Performance measurement systems

Models, characteristics and measures

A. De Toni and S. Tonchia
University of Udine, Udine, Italy

Keywords *Performance measurement, Model, Performance indicators, Design, Empirical study, Operations management*

Abstract *In spite of the increasing importance of performance measurement in operations management, few large scale empirical studies concern models, characteristics and indicators of the performance measurement systems (PMSs). Results of a survey conducted in 115 medium and large sized Italian manufacturing firms operating in three main industries are presented. Principal components analysis was carried out with the aim of describing the dimensions and the actual state of these systems. The majority of PMS models are of the "frustum" type: the traditional cost performances (the production costs and the productivity) are kept separate from the more innovative non-cost measures (quality, time and flexibility). To make the most of the potentialities of these systems, formalisation and integration with other firm systems are of prime importance, while greater space should be given to the consideration of human resources.*

Introduction

The subject of performance measurement is encountering increasing interest in both the academic and managerial ambits. This, for the most part, is due to the broadening spectrum of performances required by the present-day competitive environment and the new production paradigm known as lean production or world class manufacturing (Dixon *et al.,* 1990; Hall *et al.,* 1991). In addition there is the need to support and verify the performance improvement programmes such as just-in-time, total quality management, concurrent engineering, etc. (Ghalayini and Noble, 1996).

These programmes are characterised by their ability to pursue several performances at the same time: for example the increase in the product quality together with the lowering of the production costs and the lead times, following the reduction in discards, waste, reworks, and controls. As a result the logic of "trade-off" between performances has been more or less abandoned (Mapes *et al.,* 1997; Filippini *et al.,* 1998), and thus there is a reconsideration of the current performance measurement systems (PMSs), traditionally oriented solely towards the control of the production costs and productivity.

The revision and updating of the PMSs on the one hand relates to the innovation of accounting systems, by means of activity-based costing as it concerns, in particular, product costing (Johnson and Kaplan, 1987), and on the other hand, the extension of the measuring of the so-called non-cost performances, by nature not explicitly economic-financial, but pressingly demanded by customers (Fisher, 1992).

International Journal of Operations & Production Management,
Vol. 21 No. 1/2, 2001, pp. 46-70.

The environmental factors which urge a development of one side of PMS of the "non-cost" type are twofold: on one part linked to the environmental turbulence (in terms of frequency and unpredictability of changes) and on the other the managerial complexity (due to the passage from strategies based on cost-leadership to strategies based on differentiation/customisation, a passage which increases the competition between the firms and requires more complex organization).

Despite the "non-cost" performances (which relates to physical measures pertinent to the characteristics of the product, the production technologies and the managerial techniques of the plant) seeming to be typically operational in nature, in fact they often have tactical and strategic relevance (Eccles, 1991; Wisner and Fawcett, 1991).

Table I summarises those which the vast amount of literature on PMSs (Neely *et al.,* 1995) consider to be the main changes and trends in development that have been affected by or now concern these systems.

Adapting to the "value strategies" (Rappaport, 1986), the PMSs are evolving from a characterisation based on the measuring and control of costs to one based on measuring the creation of value and thus on the non-cost performances. This occurs by considering the performances not from the point of view of trade-off, with some performances privileged to the detriment of others, but jointly pursuing the performance results on different levels, and thus of performance compatibility.

The consideration of the value, in addition to the traditional financial performances (measured by ROI, discounted cash flow, etc.), determines a marked customer orientation, considering a long-run period in which to analyse the satisfaction and fidelity of the customer.

With regard to measures and organisation specifically, the PMS innovations affect both the micro- and the macro- organisational aspects: the spreading of job enrichment/enlargement and teamwork displace attention from individual to group performance (Meyer, 1994); the adoption of management-by-process emphasises the transverse performances as compared to the single-function performances (De Toni and Tonchia, 1996).

Besides, the performance evaluation is important in relation not to the predetermined standard but to the continued improvement to be achieved

Traditional PMS	Innovative PMS
Based on cost/efficiency	Value-based
Trade-off between performances	Performance compatibility
Profit-oriented	Customer-oriented
Short-term orientation	Long-term orientation
Prevalence of individual measures	Prevalence of team measures
Prevalence of functional measures	Prevalence of transversal measures
Comparison with standard	Improvement monitoring
Aim at evaluating	Aim at evaluating and involving

Table I.
PMS evolution

(Schmenner and Vollmann, 1994; Daniels and Burns, 1997). Finally, the aim must be to involve and motivate the assessed employees too (Flamholtz *et al.,* 1985).

The article proposes to describe the present state of the PMSs, by means of a survey carried out in 115 medium and large sized Italian manufacturing firms. In fact, in spite of the increasing importance of performance measurement in operations management, few large scale empirical studies concern models, characteristics and indicators of the PMSs.

The article is developed through five sections. In the first the research methodology is described. The following three sections respectively regard models, characteristics and performance dimensions/indicators of PMSs, comparing the literature with the empirical results of the research. The final section deals with the conclusions and they are discussed with the idea of suggesting practical means for an effective implementation of these systems.

Research methodology

The literature on PMSs appears as a large, composite and articulated array, but not rich in conceptual frameworks; indeed, compared with the liveliness of the scientific debate and the growing importance attributed to PMSs by managers, the contributions are often limited to the presentation of excellent case-studies, while empirical investigations of a wider spectrum, such as surveys, are rare.

In view of the lack of consolidated theoretical models and empirical investigations on a vast scale, the exploratory survey methodology was adopted, aimed at identifying and studying the constructive elements of PMSs. The present research is the first large-scale study carried out in Italy on this theme.

The research is divided into three phases:

(1) a wide-ranging analysis of the literature regarding the innovations that have taken place in PMSs over the last years enabled the main PMS characteristics, the major dimensions of performance and their corresponding indicators to be hypothesised;

(2) in order to investigate the real PMSs, a tool to detect data was prepared, pre-tested on experts and pilot-firms (as suggested by Dillman, 1978), and later mailed to the general manager and the plant/production manager, in the form of two questionnaires containing in total 228 items of an objective (numerical values) and subjective nature (perceptual Likert scales);

(3) the resulting data was subjected to reliability and validity analyses, and then analysed using uni- and multi-variate statistical techniques.

