Properties of performance indicators in operations management

A reference framework

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Abstract

Purpose – The purpose of this paper is to attempt to provide a reference framework for the major properties of performance indicators, using the formalism of the Representation Theory.

Design/methodology/approach – Performance indicators shown are commonly used in many different areas of operations management in order to analyse process evolution. However, in practical applications many questions arise: "How many indicators should be used for representing a given process?", "Is there an optimal set?", "How to check whether the indicators used suitably represent the system investigated?", etc. In the literature these questions have been addressed in relation to a number of different application fields. This has led to a maze of classifications and properties, which may create confusion in both the academic and the practitioner communities. In a previous work, the paper carried out an analysis of the existing literature, examining and comparing different approaches. This present work identifies and analyses the major properties which effective indicators should exhibit, and suggests an operational methodology to choose the "best" set of indicators.

Findings – The findings in this paper produce a detailed analysis of the properties of indicators and establish a schematic methodology facilitating the selection and verification of indicators. To make the process clearer, properties are explained by the use of practical examples.

Research limitations/implications – Indicators are utilized in many different contexts for a variety of purposes (for example, logistics, business management, manufacturing, sports competitions, etc.). The paper provides a general analysis of the most important properties of indicators, without entering into specific application contexts.

Practical implications – The paper proposes an operational methodology to support the selection and testing of the best indicators for a given process. This methodology may also be used for integrating other existing approaches.

Originality/value – Properties of indicators are examined from a mathematical/symbolic point of view, using the formalism of the Representation Theory.

Keywords Quality indicators, Operations management

Paper type Research paper

Introduction

Indicators of performance make it possible to model and to analyse the condition of a generic process. There are many kinds of indicators, commonly used in many different fields. Indicators should represent all the different dimensions of a process, in order to support evaluations and decisions (Hauser and Katz, 1998).

To define indicators, it is necessary to identify the distinctive aspects of the system investigated. The success of this operation usually depends on the experience and the imagination of the one performing it (Melnyk *et al.*, 2004).

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In the literature there are many methods helping to define and analyze indicators. The most diffused are the Balanced Scorecard, the Critical Few method, the Performance Dashboards, the EFQM award (Kaplan and Norton, 1992; PBM-SIG (Performance Based Management Special Interest Group), 2001; EFQM, 2007). The sheer number of approaches can cause confusion in practical applications. The aim of this paper is to analyse the major properties that indicators should satisfy in order to suitably represent a generic process.

Two previous papers suggested some basic ideas for a general theory about performance indicators and their properties, and prepared the basis for this work (Franceschini *et al.*, 2006). Particular attention was focused on the condition of "uniqueness of the representation". In general, it can be shown that indicators do not match this condition (Franceschini *et al.*, 2006).

The main aim of the present paper is to propose a reference framework of the major properties of indicators. Special attention is given to the properties of the set of indicators and derived indicators. The analysis is carried out using the formalism of the Representation Theory (Finkelstein, 2003; Roberts, 1979). The paper finally illustrates an operational method to identify and test the most proper indicators for a given process.

Terminology background

Definition of indicator

In the current scientific literature terms such as "metric", "performance measure" and "performance indicator" are usually considered as synonyms (Melnyk *et al.*, 2004). We give a definition of indicator founded on the Representation Theory formalism. This definition 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" in order to perform evaluations, make comparisons, formulate predictions, take decisions, etc.

Given a process, one or more different representation-targets can be defined. For example, if the empirical system is the "logistic process" of a company, two possible representation-targets are "the classification of suppliers" and the "management of the manufactured goods inventory". Usually, a representation-target can embrace different dimensions of a process. Each dimension corresponds to a system aspect to represent. The goal of indicators is to operationalize the concept of representation-target.

Given a representation-target, we define A as the set of all the possible empirical manifestations of a dimension of a process to be represented: $A = \{a_1, \ldots, a_i, \ldots\}$, and Z as a the set of the corresponding symbolic manifestations: $Z = \{z_1, \ldots, z_i, \ldots\}$ (Finkelstein, 2003).

In general an indicator (I) is an application that – according to the representation-target – homomorphically maps the empirical manifestations into corresponding symbolic manifestations (see Figure 1) (Franceschini *et al.*, 2006).

It should be noted that the mapping of (I) is not one-to-one. Separate but not distinguishable manifestations, according to the representation-target, are mapped onto the same symbol. In Figure 1, manifestations a_1ea_2 are considered indistinguishable and therefore they are mapped into the same symbol z_1.

In general, for indicators, relationships among the empirical manifestations (equivalence, order, composition, etc.) are not required to be linked to the relationships among the symbolic manifestations. More precisely, the isomorphical mapping between the empirical and symbolic relations, which is basilar in the definition of the concept of measurement, is not required (Finkelstein, 2003; Franceschini *et al.*, 2006).

The condition of "uniqueness"

It can be shown that, given a specific representation-target, the related indicator (or indicators) is not univocally defined (Franceschini *et al.*, 2006). The most evident consequence is that we may have more than one way to describe the same representation-target. Since different possible sets of indicators may be found, in order to represent the same representation-target, some questions arise: "what is the best way of selecting them?"; "when are we sure that the representation is exhaustive?" This paper will try to answer these questions.

