Remarks About the Use of Symbol Indicators for Logistics and Manufacturing Process Evaluation

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Abstract

One of the most critical aspects in operations management is making firm goals representable. This is usually done by translating the organization results and objectives in "performance indicators". The scientific literature shows many applications in different fields such as quality, production, logistics, marketing, etc.... The aim of the present paper is to explore the world of symbol indicators, starting from the basic concepts expressed by the representational approach. A mathematical structure to the concept of indicator is presented, grounded on the Representational Theory of Measurement. Focusing the discussion on typical aspects concerning logistics and manufacturing fields, we explore the general properties of symbol indicators, their characteristics, and the conditions for their usability.

Keywords

Performance indicators, metrics, performance measurements, process representation.

1 Introduction

In operations management, a typical approach for making firm goals representable is translating the organization results and objectives in "performance measures". The scientific literature shows many applications in different fields such as production, logistics, marketing, etc... [Caplice, Sheffi, 1995; Brown, 1996; Evans, 2004]. Some authors assert that every metric, whether it is used explicitly to influence behavior, to evaluate future strategies, or simply to take stocks, will affect actions and decisions [Hauser, Katz, 1998; Evans, 2004].

In the current scientific literature terms such as "metric", "performance measure" and "performance indicator" are usually used as synonyms. The concept of performance measure/indicator is not new also in Quality Management [Juran, 1988]. Recent years are characterized by a widespread interest in this area. This phenomenon is mostly related to the new edition of ISO 9000 standards, which emphasize the concepts of "Quality Measurement" and "Customer Satisfaction Measurement" [ISO 9004:2000].

The current pressing interest around performance measurement is well highlighted by an article of Melnyk, Stewart and Swink [Melnyk, Stewart, Swink, 2004]. With the aim of giving some initial theoretical grounding for metrics research topic, these authors try to provide a general definition of metric based on the concept of "overall performance measurement system". The goal is extracting an overall sense of performance (this allow comparison, making decisions, planning strategies, predicting future developments, etc...). One of the most cited approaches for developing such an integrative system is the "balance scorecard" [Kaplan, Norton, 1992, 1996, 2001]. Another important aspect is the trade-off between metrics set richness and complexity [Melnyk, Stewart, Swink, 2004].

The aim of the present paper is to explore the world of symbol indicators, starting from the basic concepts expressed in the representational approach [Franceschini, Galetto, Maisano, 2007]. When dealing, for example, with performance assessment of a given manufacturing or logistic plant, a practical way is to define some indicators which make tangible the different aspects of the system at hand. In this case, indicators such as throughput, defectiveness, delivery time, due date, output variability, efficiency, customer satisfaction, etc... are commonly employed. However, going on into the problem, many questions arise: “Which indicators shall we use?”, “How many?”, “Have they to be quantitative/numerical?”, “Is there an optimal set?”, etc.

The point of view shown in this paper helps to give an answer to all these questions. In particular, a mathematical structure to the concept of “indicator” is presented [Franceschini, Galetto, Maisano, 2007]. The approach is based on the Representational Theory of Measurement [Roberts, 1979; Finkelstein, 2003; Cecconi, Franceschini, Galetto, 2006]. In this framework, an indicator can be seen as a “map” from an empirical system (the “real world”) into a representation system [Franceschini, Galetto, Maisano, Viticchiè, 2006].

Such a definition highlights that the representation system is not necessarily a numerical system, and many practical application show this important aspect. In many cases, indicators may be expressed by symbols and not numbers. Consider, for example, the practice of “triage” in accident and emergency services for sorting patients. The state of a patient is “represented” using triage tags or colored flagging.

In general, in logistics and manufacturing systems many performance indicators rise from a symbolic representation. Very often, in practical applications an arbitrary numerical conversion of symbols is exploited. Although the numerical conversion of symbols simplifies the subsequent mathematical analysis, it could originate misleading results.