The investigation was carried out on the leading 200 Italian firms of the mechanical industry and the leading 200 Italian firms of the electro-mechanical and electronic industries, classified on the basis of the revenue of the last available financial year. The criterion for the choice of the sample, stratified into the typical Italian manufacturing industries, was the size of the firm, hypothesising that a PMS, in the sense of a complete and articulated system, is first of all justified above a certain dimensional threshold. In addition, the amplitude of the performance parameters required by the competition and the complexity of the management/evaluation of the activities, proportional to the size of the business, favour – for the first investigation on the subject – medium to large sized firms.

The response rate was very good for a mail contact methodology (28.75 per cent), and shows the firms' interest in the subject. The subsequent statistical analysis was therefore carried out on the 115 firms which had returned the questionnaires correctly filled in. These included: Fiat, Olivetti, Italtel, Zanussi-Electrolux, Aprilia, Magneti Marelli, Merloni, etc.

Of the 115 firms analysed, 72 belong to the mechanical, 27 to the electronic, and 16 to the electro-mechanical industry; the quality of 88 has been attested according to ISO 9000 standards. The average revenue is US$140.6 million (with a coefficient of variation CV – defined as the ratio between standard deviation and mean value – of 200 per cent, a minimum value of 13.6 million and a maximum of 2252.1 million) and 1,250 employees as an average (with a CV of 300 per cent, and a minimum value of 75 and a maximum of 35,000 employees).

The "items" of the questionnaires are numerical values or perceptual Likert scales (Rossi *et al.,* 1983). In the latter case, people are asked to rate each statement on a five-point scale, ranging from "strongly disagree" to "strongly agree". If a variable is related to a complex concept (Fowler, 1984), it is multi-item and its value corresponds to the mean value of the scales. In determining the measurement properties of the constructs used in the statistical analysis – that is, the multi-item variables – reliability and validity were assessed (Dick and Hagerty, 1971), using respectively Cronbach's α and principal components analysis.

Reliability has two components (Flynn *et al.,* 1990): stability (in time) and equivalence (in terms of means and variances of different measures of the same construct). The main instruments for the reliability assessment are: the "test-retest method" (for stability) and Cronbach's α (for equivalence) (Cronbach, 1951). We concentrated on the second aspect, because these variables have been developed for the first time. All of the multi-item variables have a Cronbach's α of at least 0.67, well exceeding the guidelines set for the development of new variables (Nunnally, 1978).

Validity regards the content, criterion and construct (Flynn *et al.,* 1990). Content validity cannot be determined statistically, but only by experts and by referring to the literature. Criterion validity regards the predictive nature of the research instrument to obtain the objective outcome (e.g. the existence of a multi-performance PMS should be correlated with the availability of scores in several different performance). Construct validity measures whether a variable is an appropriate operational definition of the construct or not.

For the content validity, we examined over 700 works, published over the last ten years and concerning performance measurement or correlated themes (manufacturing strategy, advanced accounting practices, time-based competition, vendor rating, etc.).

For the criterion validity, a supplementary investigation (Tonchia, 2000) was carried out to study the PMS characteristics and indicators in relation to the firm performance levels.

Construct validity, on the other hand, was established through the use of principal components analysis (PCA). The purpose of PCA (Pearson, 1901) is to derive a small number of linear combinations (principal components) of a set of variables that retain as much of the information in the original variables as possible. These linear combinations have coefficients equal to the eigenvectors of the correlation (covariance) matrix; the eigenvectors are orthogonal. The principal components are sorted in descending order of the eigenvalues, which are equal to the variances of the components.

Though the term factor is often used, it is more correct to refer to it as "factor analysis" (Spearman, 1904), characterised by the fact that, in this case, latent variables are not generally computable as linear combinations of the original variables as in PCA.

Here PCA was carried out in order to uncover the underlying dimensions, eliminate problems of multicollinearity (in other words the distorting effects provoked by variables, inside a group, strongly correlated to each other (Belsley *et al.,* 1980)) and ultimately reduce the number of variables to a limited number of orthogonal factors.

First, each multi-item variable was factor analysed separately: for the items loaded on more than one factor, the items responsible for the other factors beyond the first were eliminated (or considered in another variable) and Cronbach's α was re-calculated. The presented variables are all in their final version.

A similar procedure was then adopted to group several variables in order to get a more manageable set of variables without lacking too much information. Rotation was applied to aid interpretation. Rotation is the application of a linear transformation to components: the most used is varimax rotation, which maximises the variation of the squared factor loadings for each component; factor loadings represent correlations between the original variables and each factor (Dillon and Goldstein, 1984). Usually only the components (or factors) with eigenvalues greater than one are retained (Kaiser, 1958), because together they account for most of the overall variance (the cumulative percentage of total variance explained is here generally greater than 70 per cent).

Interpretation of the matrix of factor loadings was carried out following a rule according to which only loadings superior to 0.65 would be considered (excepting a few cases in which a variable is transverse to several factors): imposing such a limit allows one to retain only those variables which contribute in a high degree to the formation of a given factor, called according to the name of the variables with higher factor loadings.

Models of PMSs

The main models of PMSs found in the literature can be referred to five typologies:

(1) Models that are strictly hierarchical (or strictly vertical), characterised by cost and non-cost performances on different levels of aggregation, till they ultimately become economic-financial (Berliner and Brimson, 1988;

Lockamy and Cox, 1994; Partovi, 1994; Rangone, 1996); the first hierarchical model was that of Gold (1955), which connects productivity and ROI.

(2) Models that are balanced scorecard or *tableaux de bord*, where several separate performances are considered independently; these performances correspond to diverse perspectives (financial, internal business processes, customers, learning/growth) of analyses, that, however, substantially remain separate and whose links are defined only in a general way (Maskell, 1991; Kaplan and Norton, 1992 (although recently (1996) their model has been integrated with some vertical linkages, from the operational measures up to the financial ones); Brown, 1996).

(3) Models that can be called "frustum", where there is a synthesis of low-level measures into more aggregated indicators, but without the scope of translating non-cost performance into financial performance; typically the economic-financial measures are kept separate from the aggregate ones of customer satisfaction (Lynch and Cross, 1991; Hronec, 1993).