Indicators classification

A brief classification of the main typologies of indicators is reported hereafter.

Indicators and sets of indicators

A complex representation-target can cover different dimensions. Each one represents a specific aspect of the process. So, a complex representation-target can be operationalized using a set of indicators. In some situations, it is possible to define an aggregated indicator, which synthesises the performance of the set of indicators. This will be better explained later.

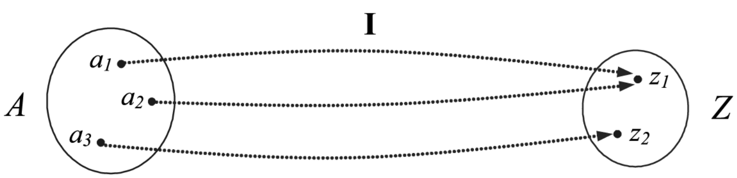
Objective and subjective indicators

Indicators can be classified in two main categories: objective and subjective.

Objective indicators objectively link empirical manifestations to symbolic manifestations. The mapping does not depend on the subject who performs it.

Subjective indicators subjectively map empirical manifestations into symbolic manifestations, depending on subjective perceptions or personal opinions. Therefore, different people can map the same empirical manifestation into different symbolic manifestations.

Subjective indicators are essential to acquire information on personal attitudes, opinions, and perceptions (Narayana, 1977).



Notes: An indicator (I) homomorphically maps a set of real empirical manifestations (A) into a set of symbolic manifestations (Z). In formal terms I: A→Z

Figure 1. Schematic representation of the concept of indicator from the Representation Theory point of view

Basic and derived indicators

Basic indicators are obtained from a direct observation of an empirical system (for example the "number of defectives on a production line", or "the cycle time of a manufacturing process").

Derived (or aggregated) indicators are obtained combining the information of one or more "sub-indicators" (basic or other derived) which are aggregated and synthesised.

Given a representation-target, the same set of 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). The aggregation of several indicators into a derived indicator is not always easily achievable, especially when the information to synthesise is assorted.

State of a process

Generally, complex processes can be structured according to different representation dimensions, for each of those it is possible to define (at least) one indicator. A generic process may lie in different conditions/states. The state of a process is the set of symbolic manifestations assumed by the indicators representing a specific process condition. This concept is schematically illustrated in Figure 2.

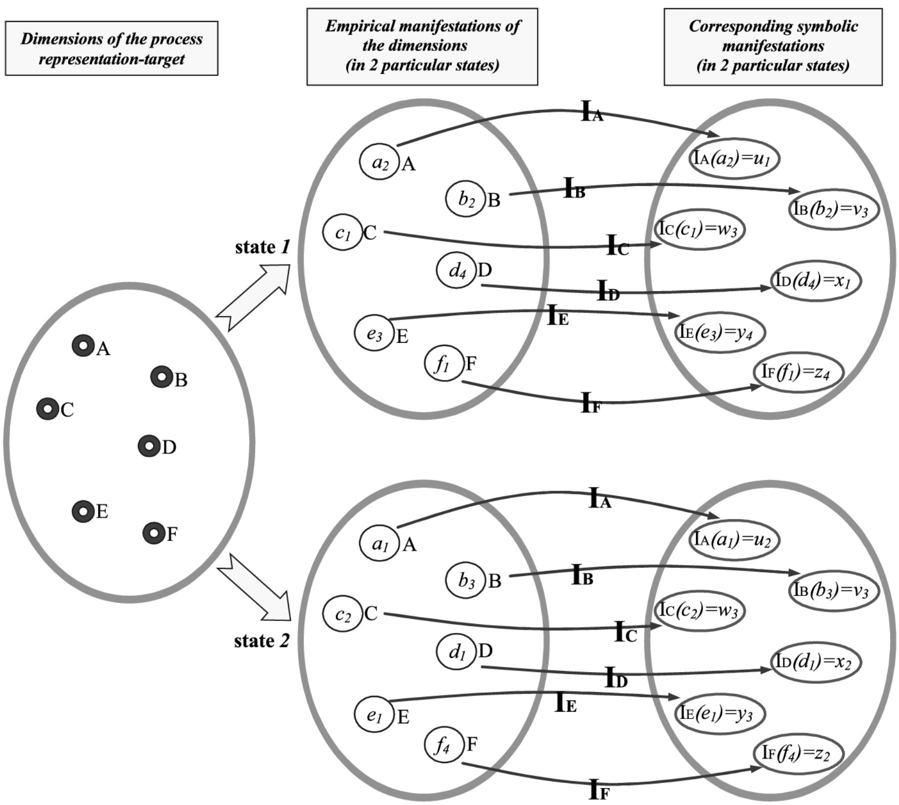


Figure 2.
Schematic representation of the concept of "state of a process". Each dimension maps the empirical manifestations into corresponding symbolic manifestations

Let us consider, for example, three indicators representing a company's sales:

(1) I_A: number of products daily sold (units).

(2) I_B: daily turnover (€).

(3) I_C: daily takings (not including the credit given) (€).

Two possible "states of the process" are:

(1) i-st day: $I_A(i) = 203$ units, $I_B(i) = 820$ €, $I_C(i) = 600$ €.

