}}$ and $I^{\mathrm{B}}_{\mathrm{TOT}}$) by themselves.

Figure 5 Basic and derived indicators implemented by Agency A

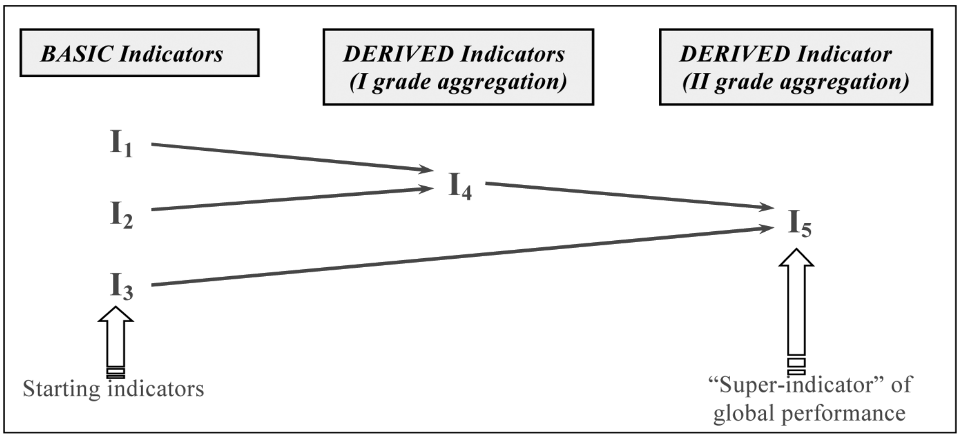


Note: Each of the first-grade derived indicators (I'_{NO_X}, I'_{HC}, I'_{CO}, $I'_{PM_{10}}$) provides the information of a single indicator (I_{NO_X}, I_{HC}, I_{CO}, $I_{PM_{10}}$, respectively). The second-grade derived indicator (I^{A}_{TOT}) aggregates the four previous indicators.

This example shows that, given a representation-target, the same indicators can be aggregated in different ways. Each aggregation is an action of responsibility that can lead to 'wrong' results, if improperly carried out (Roy and Bouyssou, 1993). Additionally, the example shows that some derived indicators may be aggregated into a higher-level derived indicator.

By extending this concept, we can imagine to define a 'super-indicator', synthesising all the aspects of the process investigated. After defining the basic indicator, the real challenge is to collect them together, 'in order to set up a model, which provides general information on the process global performance' (Melnyk et al., 2004). The global performance of a system can be seen as a derived 'super-indicator' that summarises all its most important dimensions (see Figure 6).

Figure 6 Representation of the concept of *global performance*

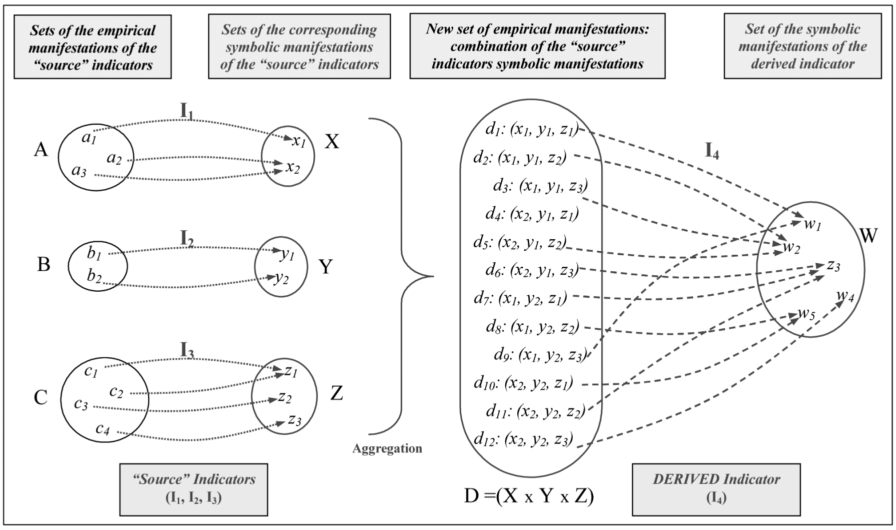


Note: All the starting basic indicators are aggregated into one (global) derived indicator, synthesising all the information.