The "frustum" approach permits the vertical architecture to be defined at the lowest levels, involving the aggregation and synthesis of the performances, while at the higher levels the "frustum" approach is nearer to a balanced architecture, thus with a tableau of economic-financial performances and customer satisfaction/market performances. The same "pyramid" of Lynch and Cross is closed at the apex by that which the authors call "firm vision", which, however, is composed of financial performances on the one hand and those relative to the market on the other.

(4) Models which distinguish between internal and external performances; these latter are the only ones directly perceived by the customers (Bartezzaghi and Turco, 1989; Bolwijn and Kumpe, 1990; Johnson, 1990; Thor, 1993).

(5) Models which are related to the value chain; these models, in respect to the preceding ones, also consider the internal relationship of customer/supplier (Sink and Tuttle, 1989; Moseng and Bredrup, 1993).

The above mentioned models are characterised by three different architectonic connotations: vertical, balanced (or a tableau), horizontal (or by process). These architectonic connotations permit the preceding PMS models to be classified as reported in Figure 1. As can be seen, the frustum models as well as those that distinguish between internal/external performances (without reference to the value chain) show both types of tectonics at the same time.

Figures 2 and 3 present the constructive variables of a PMS, both in terms of the characteristics (described in the following section) and the dimensions/measures of the performances analysed (described in the section following that on the characteristics), as appear from the empirical evidence. The framework was validated starting from a first framework based on the literature, and integrated with the separations into classes and sub-classes resulting from the PCA, reported in the following paragraphs.

PMS characteristics

The numerous characteristics of the PMSs held, in the literature, to be fundamental, following the empirical verification using PCA, have been grouped into three classes (Figure 2):

(1) PMS formalisation;

(2) PMS integration with other firm systems;

(3) PMS utilisation.

ARCHITECTURE VERTICAL	strictly hierarchical models		frustum models		
ARCHITECTURE BALANCED		"balanced scorecard" models		models with internal-external performances	
ARCHITECTURE HORIZONTAL (BY PROCESS)					models related to value chain

Figure 1.
Classification of the PMS models

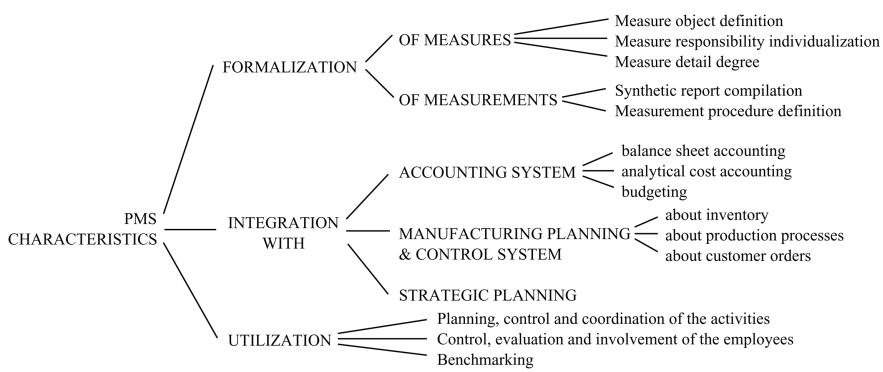

Figure 2.
Framework for PMS characteristics

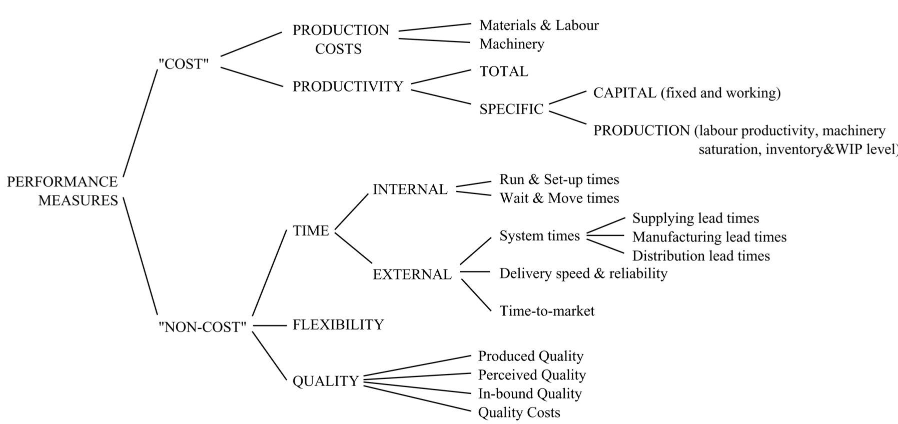

Figure 3.
Framework for PMS measures

PMS formalisation

The formalisation of the PMS includes the formalisation of the measures and the formalisation of the measurements, meaning by measurement "a productive process having the measure as product" (Speitel, 1992). In other words, there are two basic questions that must be answered:

(1) "what" will be measured; and

(2) "how" will it be measured? (White, 1996).

Neely *et al.* (1997) suggest useful recommendations for both the design of the performance measures (22 requirements to define a measure) and the performance measurement process (through a practical "record sheet").

Table II shows:

- The mean value of the principal variables regarding the formalisation of the PMS.
- The coefficient of variation (CV), defined as the ratio between standard deviation and mean value of each variable.
- The Cronbach's α (because all the variables are multi-item ones), as a test of reliability.
- The percentage of variance (Var.) explained by the first component (1st C.) According to the PCA carried out on the items of each variable (this as a test of validity).
- The factor loadings (1st factor etc.) according to the PCA carried out on more than one variable and to the successive varimax rotation (all possible combinations of aggregates of variables were tested in order to find the groups with the highest eigenvalues: these eigenvalues are shown at the bottom on the right in decreasing order, with the name of the corresponding groups of variables reported by the asterisks); factor loadings are italicised to highlight the variables that rest on each factor.
- The cumulative percentage of total variance (Cum.Var.) explained by the above factors (shown at the bottom on the left).