(2) j-nd day: $I_A(j) = 178$ units, $I_B(j) = 680$ €, $I_C(j) = 546$ €.

Each state is a "snapshot" of the process condition in a particular day.

Formal properties of indicators in literature

We have analyzed the existing literature with the purpose of finding the major properties that indicators should satisfy for a suitable process representation. Generally, the organization of properties is quite complex, without an organic reference structure, just referring to a specific application context (Caplice and Sheffi, 1994, 1995). Properties proposed in literature are often described without a formal mathematical approach (Artley and Stroh, 2001; Melnyk *et al.*, 2004). Furthermore, there is a lack of an organic analysis aimed at providing a general classification and rationalization of indicators properties. Many papers treat the argument from a focused point of view, stressing the aspects, which meet the major interest for a specific field of application (Brown, 1996; Evans, 2004). The result is that we have a great deal of properties referring to some aspects (efficiency, efficacy, economy, etc.), and dearth for others (uniqueness, monotony, compensation, etc.). This maze of classifications and properties may create confusion both in the scientists and in the practitioner's communities (Perrin, 1998; Melnyk *et al.*, 2004).

In the next sections, we present a taxonomy of indicator properties. They are classified into four groups: properties of derived indicators, properties of sets of indicators, general and accessory properties. These properties can represent a useful tool to select and evaluate performance indicators in different contexts.

Table I reports a synthesis of this approach. It can be reasonably assumed that a large part of the properties found in the literature, presented by different authors, can be incorporated in this scheme of classification (Kaydos, 1991, 1999).

Properties of sets of indicators

A set of indicators is a way to represent a process or a part of it. Selected indicators should represent the real dimensions of a process, without omissions or redundancies. "Exhaustiveness" and "non-redundancy", which are discussed in the following paragraphs, are necessary but not sufficient conditions for this purpose.

Exhaustiveness

For a generic process we may identify different dimensions. Each of them can be represented by (at least) one indicators. A set of indicators is considered non-exhaustive if there are no indicators referring to one or more specific dimensions.

The property of exhaustiveness can be explained in another way. If indicators are unable to discriminate two process states – 1 and 2 – and if some empirical manifestations of the state 1 can be distinguished from these of the state 2, then the

Category	Properties	Short description
Properties of *sets* of indicators $S = \{I_i, I_j, I_k\}$	Exhaustiveness	Indicators should properly represent all the system dimensions, without omissions
	Non-redundancy	Indicators set should not include redundant indicators
Properties of derived indicators $(I_i, I_j, I_k) \Rightarrow I_{TOT}$	Monotony	Increase/decrease of one of the aggregated indicators should be associated with a corresponding increase/decrease of the derived indicator
	Compensation	Changes of different aggregated indicators may compensate one another, without making the derived indicator change
General properties	Consistency with the representation-target	The indicator should properly represent the representation-target
	Level of detail	The indicator should not provide more than the required information
	Non-counter-productivity	Indicators should not create incentives for counter-productive acts
	Economic impact	Each indicator should be defined considering the expenses to collect the information needed
	Simplicity of use	The indicator should be easy to understand and use
Accessory properties	Long-term goals	Indicators should encourage the achievement of process long-term goals
	Customer-oriented	Indicators should represent the process dimensions which most impact on customer satisfaction

Source: Franceschini *et al.* (2006)

Table I.
Proposed taxonomy of indicators properties

model is incomplete or inaccurate, and does not fulfil the property of exhaustiveness. The condition may be tested by means of the following formal test:

IF $\forall I_j \in S, I_j(1) = I_j(2)$

AND IF empirical manifestations of the state 1 are distinguished by empirical manifestations of the state 2

THEN the indicators model is not exhaustive

being:

- S set of indicators;
- I_j j-th indicator of the set; and
- 1 and 2 states of the process.

For example, an industrial company producing metal components uses the following indicators: I_1 "total number of units yearly produced", I_2 "manufacturing time", I_3 "lead times" (i.e. supply time, tool change time, time to repair failures, etc.). This set of indicators has been defined with the aim of differentiating the possible system conditions. If two possible states (*1* and *2*), undistinguished by the previous indicators, are distinguished by a further indicator (I_3) – before ignored (for example, the "number of defective units produced") – then the set is not exhaustive (see Figure 3).

The example shows that for testing the exhaustiveness of an indicators set, we need to clearly define the process, the associated representation-target, and to verify that every indicator maps distinguished empirical manifestations into distinguished symbolic manifestations.

Since every process is a dynamic system evolving over time, representation targets may change as time goes by.

For that reason, every indicator, in order to be aligned with representation targets, need to be constantly modified or improved. Exhaustiveness is a practical tool to periodically check the consistency between representation targets and indicators (Flapper *et al.*, 1996). If representation targets changes, one or more indicators may not properly represent them, not satisfying the property of exhaustiveness. The link between representation targets and firm strategy is provided by "accessory properties".

Non-redundancy

If a set (S) of indicators is exhaustive, and if it continues to be exhaustive even removing one indicator (I_k), then the removed indicator is redundant. In formal terms:

IF S fulfils the property of exhaustiveness,

AND IF $\exists I_k \in S : S \{I_k\}$ still fulfils the property of exhaustiveness

THEN I_k is a redundant indicator.

where:

S original set of indicators;

$S \{I_k\}$ original set of indicators, not including the indicator I_k.