3.4 The representational approach for derived indicators

The concept of derived indicator can also be interpreted according to the Representation Theory. The empirical system of a derived indicator is given by the combination of the symbolic manifestations of the aggregated indicators. The derived indicator omomorphically maps this combination into further symbolic manifestations (see Figure 7).

Figure 7 Schematic representation of a derived indicator, according to the *Representation Theory*



Note: The 'source' indicators – I_1, I_2, I_3 – can either be basic or derived. The composition of their symbolic manifestations is the input for the derived indicator (I_4).

The aggregation of several indicators into one derived indicator are not always simply achievable, especially if the information to synthesise is assorted.

Let us consider, for example, the case of a manager of a manufacturing company who decides to reengineer a particular product to improve the quality and reduce possible failures. Firstly, he searches for the most significant defects in the product and then he tries to sort them in order of priority. Each possible failure is associated with two indicators: the index of the estimated gravity (g) and the frequency (f).

These indicators are aggregated into a single derived indicator called Priority Index (PI).

$$PI = f \times g$$

where PI is the priority index (aggregated performance), f is the failure frequency (local performance) and g is the estimated gravity index (local performance).

The detected failures are sorted by PI values in a descending order.

This method seems to be easy, but it may result to contradictory conclusions. For instance, the order of priority may change unexpectedly, depending on the encoding of the index of estimated gravity (g). Let us analyse the following example. The index of gravity is evaluated by using two scales: α and β. Either of them is subdivided into four ordered levels (*L1, L2, L3, L4*) encoded in two different ways (see Table 1).

Table 1 Encoding of the index of estimated gravity (g) by two different scales

Reference levels of the index of estimated gravity (g)	*L1*	*L2*	*L3*	*L4*
Scale α	1	2	3	4
Scale β	4	5	6	7

Table 2 gives the derived indicator *PI*, obtained by using the two different scales to evaluate the estimated gravity index g.

Table 2 Comparison between two different methods of encoding the gravity index g

	F	*G*			*PI (=f × g)*	
		Level	*Scale* α	*Scale* β	*Scale* α	*Scale* β
FAILURE n.1	0.5	L2	2	5	$0.5 \times 2 = 1$	$0.5 \times 5 = 2.5$
FAILURE n.2	0.3	L4	4	7	$0.3 \times 4 = 1.2$	$0.3 \times 7 = 2.1$

In this case, under the same conditions, the ordering of two generic defects (FAILURE n.1 and FAILURE n.2) changes depending on the scale of g. The indexes of estimated gravity (empiric manifestations) are encoded in integers (symbolic manifestation). This operation introduces new relations among the symbolic manifestations, which empirically do not exist. For example, as specified by encoding α the '4' value is four times the '1' value, … (ratio properties). In the origin, the only relation among empirical manifestations is the order relationship ($L4 > L3 > L2 > L1$).

4 A brief outline of the indicators properties

The classification of indicators is a starting point to identify the properties that they should have, to properly represent a generic process. We examined the existing literature, which are describing lots of properties and definitions often unstructured and presented in different ways by authors. Researchers have identified several criteria to consider when selecting individual performance indicators for manufacturing as well as for business functions in general. Table 3 gives the classification suggested by Caplice and Sheffi (1994, 1995). This figure summarises the main properties of indicators, presented in the literature by a few authors.

As given in Table 3, the organisation of the properties is quite variegated, without an organic reference structure. A structured taxonomy of indicator properties is still lacking. Table 4 proposes a new categorisation that will be discussed in Section 4.1.

