# An integrated production performance measurement system

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**Presents an original integrated production performance measurement system (IP2MS) based on a model able to examine simultaneously several production performances of different operation centres of a firm. The need for an integrated examination of the performances is of crucial importance for today's manufacturers in order to achieve a competitive advantage. Obtains a quantitative and homogeneous appraisal of the production performances; furthermore, identifies activities responsible for the major differences between actual and desired levels of performance. The proposed model has been empirically tested in some significant medium-large enterprises of Northern Italy.**

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## Introduction

The re-evaluation of the importance of manufacturing with the aim of achieving competitive advantages and on the other hand the assertion that the pursuit of excellence requires an equilibrated mix of performances (Kaplan and Norton, 1992) and pressure to continuous improvement (Dixon *et al.*, 1990), rather than mere attention to determinate standards of efficiency, suggest that the present day performance measurement and control systems should be reconsidered (Hall *et al.*, 1991; Lynch and Cross, 1991).

The emergence of the new manufacturing paradigm, known as lean production is imposing changes on the performance measurement systems too (Neely *et al.*, 1995). The new performance measurement systems should be suited to the characteristics of the production systems and the criteria of management adopted (Hronec, 1993), be coherent with the strategies of the firm and give support to their realization (Wisner and Fawcett, 1991), they should integrate with the reporting systems typical of the management accounting on one side and with the manufacturing planning and systems (MPCS) on the other.

These considerations underline two facts:

1 The revolution in industrial accounting that has taken place over recent years, due to the diffusion of activity-based costing – ABC (Berliner and Brimson, 1988)[1], should not be considered as something apart but must involve, in addition to the accountants, also the production managers. There must be an integration of accounting reports and production performance measures (Schnoebelen, 1993), as accounting reports alone are insufficient for estimating the performance of the operations, but nevertheless they can furnish useful information and in an economical way, since they are already used for management accounting, to the production.

2 Traditional operational measures emphasize variance-to-standards rather than encouraging continuous improvement (Fisher, 1992), and they are hardly ever directly related to company's manufacturing strategy as they are too detailed (White, 1996): they are necessary indicators of synthesis, referring both to single production processes and to the entire production process of the firm (De Toni and Tonchia, 1996), which regard the new manufacturing contexts, where competition is on several issues (Flapper *et al.*, 1996; Ghalayini and Noble, 1996). Thus the logic of "trade-off" has been overtaken (Schmenner and Vollmann, 1994), by the consideration of a set of competitive priorities to which are linked performances oriented not only towards efficiency (i.e. the productivity of the resources) but also to the dimension of time (time-to-market, reliability, flexibility) (Gerwin, 1993; Kumar and Motwani, 1995) and quality (product performances and product conformance) (De Toni *et al.*, 1995).

For example, a time-based competition strategy (Blackburn, 1991), based on JIT principles and regarding the entire value-delivery chain (from suppliers to distributors), requires performance criteria that do not emphasize individual operation time standards but instead stress the reduction of the set-up time, the flexibility of the workforce and the capability of producing high quality products by a specified completion date. Criteria, such as direct labour efficiency and machine utilization, may pressure managers and supervisors for short-term results, discouraging process improvement and mislead from real objectives; other criteria, such as inventory level, are less important in a JIT environment (Crawford and Cox, 1988).

The authors of this paper have developed an original integrated production performance measurement system (IP2MS), based on a model able to examine simultaneously

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several production performances of different operation centres of a firm. A quantitative and homogeneous appraisal of the production performances is obtained, based on both objective measures and subjective judgements. The results of the application of the system are:

- the evaluation of the performances at the firm level;
- the comparison between actual and desired levels of performance;
- the identification of the activities responsible for the major differences between actual and desired levels of performance, for future improvements to be made;
- the re-allocation of the production resources, according to the strategic issues.