	I_1	I_2	I_3	I_4
STATE 1	300,000 units	400 h	700 h	2.1%
STATE 2	300,000 units	400 h	700 h	3.5%

unexhaustive (I_1, I_2, I_3)

exhaustive (I_1, I_2, I_3, I_4)

Figure 3.
Unexhaustive set of indicators (I_1, I_2, I_3) made exhaustive adding a new indicator (I_4)

For example, in a manufacturing company producing plastic components, the process is represented by four indicators: I_1 "total number of units (yearly) produced", I_2 "number of defective units yearly produced", I_3 "manufacturing time", I_4 "efficiency of the production" calculated as $I_4 = (I_3 - I_5)/I_3$ (term I_5 refers to "lead times", such as supply time, tool change time, repairing time etc..), I_5 "lead times".

Assuming that the set of indicators fulfils the property of exhaustiveness, the indicator I_3 is removed from the set. If the residual set (I_1, I_2, I_4, I_5) continues to be exhaustive, then the indicator I_3 is categorized as redundant (see Figure 4).

Usually, indicators that can be deduced from other ones – that is to say, derived indicators, as in this case (I_3, function of I_4 and I_5) – are redundant. The presence of redundant indicators does not provide additional information on the process.

Properties of derived indicators

Derived indicators aggregate and summarize the information of a given set of sub-indicators. Generally, the more the process is complex, the more the indicators needed are numerous and different (Melnyk *et al.*, 2004). Derived indicators simplify process analysing and monitoring.

For example, to estimate the air pollution level, we consider four basic indicators representing the concentrations of four different pollutants. The concentration of each pollutant is mapped into a five-level scale by a single indicator, depending on the health risk (1 – harmless; 2 – acceptable; 3 – unhealthy; 4 – very unhealthy; 5 – hazardous) (Franceschini *et al.*, 2005). Let us suppose to analyse two conditions (1 and 2) as Table II shows.

To evaluate the air global condition, it is convenient to define a derived indicator I_{TOT}, aggregating the information of the previous ones.I_{TOT} is defined as the maximum of the four sub-indicator values (Franceschini *et al.*, 2005):

$$I_{TOT}(1) = \max(I_{NO2}, I_{SO2}, I_{CO}, I_{PM_{10}}) = \max(4, 4, 3, 4) = 4$$

$$I(2) = \max(I_{NO2}, I_{SO2}, I_{CO}, I_{PM_{10}}) = \max(1, 1, 1, 5) = 5$$

So, according to the derived indicator I_{TOT}, the system condition 2 is worse than the condition 1.

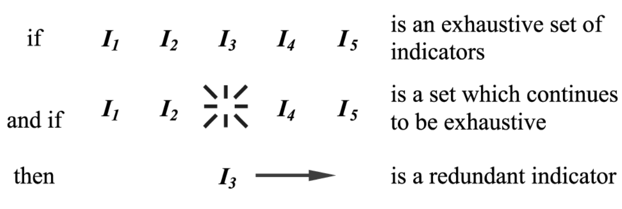


Figure 4.
Schematization of the concept of redundant indicator

Table II.
Comparison between two different air pollution conditions

	I_{NO2}	I_{SO2}	I_{CO}	I_{PM10}
State 1	4	4	3	4
State 2	1	1	1	5

The aggregation of indicators can considerably simplify the analysis of a system, but sometimes it can also be questionable or even misleading. The effectiveness of a derived indicator strongly depends on the aggregation rules (Franceschini *et al.*, 2006). For instance, the condition 2 in Table II is considered the worst, even if the risk level of three pollutants (I_{NO_2}, I_{SO_2}, and I_{CO}) is much lower than for condition 1. On the next sections we will illustrate some properties, which may assist the aggregation of sub-indicators into derived indicators.

Property of monotony

We consider a set of sub-indicators aggregated by a derived indicator. If the increase/decrease of one sub-indicator is not associated to the increase/decrease of the derived indicator, then the derived indicator does not fulfil the condition of monotony.

This definition implicitly entails that the symbolic manifestations of the sub-indicators are defined at least on an ordinal scale. That is to say that it allows local comparisons among the symbolic manifestations, like $I_k(1) > I_k(2)$ (see Figure 5). When indicators are represented on scales with no order relation (for example category scales: Yes-No, A-B-C, etc.), the property of monotony (as well as the concept of local performance) loses its meaning (Roberts, 1979).

In more detailed terms, if a process is represented by different sub-indicators aggregated into a derived indicator (I_{TOT}), and if the process skips from state 1 to state 2, increasing/decreasing one sub-indicator I_k, (not changing other indicators' performance), then I_{TOT} should increase/decrease too. Otherwise, I_{TOT} is not monotonous.