	Value	CV (%)	α	1st C. Var. (%)	1st factor	2nd factor
Measure object definition	3.76	22	0.70	62.9	*0.852*	0.220
Measure responsibility individualization	3.58	26	0.87	61.2	*0.869*	0.195
Measure detail degree	3.63	27	0.77	68.9	*0.654*	0.422
Synthetic report compilation	3.60	29	0.74	66.3	0.206	*0.862*
Measurement procedure definition	3.61	29	0.79	70.0	0.267	*0.777*
Cum.Var. = 72.7 per cent					2.02[a]	1.61[b]

Notes: [a] Measure formalisation; [b] Measurement formalisation

Table II. The characteristics of PMSs: formalization

A similar representation relates to Tables III, IV, VI, VIII; Table V does not show either the Cronbach's α or the percentage of variance explained by the first component, as all the variables of cost performance are mono-item; Table VII differs from Table VI as six factors are rotated instead of two.

The formalization level of measures depends on the following variables:

(1) Ease of definition of the measure object – the definition of the measure involves: the identification of the objects/phenomena to be measured, the investigation of their measurability, the choice of the best metrics, the determination of the comprehensibility and possibility of sharing the measures, as well as the essentialness, that is their non-redundancy, and the compatibility with the pre-existing measures, finally the identification of the receiver/user and of the use of the measure, which can be:
   - decisional;
   - aimed at obtaining measures of synthesis;
   - evaluative (the "evaluation" is a successive instance of the "measuring": the evaluation (gives a meaning) to the collected values (Sink and Tuttle, 1989)).

Table III. The characteristics of PMSs: integration with the manufacturing planning and control system

	Value	CV (%)	α	1st C. Var. (%)	1st factor	2nd factor	3rd factor
Inventory data integration	4.47	19	0.77	81.2	0.112	*0.986*	0.115
Time data integration	3.28	41	0.85	77.0	*0.868*	0.139	0.140
Quality data integration	2.60	48	0.81	72.0	*0.841*	0.043	0.242
Order data integration	3.37	42	0.86	87.6	0.257	0.126	*0.956*
Cum.Var. = 88.8 per cent					1.54[a]	1.01[b]	1.00[c]

Notes: [a] Integration regarding inventories; [b] Integration regarding production processes; [c] Integration regarding customer orders

Table IV. The characteristics of PMSs: utilization

	Value	CV (%)	α	1st C. Var. (%)	1st factor	2nd factor	3rd factor
Control	3.74	23	0.89	54.6	*0.634*	*0.625*	0.026
Planning	3.59	23	0.87	61.0	*0.861*	0.260	0.189
Coordination	3.59	30	0.78	70.1	*0.905*	0.125	0.019
People involvement	2.63	41	0.85	57.8	0.322	*0.770*	0.197
People evaluation	2.62	37	0.87	79.8	0.092	*0.872*	0.172
Benchmarking	2.80	40	0.84	76.0	0.102	0.216	*0.967*
Cum.Var. = 83.3 per cent					2.08[a]	1.87[b]	1.04[c]

Notes: [a] Planning, control and coordination of the activities; [b] Control evaluation and involvement of the employees; c Benchmarking

	Value	CV (%)	1st factor	2nd factor	3rd factor	4th factor
Material costs	4.64	16	0.006	0.176	0.146	*0.653*
Labour costs	4.44	25	0.042	0.009	0.332	*0.816*
Machinery energy costs	3.43	47	–0.010	0.073	*0.824*	0.314
Machinery material consumption	3.03	55	0.240	–0.001	*0.838*	0.233
Inventory and WIP level	4.29	24	–0.042	*0.753*	0.007	–0.083
Machinery saturation	3.40	40	–0.032	*0.697*	0.429	–0.061
Total productivity	3.62	42	*0.568*	*0.600*	0.209	0.207
Direct labour productivity	4.39	22	0.279	*0.790*	–0.030	0.228
Indirect labour productivity	3.59	38	0.373	*0.537*	–0.137	0.201
Fixed capital productivity	3.36	45	*0.751*	0.149	0.264	–0.167
Working capital productivity	3.49	41	*0.765*	0.130	0.228	–0.146
Value-added productivity	2.95	54	*0.873*	0.042	0.082	0.064
Value-added productivity/employee	2.96	50	*0.766*	0.005	–0.133	0.219
Cum.Var. = 66.1 per cent			3.62[a]	2.79[b]	2.26[c]	1.57[d]

Notes: [a] Capital productivity; [b] Production productivity; [c] Machinery working costs; [d] Material and labour costs

Table V. Indicators of cost performance

	Value	CV (%)	α	1st C. Var. (%)	1st factor	2nd factor
Time-to-market	2.96	39	0.83	75.5	*0.654*	0.309
Distribution lead times	2.65	50	0.92	92.5	*0.587*	0.268
Delivery reliability (to clients)	3.22	33	0.82	60.0	*0.780*	0.136
Supplying lead times	3.62	30	0.72	78.1	*0.590*	0.400
Supplier delivery reliability	3.03	35	0.86	65.0	*0.683*	0.239
Manufacturing lead times	3.43	36	0.74	79.5	*0.568*	0.399
Standard run times	4.49	20	–	–	0.267	*0.568*
Actual run times	4.21	29	–	–	0.274	*0.547*
Wait times	2.23	55	0.68	75.8	0.280	*0.776*
Set-up times	3.46	39	0.68	75.5	0.101	*0.811*
Move times	2.03	61	0.80	83.1	0.168	*0.731*
Inventory turnover	3.74	34	–	–	*0.668*	0.064
Order carrying-out times	3.66	31	0.67	75.3	*0.672*	–0.013
(Mean) flexibility	3.32	29	0.84	57.2	*0.572*	0.188
					3.94[a]	3.02[b]

Notes: [a] External times; [b] Internal times

Table VI. Indicators of internal and external time performances

(2) Ease of individualisation of the responsibility for the result given by the measure – the responsibilities can be: single or of a group and, if of a group, relative to one group or several, according to the criterion of the greatest influence.

(3) Detail degree of the measure.