Table 3 Comparison of different individual properties of indicators (Caplice and Sheffi, 1994)

Requirements of the indicators	*Properties defined by different authors*						
	Mock and Grove (1979)	*Edwards (1986)*	*Juran (1988)*	*NEVEM Workgroup (1989)*	*Kearney (1991)*	*Mentzer and Konrad (1988)*	*Caplice and Sheffi (1994)*
Does the indicator capture actual events and activities accurately?	Valid	Reliable		Valid	Valid		Validity
Does the indicator control for inherent errors in data collection? Is it repeatable?	Reliable					Measurement error	Robustness
Is the indicator using a correct type of numerical scale for the values?	Scale type						Behaviourally sound
Is the indicator still accurate if the scale is transformed to another type?	Meaningful						Behaviourally sound
Do the benefits outweigh the costs of using the indicator?	Economical worth	Cost/benefit	Economical	Profitability	Cost-effective		Economy
Will the indicator create incentives for improper or counterintuitive acts?	Behavioural implications					Human behaviour	Behaviourally sound
Does the indicator use data currently available from the existing ones?		Available					Compatibility
Is the indicator compatible with the existing information system and flow?			Compatible to existing systems	Compatible	Compatible		Compatibility
Does the indicator provide a guide for an action to be taken?		Useful		Utility	Usefulness		Usefulness
Can the indicator be compared across time, location and organisations?		Consistent	Apply broadly	Comparable	Comparable	Comparable	Robustness
Is the indicator viewed and interpreted similarly by all affected parties?			Uniform interpretation and agreed upon basis				Robustness
Is the indicator simple and straightforward enough to be easily understood by those affected?			Understandable				Usefulness
Does the indicator include and measure all of the important components and aspects of the system?				Covering potential	Coverage	Under-determination	Integration
Does the indicator promote coordination across various players in the supply chain?							Integration
Is the indicator of a sufficient level of detail and precision for a decision maker?				Accurate	Complete		Level of detail

Table 4 Main properties identified for *single* indicator

Category	*Properties*	*Short description*
General properties	Consistency with the representation-target	The indicator should properly operationalise the representation-target
	Level of detail	The indicator should not provide more than the required information
	Economic impact	Every indicator should be defined considering the expenses to collect the needed information
	Simplicity of use	The indicator should be easy to be understood and to be used

Note that the general properties are useful to test all sorts of indicators, basic or derived. In Section 4.1, we focus on these specific properties.

4.1 General properties

In this section, four important properties of single indicator are described as follows.

4.1.1 Consistency with the representation-target

According to the definition, each indicator should properly operationalise a representation-target. An indicator omomorphically maps all the empirical real manifestations onto corresponding symbolic manifestations. This mapping is a preliminary operation that should be fully controlled before using the indicator (Denton, 2005; Rathore and Andrabi, 2004).

This concept is well expressed in the following example. Referring to the representation-target '*sales of a manufacturing company*', the indicator (I_s) – 'total number of goods sold during the whole year' – is defined to represent the process. Later, company managers realise that it would be more useful to provide quarterly information on sales to estimate the seasonal trend. Consequently, a new indicator (I'_s), representing the total number of goods sold quarterly, replaces the first one (I_s). According to the representation-target, the second indicator is more accurate than the first one. It comprehends a few important empirical manifestations (quarterly information on sales) that are ignored by I_s.

4.1.2 Level of detail

An indicator with an excessive level of detail often provides more information than required. It can complicate the analysis and be economically wasteful. In addition, if an indicator maps two empirical manifestations, which should not be distinguished according to the representation-target, onto different symbolic manifestations, then the level of detail could be higher.

In formal terms:

IF $I_i(1) = z_1$ *and* $I_i(2) = z_2$, *being* $z_1 \neq z_2$

AND IF *the empirical manifestations of the states 1 and 2 should not be distinguished, according to the representation-target;*

THEN I_i *has an excessive level of detail.*

where I_i is the indicator investigated, z_1, z_2 are the different symbolic manifestations and 1, 2 are the states of the system.

Consider, for example, the case of a manufacturing company producing metal screws. They use the following representation-target: the 'daily production rate of screws'. If the corresponding indicator (I) represents the 'daily weight of screws' with an accuracy of ±1 g – being reasonable ±10 kg – then it has an excessive level of detail.

In other words, if the mapping is more accurate than required, two different empirical manifestations, which are indifferent according to the representation-target, can be unreasonably distinguished (i.e. two different daily productions of screws: $I(1) = 652.321$ kg/day and $I(2) = 650.000$ kg/day).