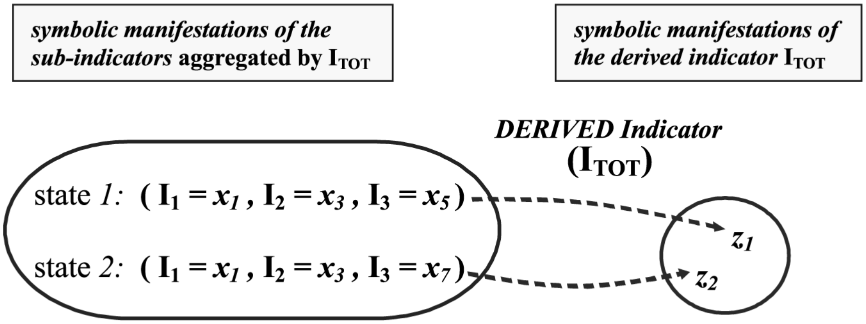
In formal terms:

IF $\forall I_j \in S \ \{I_k\}, I_j(2) = I_j(1)$,

AND IF $I_k(2) > I_k(1)$

AND IF $I_{TOT}(2) > I_{TOT}(1)$

THEN the derived indicator I_{TOT} is monotonous.



Note: If process skips from state *1* to state *2*, being $I_1(1) = I_1(2)$, $I_2(1) = I_2(2)$ and $I_3(2) > I_3(1)$, then the Monotony entails that $I_{TOT}(2) > I_{TOT}(1)$

Figure 5. Schematic representation of the condition of monotony. If process skips from state 1 to state 2, being $I_1(1) = I_1(2), I_2(1) = I_2(2)$ and $I_3(2) > I_3(1)$, then the Monotony entails that $I_{TOT}(2) > I_{TOT}(1)$

where:

S	indicators set;
I_k	increasing indicator;
$S \backslash \{I_k\}$	original set of indicators, not including I_k;
I_{TOT}	derived indicator;
1 and 2	two process states.

Let consider, for example, the pollution level estimation of the exhaust emissions of a motor vehicle. It is estimated by a derived indicator (I^A_{TOT}), synthesises the information of four sub-indicators: $I^A_{TOT} = \max(I_{NO_X}, I_{HC}, I_{CO}, I_{PM_{10}})$ (Franceschini *et al.*, 2005).

Assuming that pollution level skips from state 1 to state 2, three sub-indicators do increase, the value of the derived indicator (I^A_{TOT}) not necessarily increases (see Table III).

In other terms, I^A_{TOT} can be "insensitive" to sub-indicators' variations.

The example shows that using a derived indicator, which is not monotonous, we may lose some information (according to I^A_{TOT}, there is no difference between state 1 and state 2).

Property of compensation

The property of compensation can be studied when a process is represented by sub-indicators aggregated by a derived indicator. If changes of sub-indicators compensate each other − without making the derived indicator value change − then the derived indicator fulfils the property of compensation. In formal terms, a derived indicator (I_{TOT}) fulfils the property of compensation if the following condition is verified:

IF	$I_{TOT}(2) = I_{TOT}(1)$
AND IF	$\exists I_i \in S : I_i(2) \neq I_i(1)$
THEN	$\exists$ at least one indicator $I_j \in S : I_j(2) \neq I_j(1)$

where:

S	indicators set;
I_{TOT}	derived indicator;
1 and 2	two process states.

Let us consider the following example. To estimate the pollution level of motor vehicle exhaust emissions, we consider I^B_{TOT} as the synthesis indicator (Franceschini *et al.*, 2005):

$$I^B = (I_{NO_X} + I_{HC} + I_{CO} + I_{PM_{10}})/4$$

Table III. Example of a non-monotonous derived indicator (I^A_{TOT})

	INO_x	IHC	ICO	IPM_{10}	I^A_{TOT}
State 1	1	1	1	3	*3*
State 2	2	3	2	3	*3*

As illustrated in Table IV, the pollution level skips from state 1 to state 2. The decrease of I_{NO_x} and I_{HC} are compensated by the increase of I_{CO}. I^{B}_{TOT} value does not change.

Compensation is a typical property of additive and multiplicative models.

General properties

The following properties refer to single indicators. They are effective both for *basic* and derived indicators.

Consistency with the representation-target

According to the general definition given in section 2.1, every indicator should properly operationalize a representation-target, by mapping empirical manifestations into corresponding symbolic manifestations. This mapping should be thoroughly verified before using the indicator (Denton, 2005).

Level of detail (resolution)

An indicator with excessive level of detail provides more than the achievable (or required) information, so it could complicate the analysis and could be economically wasteful. Even more, if an indicator maps two empirical manifestations, not distinguished according to a representation-target, into different symbolic manifestations, then the level of detail is excessive (see Figure 6). To realize whether the indicator mapping resolution level is finer than necessary, we have to carefully analyse the representation-target definition level.

	INO_x	IHC	ICO	IPM_{10}	I^{B}_{TOT}
State 1	2	2	1	3	(2 + 2 + 1 + 3)/4 = 2
State 2	1	1	3	3	(1 + 1 + 3 + 3)/4 = 2