In this paper we explore the general properties of symbol operators, their characteristics, and the conditions for their usability. Practical effects of these properties are presented by the use of some examples in logistics and manufacturing.

2 Indicator definition

The definition of indicator is strictly related to the notion of *representation-target*, which is the operation aimed to make a *context*, or part of it, “tangible” in order to perform evaluations, make comparisons, formulate predictions, take decisions, etc.... Examples of contexts are: a manufacturing process (if we are dealing with production management), or a distribution/supply chain (if dealing with logistics), or a result of a competition (if dealing with sports). Given a context, one or more different representation-targets can be defined.

An *indicator* (or a *set of indicators*) is a tool which operationalizes the concept of representation-target, referring to a given context [Franceschini, Galetto, Maisano, Viticchiè, 2006].

For example, if the context is the “logistic process” of a company and the representation-target is “the classification of suppliers”, the “delivery time” and the “lead time” can be two of the possible related indicators.

In general, it can be shown that, given a representation-target, a set of associated indicators is not algorithmically generable [Roy, Bouyssou, 1993].

3 The “representational” approach

To better understand the definition of indicator, the concept of measurement must be reminded. According to the Representational Theory of Measurement, a *measurement* is a “map” from an empirical relational system (the “real world”) into a representation relational system (usually, a numerical system) [Roberts, 1979; Finkelstein, 2003].

Given a set of all possible *manifestations* for a specific aspect of a well defined representation context:

$$\mathrm{A} = \{a_1, ..., a_i, ...\} \tag{1}$$

and a family of *empirical relations* among the elements of A:

$$\mathrm{R} = \left\{R_1, \ldots, R_m\right\} \tag{2}$$

then the following *empirical relational system* can be defined:

$$\mathfrak{A} = \left\langle \mathrm{A}, \mathrm{R} \right\rangle \tag{3}$$

Analogously, if Z is a set of *symbols*:

$$\mathrm{Z} = \left\{z_1, \ldots, z_i, \ldots\right\} \tag{4}$$

and P is a family of *relations* on Z:

$$\mathrm{P} = \left\{P_1, \ldots, P_m\right\} \tag{5}$$

then

$$\mathfrak{Z} = \left\langle \mathrm{Z}, \mathrm{P} \right\rangle \tag{6}$$

is a *symbol relational system*.

In general, according to the so called "Symbolic Representational Theory", a measurement is an objective empirical function which maps homomorphically the empirical relational system $\mathfrak{A} = \left\langle \mathrm{A}, \mathrm{R} \right\rangle$ into the symbol relational system $\mathfrak{Z} = \left\langle \mathrm{Z}, \mathrm{P} \right\rangle$ (see Figure 1) [Finkelstein, 2003].

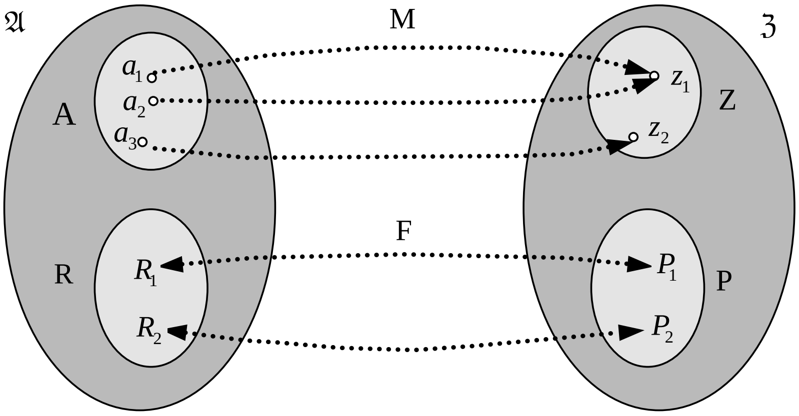

Figure 1: Schematic representation of the concept of measurement, defined as a homomorphism from the empirical relational system ($\mathfrak{A}$) into the representation one ($\mathfrak{Z}$) [Roberts, 1979; Finkelstein, 2003].