	1st factor	2nd factor	3rd factor	4th factor	5th factor	6th factor
Time-to-market	*0.449*	0.161	*0.569*	0.086	–0.019	*0.422*
Distribution lead times	*0.770*	–0.082	0.183	0.220	0.067	0.182
Delivery reliability (to clients)	0.192	0.087	*0.683*	0.110	0.484	0.122
Supplying lead times	*0.632*	0.210	0.190	0.214	0.268	0.094
Supplier delivery reliability	0.170	0.110	*0.784*	0.180	0.232	0.145
Manufacturing lead times	*0.815*	0.205	0.104	0.135	0.162	0.069
Standard run times	0.148	*0.769*	–0.062	0.090	0.348	0.216
Actual run times	0.132	*0.692*	0.389	0.016	–0.103	–0.293
Wait times	0.323	0.218	0.227	*0.805*	–0.009	0.087
Set-up times	0.059	*0.772*	0.101	0.397	0.034	0.152
Move times	0.177	0.137	0.056	*0.908*	0.093	0.064
Inventory turnover	0.081	0.109	0.131	0.112	*0.743*	0.395
Order carrying-out time	0.279	0.081	0.277	–0.031	*0.774*	–0.182
(Mean) flexibility	0.239	0.075	0.223	0.110	0.100	*0.823*
Cum.Var. = 77.2 per cent	2.24[a]	1.89[b]	1.85[c]	1.83[d]	1.69[e]	1.29[f]

Notes: [a] System times; [b] Run and set-up times; [c] Delivery reliability; [d] Wait and move times; [e] Delivery speed; [f] Flexibility

Table VII.
Indicators of detailed time performances

	Value	CV (%)	α	1st C. Var. (%)	1st factor	2nd factor	3rd factor	4th factor	5th factor
SPC measures	2.76	40	0.86	65.8	0.417	*0.761*	0.108	0.019	0.199
Machine reliability	1.85	58	0.95	95.3	0.299	0.172	0.070	0.198	*0.770*
Reworks	3.69	33	–	–	*0.840*	0.058	–0.053	0.057	0.201
Quality system costs	3.21	34	0.83	66.0	*0.705*	0.392	0.053	0.094	0.176
In-bound qual. (n.c.)	4.00	27	–	–	0.153	0.138	*0.790*	–0.068	–0.134
In-bound qual. (cert.)	2.99	48	–	–	0.042	0.021	*0.734*	0.169	0.344
Vendor qual. rating	3.18	44	–	–	0.000	0.489	*0.502*	–0.044	0.408
Custom. satisfaction	2.59	44	0.87	79.9	0.273	0.463	0.194	*0.636*	–0.250
Technical assistance	2.82	42	0.81	72.7	0.088	0.002	–0.032	*0.870*	0.287
Returned goods	3.36	46	–	–	0.054	*0.831*	0.080	0.120	0.079
Cum.Var. = 74.1 per cent					2.11[a]	1.93[b]	1.57[c]	1.28[d]	1.25[e]

Notes: [a] Quality costs; [b] Produced quality; [c] In-bound quality; [d] Perceived quality; [e] Machine reliability;

Table VIII.
Indicators of quality performances

The formalisation level of measurements regards the definition of the measurement procedures, in particular the detail with which the following items are specified: criteria of measuring (moment, place and method of detection), frequency of detection, standard cost of the detection, obligations/responsibilities for each detection.

In addition there are characteristics of the measuring process that can be considered "meta-performances": the precision (that is obtaining the same measure in the replications of the measuring), the accuracy (likelihood ratio, that is the correspondence with a value that is presumed or accepted as being true), the completeness (that is the surveying of all the aspects that converge to produce the measure), the timeliness and the maintainability/adaptability of the measuring process.

The synthesis or synthetisation, which comprises the rules for arranging the basic measures into aggregate measures, can, in theory, be considered both a "measuring" (in the sense of a process that produces a measure, even if of synthesis) and a "measure" (in fact, synthetic). For example, Flapper *et al.* (1996) distinguish the performance indicators by: measurement unit (monetary/physical/dimensionless i.e. ratios), decision type (strategic/tactical/operational), and level of aggregation (overall/partial). However the empirical evidence due to the PCA leads one to consider the synthesis/synthetisation more as a process than a measure, so it is associated with the definition of the measurement procedures to determine the formalisation of measurements.

As can be seen from Table II, all the variables regarding the PMS formalisation have similar mean values, with coefficients of variation (CV) always below 30 per cent.

PMS integration with other firm systems

The PMS is not, nor can it be, an isolated system: both because it shares inputs with the other systems (this helps to economise in data collection) and because it produces outputs for other systems (Kaydos, 1991). As a consequence, the PMS has a precise "position" inside the firm, due to its tasks of promoting the integration between the various areas of business and deploying the business objectives throughout the organisation (Bititci *et al.,* 1997). Furthermore, "in order to do performance measurement, an enterprise model is needed", considering – for example – the selected choices for the design of the production system, functions and processes, and the adopted managerial philosophies (Rolstadas, 1998).

A PMS must be integrated with at least three other types of systems (Figure 2):

(1) the accounting system (regarding both the balance sheet accounting, the analytical cost accounting and the budgeting);
(2) the manufacturing planning and control system (MPCS);
(3) the strategic planning.

As far as integration with the accounting system is concerned, data relative to cost performances are a part of, and are elaborated within, the ambit of the analytical cost accounting, which is then linked to the traditional indices of the balance sheet accounting, while the budgeting does not normally include performances other than the economical and financial ones. All the tools and the typical accounting indicators are widespread in the firms.

In regard to integration with the strategic planning, precisely with the manufacturing strategy, without doubt the PMS is correlated to it (Blenkinsop and Burns, 1992), but the subject has not yet had the benefit of an adequate theoretical systematisation, based upon the empirical evidence: only a few contributions exist (e.g. Ahmed *et al.,* 1996; Morita and Flynn, 1997). It is for this reason that it has been made a complementary study (Tonchia, 2000) of the specific connections between PMS and manufacturing strategy, considering, besides the relationships between characteristics/indicators of the PMSs and the context variables (complexity of the product/process, complexity of the supplying and of the output markets), the links between the PMS and the technological, organisational and managerial choices in manufacturing, and with the operations performance levels. In fact, a strategy (also a manufacturing strategy) is first expressed in the definition of the "competitive priorities", pointing out the performance dimensions which must be measured (in other words, different strategies determine different performance objectives (Slack *et al.,* 1998)), and successively by putting into action the "technological, organisational and managerial choices" made to carry out these objectives, and thus obtain the "performance levels" (Hayes and Wheelwright, 1984; Swamidass and Newell, 1987; Mills *et al.,* 1995).