Table IV. Derived indicator fulfilling the property of compensation

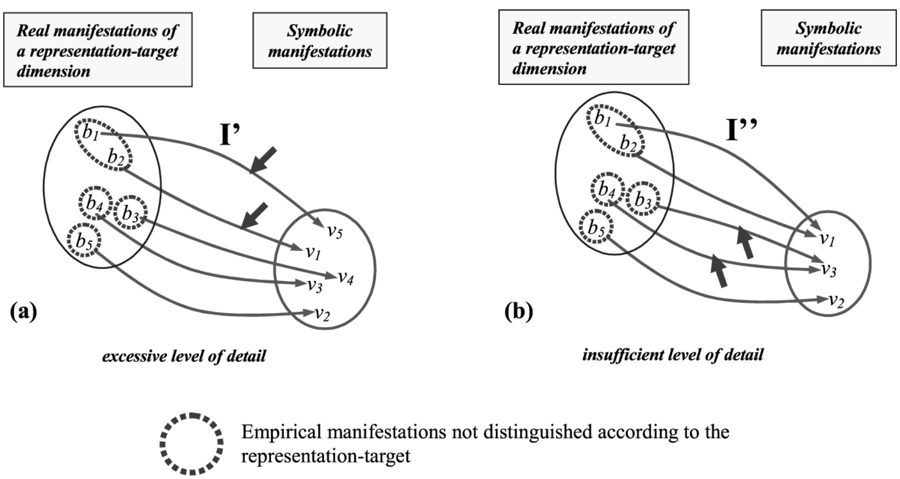


Figure 6. Representation scheme of indicators with excessive (a) and insufficient (b) level of detail

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 are not distinguishable, according to the representation-target;

THEN I_i has an excessive level of detail (resolution).

where:

I_i is the indicator investigated;
z_1 and z_2 are different symbolic manifestations; and
1 and 2 are two undistinguishable states of the system.

On the other hand, an indicator resolution could be lower than required. In such a situation important information on the process investigated could be lost. Even more, if an indicator maps two empirical manifestations, which should be distinguished according to the representation-target, into the same symbolic manifestation, then the level of detail could be insufficient (see Figure 6).

In formal terms:

IF $I_k(1) = z_1; I_k(2) = z_2$, being $z_1 \neq z_2$

AND IF the empirical manifestations of the states 1 and 2 are distinguishable, according to the representation-target;

THEN I_i has an insufficient level of detail.

where:

1 and 2 two states of the process;

z_1 and z_2 corresponding symbolic manifestations.

Non-counter-productivity

Before introducing the concept of non counter-productivity, we should make some preliminary remarks. Typically, in a company or in a process managed by indicators, managers and employees focus their attention on indicators linked to short-term rewards or bonuses, overlooking the global targets of their tasks (Hauser and Katz, 1998). This behaviour can sometimes be counter-productive for the achievement of long-term goals. Even more, indicators may differently impact the overall behaviour of a system with uncontrollable consequences.

For example, the main purpose of a construction company is to reduce the construction work time, in order to take a competitive advantage. This purpose may generate some counterproductive actions:

- to save time, employees do not obey safety rules (i.e. they do not use the safety helmets and harness);
- working vehicles, rushing around the building site to save time, become dangerous for the public safety; and
- the customer satisfaction decreases, because the results of the work are poor, due to the excessive speed up.

In this case, focusing too much on a single dimension of the process can be counter-productive in general terms.

The idea of counter-productivity can be shown as follows. Some sub-indicators (I_k, I_i, I_l, etc.) are aggregated in a derived indicator (I_{TOT}), representing the global performance. If the increase of a specific sub-indicator (I_k) is associated with the decrease of one or more indicators (for example I_i, I_l, I_m), determining a decrease of the global performance (I_{TOT}) too, then I_k is counter-productive. This definition entails that the symbolic manifestations of the sub-indicators are defined at least on an ordinal scale (Roberts, 1979). Which means that the scale used to measure the sub-indicators allows local comparisons among symbolic manifestations, like $I(2) > I(1)$. The concept of counter-productivity is meaningless for indicators represented in scales without order relation (for example category scales: Yes-No, A-B-C, etc.). Figure 7 provides a representation scheme of the concept of counter-productivity.

To assess counter-productivity, process indicators must be well known by users. In other terms, indicators and associated bonuses must be familiar to managers and employees involved in the process. If counter-productive indicators are linked to bonuses, and are simpler to be increased than others, the attention of the employees may dangerously focus on them. The concept of counter-productivity may be defined in more formal terms.

Let suppose that a process represented by n indicators aggregated into a derived indicator I_{TOT}, is in the state 1. If the process skips from the state 1 to the state 2, and the increase of a sub-indicator (I_k) is connected to the decrease of one or more other sub-indicators ($I_k, I_i, I_m, \ldots$):

- $I_k(2) > I_k(1)$
- $I_h(2) < I_h(1)$
- $I_i\ (2) < I_i(1)$
- $I_m(2) < I_m(1)$.
- ……