Two mappings are defined:

$$\mathrm{M} : \mathrm{A} \rightarrow \mathrm{Z} \quad \text{(homomorphism)} \tag{8}$$

and

$$\mathrm{F} : \mathrm{R} \rightarrow \mathrm{P} \quad \text{(isomorphism)} \tag{9}$$

so that $M(a) = z$ is the image in Z of a generic element a, and $F(R) = P$ is the image in P of a generic relation R.

M is a homomorphism. The mapping is not one-to-one. Separate but indistinguishable manifestations are mapped into the same symbol.

The "representation code" for $\mathfrak{A}$ is defined as follows:

$$\mathrm{C} = \left\langle \mathrm{A}, \mathrm{Z}, \mathrm{M}, \mathrm{F} \right\rangle \tag{10}$$

The inverse of C is called "interpretation code". z is the symbol of a.

In most applications the mapping is performed into a numerical relational system, defined as:

$$\mathfrak{N} = \left\langle \mathrm{N}, \mathrm{P} \right\rangle \tag{11}$$

where N is a class of numbers:

$$\mathrm{N} = \{n_1, \ldots, n_i, \ldots\} \qquad n_i \in \mathbb{R} \tag{12}$$

and P is a subset of relations on $\mathbb{R}$.

Referring to the Representational Theory of Measurement, an indicator can be considered as a "map" from an empirical system (the "real world") into a representation system. However, the mapping between the empirical and symbol relations (Eq. 9), unlike measurement, is not required. For indicators, the mapping may introduce new relations or modify the existing ones.

Let us consider, for example, the problem of the choice of a car. The customer preference is an indicator, which maps the empirical system (different car models) into a representation system (ranking of the most desired cars). It is not a measurement. No order relation is defined among empirical manifestations. The order relation is subjectively introduced by the customer in the representation system.

On the basis of the representational approach, measurements may be interpreted as a subset of indicators. The basic difference between measurements and indicators is the way the relations of the empirical systems are mapped. Indicators do not require an isomorphism between empirical and representation relations (Eq. 9). That means that, while a measurement is certainly an indicator, the vice versa is not true.

It must be highlighted that, in general, given a representation-target, the related indicator (or set of indicators) is not univocally defined [Franceschini, Galetto, Maisano, Viticchiè, 2006].

An immediate consequence of the non-uniqueness condition is that a representation-target can be described by different set of indicators. This leads to the need of establishing a methodology (or an empirical procedure) to individuate the set of indicators which better embodies a given representation-target.

Different set of indicators may differently influence the overall behavior of a system with uncontrollable consequences [Hauser, Katz, 1998; Evans, 2004]. The choice of the best set of indicators involves the analysis of the impact that the indicators will produce on the observed system, as well as their properties [Roy, Bouyssou, 1993; Caplice, Sheffi, 1995; Franceschini, Galetto, Maisano, 2007; Franceschini, Galetto, Maisano, Mastrogiacomo, 2008].

Considering that a complex representation-target can cover different aspects of the contest, its operationalization automatically entails the use of a *set of indicators*. In some situations, it is possible to define an aggregated indicator which synthesizes the overall performance of the set of indicators.

Indicators can be further classified as [Franceschini, Galetto, Maisano, Viticchiè, 2006]:

- *basic* indicators, obtained as a direct observation of an empirical process (for example the "number of defectives on a production line", or the "cycle time of a manufacturing process");
- *derived* (or *aggregated*) indicators, obtained combining one or more indicators (basic or other derived). They represent the aggregation or the synthesis of several indicators (for example the "mean number of faults per day on a production line", or the "mean labor cost per hour in a factory").

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, Bouyssou, 1993]. The aggregation of several indicators into one derived indicator is not always simply achievable, especially if the information to synthesize is assorted [Franceschini, Galetto, Maisano, 2007].