The integration with the manufacturing planning and control system (MPCS) is, on the other hand, targeted at economy of gathering technical and productive data. The MPCS considers them for the manufacturing planning and control; the PMS considers them for the measurement of performances, in particular time and quality.

The MPCS is present in all the firms investigated; sometimes it is supported by a local area network (LAN), while few examples exist of electronic data interchange (EDI) with customers or suppliers.

The integration between PMS and MPCS regards: the inventories, the production processes (in terms of their times and quality), and the customer orders (Table III).

The variables that refer to the integration between PMS and MPCS show a high mean value for the inventory control (4.5), moderate for the control of the production times and the progress of the orders (3.3-3.4), low for the control of the amount of discards, waste, reworks (2.6). With the exception of the inventory control, the CV is high (40-50 per cent).

PMS utilisation

Another class of characteristics concerns the aim/use of the PMS. Wisner and Fawcett (1991) individuate two reasons for a PMS: to compare one's own competitive position with that of the competitors and to check on the accomplishment of one's own objectives. Neely (1998) underlines three different roles for a PMS: to comply, to check, and to challenge. Furthermore, a PMS serves different staff units and functions of a firm (general management, quality management, production, new product development, technology, distribution, customer service, etc. (Zairi, 1994)), so also specific uses obviously exist.

Based on the results of the investigation carried out on the 115 firms examined, there seem to be three different types of general use of a PMS, obviously compatible with each other (Table IV):

(1) planning, control and coordination of the activities;

(2) control, evaluation and involvement of the human resources;

(3) benchmarking (that is the comparison with performances of the competitors and/or best firms (Sweeney, 1994)).

As can be seen from the italicised factor loadings in Table IV, the control is an aspect that regards both the productive activity and the human resources.

The variables relative to the purpose and use of the PMS, and thus to its importance, have moderate values (3.6 on average, with low CV, 20-30 per cent) as far as the planning, control and coordination of the activities are concerned, low for the evaluation and involvement of the human resources as well as the benchmarking (2.7 on average, with a higher CV, 35-40 per cent).

Performance dimensions and measures

The performances of the operations can be conceptually divided into two (Figure 3):

(1) *Cost performances, including the production costs and the productivity.* The cost performances are distinguished for having a direct link, explicable by mathematical formulae (see for example Gold's model, 1955), with the final results of the firm, that is net income and profitability;

(2) *Non-cost performances, regarding the time, flexibility and quality.* The non-cost performances are generally measured by non-monetary units of measure, and, as far as they influence the economic and financial performances (net income and profitability), the link with them cannot be calculated "a priori" in a precise manner as for the cost performances: for example, an average delivery time three days shorter or a product of better quality (which consumes 5 per cent less) surely has a positive impact on the economic and financial performances, but such an impact cannot be quantified in terms of increment in net income and/or profitability, if not subsequently.

The PCA highlights the further sub-division of the time performances (Blackburn, 1991; Barker, 1994; Kumar and Motwani, 1995) into: internal (performances perceived exclusively within the firm) and external (performances perceived also outside the firm, by the customers).

The performances concerning the quality (De Toni *et al.,* 1995; Noci, 1995; Adam *et al.,* 1997) are, instead, further differentiated into: produced quality, perceived quality, in-bound quality (or the quality of the suppliers), and quality costs.

Measuring cost performances

The cost performances include the production costs (separated into materials and labour on one hand and machinery on the other) and the productivity (which can be total or specific; in the latter case the productivity of a single factor is considered (Hayes *et al.,* 1988)).

The "specific productivities" individuated regard, on one side the capital (fixed or working) and the value-added, and on the other the production function in the technical sense (in this case labour productivity, machinery saturation, and inventory and work-in-progress (WIP) levels are considered).

The "total productivity", as was to be expected, seeing that it regards all the resources employed to attain a certain output, is a combination of the capital and production productivities (Table V).

Any productivity can be defined as the relation between output and input (Kurosawa, 1991; Raouf, 1994); dealing with operative performances, the outputs are generally produced physical quantities (possibly valorised if the products have a very different value), while the inputs consist of the fixed or working capital in the case of the capital productivity, the employment quota of the labour (direct or indirect) in the case of the production productivity. Side by side with this latter (as can be seen from the PCA in Table V) there are the control of the level of the inventories and the work-in-progress (WIP), and the machinery saturation. Value-added productivity is a total productivity where a numerator, instead of the output, is considered the value of the output less the purchasing value.

The major controls are those on the material and labour costs (4.5 on average, with a CV average of only 20 per cent) and on inventory and work-in-progress level (4.3 on average, with a low CV equalling about 25 per cent). The level of control on the energy costs and on the wear of the machinery/plants is moderate (3.2 on average, but with a high CV equalling about 50 per cent). As far as the productivity measure is concerned, that which is most measured is of the direct labour (4.4, with a low CV), then follow total productivity (3.6), the productivity of the indirect labour and the productivity of the working and fixed capital (with higher CVs). The control on the machinery saturation is moderate (3.4), while the value-added productivity is not much measured (though with a high CV).

Finally, standard costs and flexible budget are widely employed, together with financial ratios, including cash-flow analysis, but these are tools and indicators typical of the accounting system.

Measuring time and flexibility

Time performances are clearly divided into external (1st factor in Table VI) and internal (2nd factor). From a more detailed analysis (Table VII) i.e. with a rotation of the first six factors, which explains a cumulative variance of 77.2 per cent, it emerges that internal time performances are split into:

- run (or net process) and set-up times on one hand;
- wait and move times on the other.

Externally-perceived time performances are split into:

- system times (including supplying, manufacturing and distribution lead times);
- delivery speed and delivery reliability (both from suppliers and to customers);
- time-to-market (or time required to develop a new product).