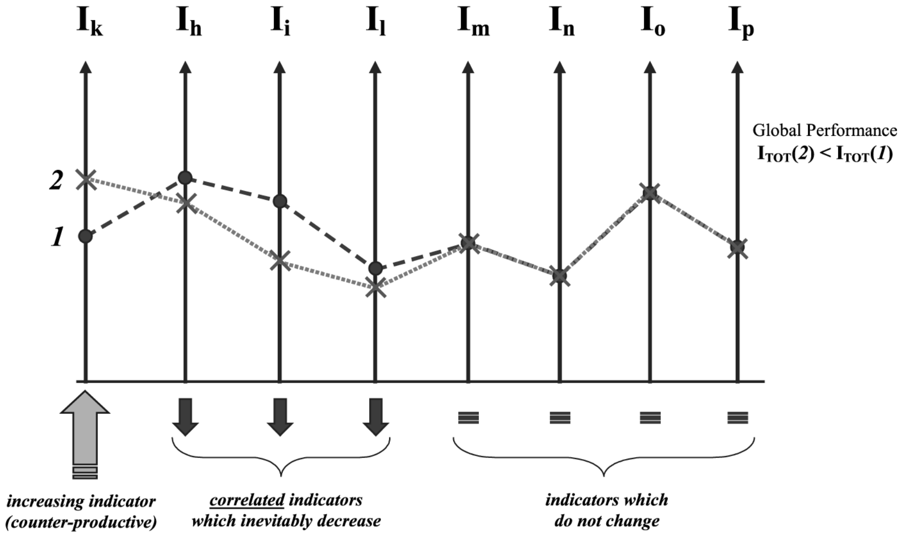


Figure 7.
Concept of counter-productive indicator (I_k)

so that the global performance of the derived indicator I_{TOT} decreases ($I_{TOT}(2) < I_{TOT}(1)$)then indicator I_k is said to be counter-productive.

When testing the counter-productivity property, the most difficult aspect is to identify the conceptual or empirical correlation between indicators involved.

To better clarify this concept, let us consider the following example. To estimate the costumer satisfaction, call-center uses several indicators. Two of them are: I_1 "average number of rings before answering the phone"; I_2 "percentage of unanswered calls". These two indicators can be counter-productive because employees can "game" the process answering the phone immediately and then putting the cal on hold before starting the conversation (Hauser and Katz, 1998). Although that behaviour increases the value of selected indicators, it is absolutely counter-productive according to other indicators of customer satisfaction. For example, the "number of exhaustive answers", the "courtesy", the "number of queued calls", etc.

In conclusion, the increase of I_1 and I_2 indicators could badly impact the process, making the global customer satisfaction decrease.

Economic impact

The economic impact of an indicator strictly depends on the nature of the system investigated. The impact can be studied in relative terms, by comparing two different indicators operationalizing the same representation-target. In general, we cannot assert whether one indicator is economic or not, but we can only assert whether the indicator is more (or less) than another one.

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

Simplicity of use

This property, as the previous one, can be studied in relative terms by comparing two (or more) different indicators operationalizing the same representation-target.

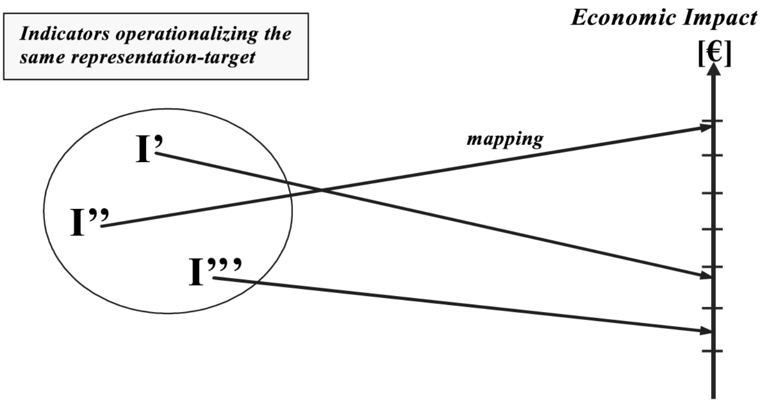


Figure 8.
Mapping performed to estimate the economic impact of a set of indicators

The comparison concerns the aspects related to the simplicity of use (for instance, indicators should be easy to understand, easy to use, they should have a clear meaning, they should be largely accepted, etc.).

Accessory properties

This article has illustrated many properties to support the analysis of indicators. However, before thinking of "how" to represent a particular aspect of the process, it is important to think of "what" are the process dimensions to represent. In practical terms, before defining process indicators, we should identify representation targets, which are derived from the firm strategy. Indicators direct and regulate the activities in support of strategic objectives (Tapinos *et al.*, 2005). Kaplan and Norton (1993), emphasize this link between strategies, action and indicators, considering four different perspectives (financial, customer, internal business process, learning and growth) (Kaplan and Norton, 1993). Each perspective should be directly linked to reasonable representation targets. The following two accessory properties are introduced to help identifying representation targets which are consistent with the strategic objectives. The properties are defined "accessory" because they are helpful for testing process representation targets, rather than indicators:

(1) *Long-term goals*. Since indicators should encourage the achievement of process long-term goals, representation-targets should concern process dimensions, which are strictly linked to these goals.

(2) *Customer orientation*. In a competitive market, one of the main goals of every company is customer satisfaction. Many indicators focus on internal needs such as throughput, staff efficiency, cost reduction, and cycle time. While these needs are all laudable, they usually have little direct impact on costumers needs. So, it is important to identify process aspects with a strong impact on customer satisfaction. Quality Function Deployment is a valid tool to reach this objective (Franceschini, 2001).

An operational method for defining and testing indicators

After illustrating major performance indicators properties, now we suggest an operative method for defining and testing the indicators of a generic process. The method is based on the following steps:

(1) Definition of the process and identification of the characteristic dimensions.

(2) Identification of representation-targets.

(3) Analysis of the representation-targets' time-horizon and impact onto process stakeholders ("accessory properties" testing).