4 The use of symbol indicators

As described above, many indicators are not expressed by numbers. The use of symbol indicators happens very often when the relations between representation symbols are ordinal or nominal [Roberts, 1979].

Consider, for example, the case of a workshop with a certain number of similar machines. To distinguish from each other, they are associated to serial numbers. This is clearly a categorization in which (serial) numbers have lost their numerical properties, and are simply used as symbols. We can say that the only available numerical relations are the "equal" ($=$) and the "not equal" ($\neq$) relations.

When dealing with symbol indicators is preferable to avoid numbers. This helps to keep away from an arbitrary numerical interpretation of symbols which could give rise to misleading results. Many studies demonstrated that the introduction of arbitrary numerical properties could drive to completely false conclusion with serious consequences on the process under observation [Franceschini, Romano, 1999; Franceschini, Galetto, Varetto, 2005].

If we consider, for example, the case of a production line of fine liqueurs, reported in Franceschini and Romano (1999). The visual control of the corking and closing process is carried out on the basis of the following assessments (see Table 1):

- "reject" if the cork does not work;
- "poor quality" if the cork must not be rejected but has some defects;
- "medium quality" if the cork has relevant aesthetic flaws but no other defects;
- "good quality" if the cork only has small aesthetic flaws;
- "excellent quality" if the cork is perfect.

The obtained results for a sample of 30 corks are reported in Table 1.

"reject"	**"poor quality"**	**"medium quality"**	**"good quality"**	**"excellent quality"**
2 corks	5 corks	9 corks	7 corks	7 corks

Table 1: Results of the visual control of a sample of 30 corks.

Suppose we decide to introduce the following codification: "reject" = 1, "poor quality" = 2, "medium quality" = 3, "good quality" = 4, "excellent quality" = 5.

Referring to the example in Table 1, the resulting arithmetic mean is: $\bar{x} = 3.4$. Hence the sample mean seems to be between "medium quality" and "good quality".

The adopted numerical conversion is based on the implicit assumption that all scale levels are positioned at the same distance. However, we are not sure that the evaluator perceives the subsequent levels of the scale in this way, nor even if s/he has been preliminarily trained. For example, the evaluator might perceive the upper levels as more distinguished from the others [Roberts, 1979]. The suitable codification of the levels of the scale for this inspector might be the following: "reject" = 1, "poor quality" = 3, "medium quality" = 9, "good quality" = 27, "excellent quality" = 81.

In this case the arithmetic mean is $\bar{x} = 28.5$, that is to say that the sample mean is between "good quality" and "excellent quality".

This ambiguous situation occurs for two reasons:

- The visual control is not properly a measurement. It is surely an indicator, the empiricity condition of measurement is maintained, but the objectivity condition is not satisfied (different operators may judge the same cork differently). In this case we say that this is an *evaluation* rather than a measurement [Cecconi, Franceschini, Galetto, 2006; 2007].

- The evaluation is expressed using a linguistic ordinal scale. That means the only mathematical properties we may associate to the symbols (“reject”, “poor quality”, “medium quality”, “good quality”, “excellent quality”) are related to “equal” relation $(=)$ or “greater than” relation $(\succ)$.

When we use numbers (as symbols) for such a representation, in principle, we do not make an incorrect operation. The error is to assign inappropriate properties to them, justifying the unfounded use of “sum” $(+)$ or “division” $(/)$ operators. The correct approach must use operators which exploit the appropriate properties only (in this case, order relations) [Franceschini, Galetto, Varetto, 2005].

This simple example shows that the use of symbol indicators and their associated relations must not evade the analysis of the logical structure on which it is grounded. Numbers are a special kind of symbols. They can be used provided that they are associated only to the relations established by the mapping operation.

5 Properties of performance indicators

As a consequence of the above observations, the definition of a set of indicators should be accompanied by a series of tests aimed to verify its applicability to a specific representation-target.

A reference scheme can be based on the properties reported in Table 2, as well as the structure coming from the representational approach [Franceschini, Galetto, Maisano, Mastrogiacomo, 2008].