The distinction of internal time performances into "run/set-up times" and "wait/move times" (these latter include also the monitoring of the adherence-to-schedule and the calculation of the machine availability, defined as the ratio between the hours of potential processing and the shift hours, and thus considering the delays for maintenance) is different from the other widespread distinction regarding time performances, that is between "value-added times" (i.e. run times) and "non value-added times" (i.e. set-up, wait and move times). Our distinction could be due to the fact that, while for run and set-up times there exist references to "standard times", wait and move times are typically deduced only "*ex post*".

Regarding the externally-perceived time performances, there is a distinction between manner of responding to the market (or "system lead times" relative to supplying, manufacturing and distribution) and "delivery" performance ("speed", in terms of time required to carry out orders plus the inventory turnover, and "reliability", the latter understood as respecting due-dates and completeness of the order as required-by/promised-to the customer (Handfield and Panesi, 1992)). This distinction is important because from the outside not only the delivery performance of the single orders is seen, but also the way in which the firm presents itself to the market and thus works (make-to-order, assemble-to-order, make-to-stock, engineer-to-order, etc.). Finally, the time-to-market has both a component of manner of responding to the market and a component of delivery/flexibility (Table VII).

The measures most used to evaluate the time performances regard, especially, the run times, both standard and actual (average values equal about 4.3 and reduced CVs). With the values comprising between 3.7 and 3.4 we find the measuring/control of the: manufacturing and supplying lead times, order carrying-out times, inventory turnover, and machinery set-up times. At a lower level (3.0-3.2) we find the measuring/control of the delivery reliability (both on the part of the suppliers and the firm towards its customers) and the time-to-market. Instead, wait and move times are not often measured, though they have high CVs (50-60 per cent).

Flexibility is, in theory, a performance apart (Figure 3) since it is an ability to change something (for example, the production volume or mix) in relation to all the three performances of cost, time and quality (De Toni and Tonchia, 1998):

$$\frac{\partial O}{\partial C_{Q,T=cost}};\quad \frac{\partial O}{\partial Q_{C,T=cost}};\quad \frac{\partial O}{\partial T_{C,Q=cost}}.$$

This latter partial derivative, which considers the change in the object with time, remaining equal costs and quality, is the one generally considered, and for this reason flexibility is often referred to as a "time performance" (Tables VI and VII). Besides, it seems to be more an externally-perceived performance than internal.

With a more thorough examination, some differences can be found between various types of flexibility, but for the sake of brevity only a mean flexibility value has been reported in Table VI; this value considers:

- volume flexibility;
- mix flexibility;
- product modification flexibility;
- process modification flexibility;
- expansion flexibility.

The last one is that most often measured, followed by the product and process modification flexibilities (these latter are also known as design flexibility). The less frequently measured volume and mix flexibilities however have much higher CVs. It would thus seem easier to measure technological flexibilities (product and process modification, and expansion) rather than managerial ones (volume and mix).

Measuring quality

From the empirical research it emerges that there are principally four types of quality measured (Table VIII):

(1) produced quality;

(2) perceived quality;

(3) in-bound (supply) quality; and

(4) quality costs.

The last performance is a hybrid between true quality and the costs; however, it is measured in reference to entities (such as discards, waste, reworks) typical of the quality (non-quality or "negative" quality).

Conceptually it could be asserted that there exist an "internal quality" (produced quality and quality costs) and an "external quality" (perceived quality downstream and in-bound quality upstream); this sub-division into two categories is not, however, upheld by the PCA, which does not join the aforementioned four types of quality two by two. Of less importance (as relative eigenvalue and variance explained) is a fifth component: machine reliability.

Produced quality includes items on the measures of the statistical process control (SPC) and the number of defective goods returned during the warranty period. The SPC is aimed at controlling the scraps and the discards resulting from the manufacturing process, using tools such as control charts, Pareto analysis, process capability indices, etc.

Perceived quality regards customer satisfaction and the technical assistance service performance.

In-bound quality includes the results of controls on certified (cert.) and non-certified (nc) purchasing, and the vendor quality rating (VQR); it should be noted that 88 of the 115 firms are certified according to the ISO 9000 EN 29000 standards.

The quality costs include the "quality system" costs (SPC costs, maintenance costs, total quality program costs, etc.), and the amount of reworking.

There is a high quality control on reception of non self-certified materials; obviously it is low (but not very) for self-certified materials, and there is a moderate use of the vendor quality rating. There appears to be a modest use of the SPC (the amount of scraps and discards are, however, checked even without the adoption of sophisticated statistical techniques), while the measuring of the returned goods percentage is more widespread, generally with cause analysis. We find fairly good values for the measuring of the times/costs of the reworks but only moderate for the control of the costs of the quality system. The measuring of the customer satisfaction and of the technical assistance performance is very low, probably due to the difficulty of their detection. Unexplainably the measuring of the machine reliability is low (even if the CV is very high). Many other CVs are high, a sign that a certain inequality exists between the firms concerning the degree of measuring of quality (for example, about 60 per cent for the SPC items relative to the control charts and the process capability indices).

Discussion and conclusions

The growing interest in the PMSs, due to the broadening of the spectrum of performances required and to the support of programmes for performance improvement (JIT and TQM), has led to, on one hand, an updating of the accounting systems and, on the other, an extension to the non-cost performances. Much has already been said, in the literature, about the updating of the accounting systems, while the extension to the non-cost performances poses the problems of greater complexity and articulation of the PMSs.

This research, thus, was aimed at the identification of the conceptual dimensions and the constructive variables of the modern PMSs, in the attempt to take part in the lively theoretical and managerial debate on the theme, a debate not yet adequately supported by empirical evidence of a broad spectrum. The great number of firms taking part in this survey bears witness to the high level of interest that the PMS design is causing.

The PMS models are distinguished by a vertical (or hierarchical), horizontal (or by process) and balanced (or "a tableau") structure. According to the prevalence of one type in respect to another, the following can be distinguished: strictly hierarchical PMSs, "balanced scorecard" PMSs, "a frustum" PMSs,

PMSs that distinguish between internal/external performances, and PMSs based on the value chain.