(4) Preliminary definition of indicators.

(5) For each indicator, check of the "consistency with the representation-target".

(6) Check of "exhaustiveness" and "non redundancy" properties for the indicators set.

(7) Definition of the measuring scale and definition of the data collecting procedure for each indicator. General properties testing ("simplicity of use", "economic impact", "level of detail", "non counter-productivity", . . .).

(8) Check of derived indicators properties: "monotony" and "compensation".

This methodology is based on a "top-down" testing (see Figure 9). First, representation-target should be identified in order to be consistent with firm strategies ("accessory properties"). Then, a preliminary definition of process indicators is given. For each indicator, we should make sure it represents a particular process representation-target ("consistency with the representation-target" property). Next step is in testing the properties of the indicators set ("exhaustiveness", "non redundancy"), then other properties of single indicators are tested (general properties": "level of

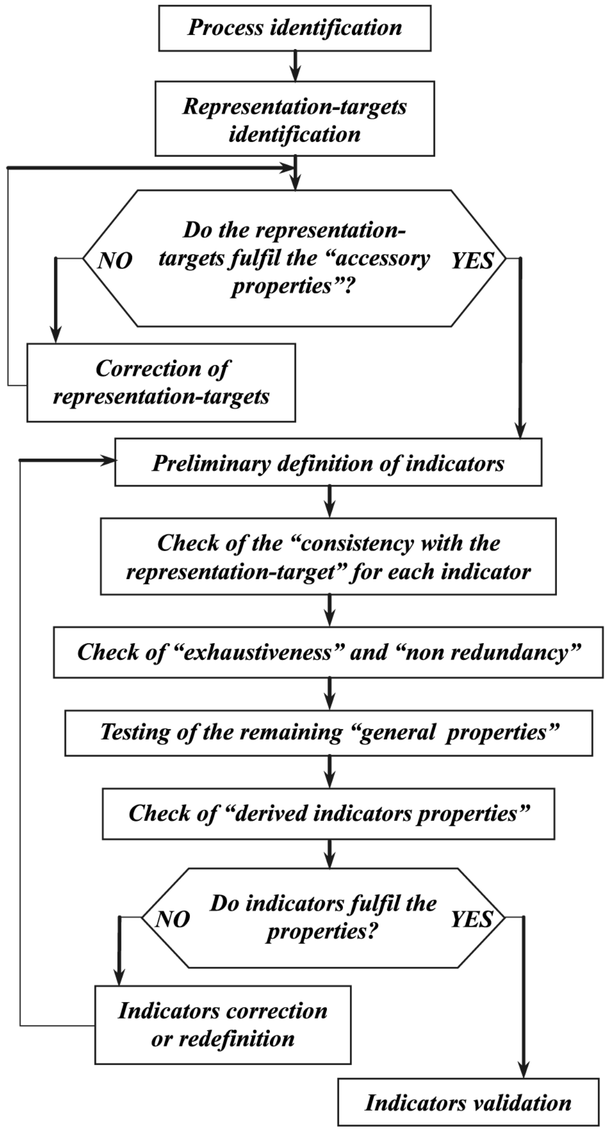


Figure 9.
Scheme of the suggested operational methodology

detail", "non counter-productivity", "economic impact", "simplicity of use"). Basically, before evaluating single indicators in detail, it is prior to assess that indicators are well integrated each other. In this phase, one of the major difficulties is identifying or predicting all possible process states.

After testing indicators "general properties" we should check derived indicators properties ("monotony" and "compensation"), and the rules with which sub-indicators are aggregated into derived indicators.

As illustrated in Figure 9, the procedure requires several recursive steps (definition, test, correction, redefinition, and so on) before developing a proper model. This operational methodology, as opposed to the others presented in literature, is based on a formal mathematical approach derived from the Representation Theory. Analysing indicators from a formal mathematical perspective makes it easier identifying possible drawbacks.

The proposed approach mainly focuses on indicators testing rather than an indicators designing. This methodology contributes to making aware of the risk of defining/selecting improper indicators and – in our opinion – it may be also used for integrating other existing approaches.

Conclusions

In the existing literature there is a great deal of methods to model a process using performance indicators (the Balanced Scorecard, the Critical Few, the Performance Dashboards, etc.). However, the success of a model often depends on the experience and the imagination of the one performing it. This paper tries to identify the major properties that indicators should satisfy in order to represent a specific process. In the literature, the organization of properties is given without a precise reference structure and properties are exclusively analysed with a descriptive approach.

The first part of the paper provides a brief theoretical background, illustrating the concepts of "indicator", "set" of indicators, "basic" and "derived" indicators, "subjective" and "objective" indicators. Then, the main properties of these categories are explained in detail, and organized into a taxonomy, using a formal mathematical approach derived from the Representation Theory. The paper highlights that, although the aggregation of two or more indicators into a derived one can considerably simplify process representation, it sometimes can produce questionable or even misleading results. A practical tool for testing the effectiveness of the aggregation is given by the check of derived indicators properties.

Finally, the paper suggests an operational method to support the selection and the testing of the indicators during the design activities of a performance indicators system. This methodology contributes to making aware of the risk of defining/selecting improper indicators, and may be also used for integrating other existing approaches.

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