According to Table 2, indicator properties are classified into three groups: properties of derived indicators, properties of sets of indicators, and general and accessory properties. This taxonomy can represent a useful tool to select, classify end evaluate indicators in different contexts.

It can be reasonably assumed that a large part of the properties reported in the literature by different authors can be incorporated in this scheme of classification [Caplice, Sheffi, 1995; Brown, 1996; Evans, 2004; Franceschini, Galetto, Maisano, Mastrogiacomo, 2008].

Some of these properties may not be applied to symbol indicators. Especially if neither metric nor ordinal relations can be associated to them.

Consider, for example, supplier classification in the logistic process management of a given manufacturing organization. Three indicators:

- commodity sector (Chemicals, chemical products and fibers EAC-12; Rubber and plastic products EAC-14; Basic metal and fabricated metal products EAC-17; Electrical and optical equipment EAC-19),
- country (UE country; not-UE country),
- method of transport (truckage; rail transport; transport by sea; air transport; multimodal transport)

are synthesized in a derived indicator in order to classify suppliers and determine what kind of ordering procedure must be applied.

According to that, suppliers may be classified as:

- type A1, if: EAC-12, not-UE, any kind of method of transport;
- type A2, if: any kind of commodity sector except EAC-12, not-UE, any kind of method of transport;
- type B1, if: EAC-12, UE, truckage;
- type B2, if: EAC-12, UE, any kind of method of transport except truckage;

- type B3, if: any kind of commodity sector except EAC-12, UE, any kind of method of transport.

Monotony property can not be applied to this derived indicator, which has no ordinal properties, and is obtained by non-ordinal indicators.

Equally, compensation property can not be applied, due to the fact that all aggregated indicators do not support metric or ordinal relations.

This example shows that, during the phases of definition and setting up of a set of indicators, all the structural and general properties should be considered and analyzed. In several cases, some of them can not be applied. The result of this analysis can be an effective reference for evaluating the applicability of a given set of indicators to the related context and representation-target.

Category	Properties	Short description
Properties of sets of indicators	Exhaustiveness	Indicators should properly represent all the dimensions of the system modeled, without omissions.
	Non redundancy	Indicators should properly represent all the significant dimensions of the system modeled, without redundancy.
Properties of derived indicators	Monotony	Increase/decrease of one of the aggregated indicators should be associated to a corresponding increase/decrease of the derived indicator.
	Compensation	Changes in value of the different aggregated indicators may compensate each other, without making the derived indicator value change.
General properties	Consistency with the representation-target	Indicator should properly operationalize the representation-target.
	Level of detail	Indicator should not provide more than the achievable (or required) information.
	Non counter-productivity	Aggregated indicators should not create incentives for counter-productive acts.
	Economic impact	Indicators should be defined considering the expenses to collect and elaborate the needed information.
	Simplicity of use	Indicator should be easy to be understood and used.
Accessory properties	Long term goals	Indicators should encourage the achievement of long-term goals of the process.
	Customer/stakeholder oriented	Indicators should represent the process aspects with a great impact on customer/stakeholder satisfaction.

Table 2: Properties of performance indicators [Franceschini, Galetto, Maisano, Mastrogiacomo, 2008].

6 Conclusion

In this paper we show that, starting from the Representational Theory of Measurement, a logical structure for symbol indicators can be set. This can be a valid support for the construction and the analysis of appropriate sets of indicators. On the basis of this approach, the relations between representation symbol and related mathematical operators can be properly identified.

We also show that, if the logical structure of a symbol indicator is disregarded, the obtained results can drive to misleading conclusion. Owing to that, we suggest a structured approach for analyzing and testing the properties of a given indicator (or set of indicators) before utilizing it.

Future work will be focused on the construction of a taxonomy of symbol indicators on the basis of their mathematical properties. The aim is to create a reference system for the choice of proper mathematical operators according to the indicator (set of indicators) in use and the operational context.

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