A primary result obtained from this research regards the nature of the structure of the PMS itself. Among the aforementioned models, it can be asserted that in the 115 firms analysed the structure adopted seems referable to the "frustum" model, in which there is synthesis between performances, but without reaching a single comprehensive result: the cost and non-cost dimensions (in their turn sub-divided into time, flexibility and quality) are kept separate.

The research, in fact, has not brought to light relations and synthesis of cost with non-cost measures, while within these two groups a marked tendency was found towards the hierarchical interpretations of the performances. For example, the external time performances (that is, those directly perceived by the customers) are articulated into: time to develop a new product (time-to-market), delivery speed and reliability, and system times (supplying, manufacturing and distribution lead times), which, considering the manner of responding to the market (make-to-stock, assemble-to-order, make-to-order, engineer-to-order), condition in the final analysis the delivery times to the customer.

But the principal results obtained from the research regard, on one hand, the structural characteristics of the PMS and, on the other, the indicators used.

As far as the characteristics of the PMS are concerned, it has been shown how they are referable to:

- formalisation;
- integration with other systems;
- aim/use.

The formalisation of the PMS can regard the measure and the measuring. The measures formalisation concerns: their definition (the object of the measure); the individualisation of responsibilities in the performance result; the degree of detail. The measuring formalisation (that is the processes that produce the measures) regards: the adoption of a procedure for gathering data; the synthesis of the data. The formalisation seems to be a fundamental prerequisite in relation to the growing importance of the PMSs.

Generally a PMS integrates with: the accounting system; the manufacturing planning and control system (MPCS); the strategic planning system (manufacturing strategy). The integration with the MPCS clearly regards the inventory level, the times and the quality of the workings and the management of orders. The actual integration of the PMS with the MPCS should be improved, especially in regard to quality.

The use of the PMS is directed towards: primarily planning, control and coordination of the production activities; secondarily (and anyway in a manner differing from the above mentioned aims) evaluation/involvement of the human resources; benchmarking to a moderate extent. The recognised and reconsidered importance of the human resources to obtain competitive success, compared with the limited use of the PMSs for the evaluation/involvement of the human resources, calls for a revision of the use of the PMSs, which are too oriented towards control.

The research has shown that there are four distinct performance dimensions, and so types of indicators:

(1) costs/productivity;

(2) time;

(3) flexibility;

(4) quality.

The first dimension is that of cost (performances of the economic-financial type or directly linked to them); the other three instead are non-cost in nature (performances of a physical type, even though influencing the economic-financial performances).

These four distinct classes of performances coincide with the four basic components by means of which the manufacturing strategy of a firm is generally expressed (Ward *et al.,* 1995). These manufacturing competencies determine the market competition focused on "price", "product" and "place" (Corbett and Van Wassenhove, 1993).

The cost performance indicators have traditional measures, such as:

- the cheapness of the production costs (regarding labour, materials, machinery);
- the productivity;
- the control of the working capital.

In more detail, material costs, direct labour productivity and inventory level measures outnumber all the other ones. As far as productivity is concerned, total productivity is distinguished from the so-called specific productivity, which regards the capital and the production in the technical sense.

This latter is, above all, a labour and machine productivity, measured by physical size (often the inventory and WIP control is also associated with it), while the capital productivity is measured on a monetary scale.

The time is a performance dimension that regards both internal times (that is those the firm controls but the customer does not see directly) and external times (those that concern the customer, in other words, delivery time and frequency of introducing new products).

It also emerged from this investigation that the external times are understood not only as delivery speed and reliability and times to develop new products (time-to-market), but also as structural logistic times of supplying, production and distribution. In fact these values condition the manner in which the firm responds to the market (make to stock, assemble to order, make to order, engineer to order), and ultimately determine the average delivery time to the customer. The intensity of measuring the external times is quite good, but it is particularly so for order carrying-out times, and the supplying and manufacturing lead times.

The internal times measured are the process times, divided into run and set-up times on one hand, and wait and move times on the other. The most diffused internal time measures especially apply to run times and machine set-up times, in virtue of the possible comparison with standard times.

The internal times may not be perceived outside the firm by the customers or may not directly influence the external times performances, as the manner of responding to the market is determinant for these latter. A firm may have poor internal time performances (for example long machine set-up times and wait times between the work centres), but make very quick deliveries to the customer as it uses make-to-stock and has rapid distribution lead times.

The measuring of the quality regards separately:

- produced quality;
- perceived quality (from which customer satisfaction is derived);
- in-bound quality (that is the supplier's quality);
- quality in terms of costs (costs of the procedures, programmes, controls and of all that is done to maintain a high standard of quality).

The in-bound quality control is high, while the statistical process control is not yet widespread (it is preferred to monitor the quality system costs, reworks and the amount of returned goods), just as customer satisfaction is not much measured.

In the comparison between performances, direct costs (labour and materials), labour productivity, the inventory, and the net process times appear to be most measured, while the time-to-market, non value-added times, delivery, both the quality produced (in terms of the statistical process control) and the customer satisfaction are relatively scantily measured. The latter performances assume notable importance in the actual productive and competitive context, for which reason they should be better considered.

The relations between characteristics/indicators of the PMS and the firm size, in terms of the mean of the last two available revenues, according to revenue ranges, and the type of the industry, were investigated using ANOVA (analysis of variance). No significant differences were found regarding either the size of the firm or the type of industry for the three examined (mechanical, electro-mechanical and electronic), except for the formalisation of the PMS, the comparison with the performances of the best competitors (benchmarking) and the intensity of measuring the produced quality, which are greater in the electro-mechanical and electronic industries. However it must be remembered that the firms investigated were chosen on the basis of a minimum threshold size.

In conclusion, useful specifications were furnished in terms of PMS structure and dimensions, permitting to define a framework for the implementation and management of the PMS, based on evidence from the literature and the experience of more than 100 leading firms.

The next steps in the research will regard relationships between the aforementioned PMS variables and external variables, such as the complexity of the product/process, complexity of the supplying and of the output markets, technological, organisational and managerial choices, performance levels reached – research still in progress – and the extension of the investigation to small and medium-sized enterprises (to verify the importance of the dimensional factor in the definition of the PMS) and the service firms (to analyse whether the type of output is a discriminating factor in the planning of the PMSs).

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