On the other hand, an indicator's level of detail could be lower than required. In such a situation, important information on the process studied could be lost. In addition, if an indicator maps two empirical manifestations, which should be distinguished according to the representation-target, onto the same symbolic manifestation, then the level of detail could be insufficient.

In formal terms:

IF $I_i(1) = I_i(2)$

AND IF *the empirical manifestations of the states 1 and 2 should be distinguished, according to the representation-target;*

THEN I_i *has an insufficient level of detail.*

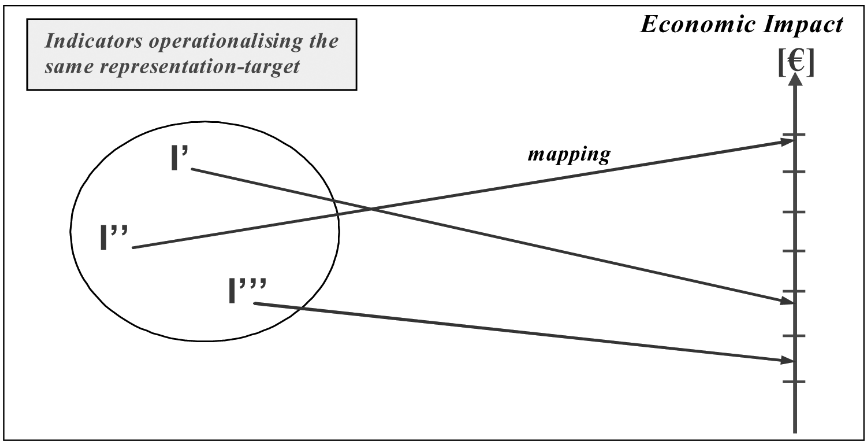
where I_i is the indicator studied and 1, 2 are the states of the system.

4.1.3 Economical impact

The economical impact of an indicator strictly depends on the nature of the system studied. This impact can be studied in relative terms, by comparing two different indicators operationalising with the same representation-target. Generally, we cannot assert whether the indicator I' is economical in absolute terms, but we can only assert that the indicator I' is more (or less) economical than the indicator I''.

To study and compare the economical impact of different indicators, we have to set up a mapping on the basis of their economical effects. Such a mapping cannot be defined in only one way. It depends on the nature of the process studied. For instance, one of the most common mappings is based on the expenses to collect information (see Figure 8).

Figure 8 Mapping performed to estimate the economic impact of three indicators



Note: For each indicator the mapping can be performed by considering the expenses to collect the necessary information.

Consider, for example, dimensional measurements. To check hole diameters two alternatives can be pursued, by giving two different indicators: I_1 is diameter measurement, taken by using an accurate calliper. To check each hole, the time taken is 9 sec. I_2 is the result of a manual testing, using a calibrated shaft that has the minimum reasonable diameter. The time needed is 3 sec.

In case the cost for the measurements is directly proportional to the time spent, then the indicator I_2 can be considered three times more economical than the indicator I_1.

4.1.4 Simplicity of use

This property, as the previous one, can be studied in relative terms, by comparing two different indicators operationalising the same representation-target. Analogously, to compare alternative indicators, we have to set up a mapping on the basis of their simplicity of use. The mapping should be 'multidimensional' to consider all the following aspects:

- the indicators should not be too complex, to avoid overloading the employees with work
- the indicators should be easily understood and effectively used
- the indicators should have a clear distinct feature to be largely accepted by the employees and
- the information that the indicators need should be easy to be found.

5 Conclusions

This paper provides an exploratory classification to discriminate the main typologies of indicators. The classification is performed at a general level, without entering the specific fields of application. The concepts of *indicator*, *set* of indicators, *dimension*, *basic* and *derived* indicators, *subjective* and *objective* indicators, are individually analysed, using a symbolic/mathematical – and not exclusively descriptive – approach, drawn from the *Representation Theory*.

We particularly focused on the derived indicators. They obtained on aggregating a few indicators, and they may synthesise many different aspects of the system observed.

A future work will consider an in-depth analysis of the indicator' set and derived indicator' properties. The classification of indicators – given in this paper – will be useful for further study.

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