The performance measurement system we propose (named the "integrated production performance measurement system" – IP2MS) utilizes data from the manufacturing planning and control system (MPCS) and from the ABC system. The data from the MPCS are used to express a judgement on the "cost performances" (such as machine efficiency, amount of rejects and waste, etc.) and on the "non-cost performances" (such as adherence to scheduling, throughput time, etc.). The data from the ABC system are used to weigh the performance of each single operation centre.

Here we will not examine the advisability of introducing an ABC system, its costs and advantages: there are several contributions on this matter (Campi, 1992; Cooper, 1991; Walley *et al.*, 1994). We only note that, if an ABC system already exists for better calculating product costs, it can be useful for implementing a performance measurement system too.

The proposed model has been empirically tested in some significant medium-large enterprises of Northern Italy.

## Evaluation of the performances

The developed model of the performance measurement system (IP2MS) considers several performances which are important for world-class manufacturers. The list includes efficiency, speed of delivery, reliability, time required for the introduction of new products or substantial changes, volume flexibility, mix flexibility, quality capability and quality conformance (i.e. consistency). Depending on the cases, each company can schedule the inclusion, in its IP2MS, of all, only some, or others of these performances. Data from an existing ABC system are utilized. The examination of the performances results from cross-functional and multi-level meetings: both top managers, production managers and workers are involved, and they are asked for judgements on performances, on the basis of the operational measures derived from the MPCS.

A weighted-ranking technique is used, first in order to construct the matrix $X_{ij}$ ($N$-rows and $M$-columns), which specifies the $i$-performance rank of the $j$-activity. It considers every single performance versus every other single performance, for each activity, and assigns a value of "one" to the performance considered more important (or that has the priority) and a value of "zero" to the other. If a decision cannot be made regarding relative importance/priority, then each performance is assigned a value of "one-half". For example: in regard to the activity "A", is efficiency or timely-delivery privileged? After all the performances have been compared, the sum of the values must be equal to $N*(N-1)/2$, where $N$ is the number of examined performances (Matta, 1989). This is made for all the $M$-activities.

The same technique is used in order to construct the matrix $Y_{ij}$ ($N$-rows and $M$-columns), which specifies the $j$-activity importance/priority in the $i$-performance. Comparisons between activities, regarding the importance/priority of a particular performance are made (e.g. the relative importance of efficiency in activity "A", activity "B" and so on). Now the sum of the values for each performance must be equal to $M*(M-1)/2$; the comparison between activities is made for all the $N$-performances.

The two matrices $X_{ij}$ and $Y_{ij}$ are respectively called "performance rank matrix" and "activity priority matrix". Matrix $X_{ij}$ has been made by column; matrix $Y_{ij}$ has been made by row. In other terms, $X_{ij}$ is derived from an "intra-activity" analysis (that is, between the performances of a single activity), while $Y_{ij}$ is derived from an "inter-activity" analysis (that is, between the activities regarding a single performance). The matrix $X_{ij}$ will serve for the evaluation of the performances; the matrix will instead serve $Y_{ij}$ for the identification of the activities responsible of the major differences between the actual and the desired levels of performance and for the re-allocation of the production resources between the activities.

The next step is to build the matrix $Z_{ij}$ ($N$-rows and $M$-columns) that considers the $X_{ij}$-results and the costs of the activities $C_j$ (with "$j$" from 1 to $M$), derived from the ABC system. Each column of the matrix $X_{ij}$ is multiplied, in a scalar way, by the cost of the activity $C_j$, and then divided by $N*(N-1)/2$:

$$Z_{ij} = \frac{C_j X_{ij}}{N(N-1)/2}.$$

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From the way it has been constructed, $Z_{ij}$ can be considered a "performance weighted-rank matrix", where the performance levels are obtained from activities that do not consume the same amount of resources. It can be observed that $\sum_i Z_{ij} = C_j$ and $\sum_j \sum_i Z_{ij} = \sum_j C_j = T$, where $T$ is the total cost of all the activities.

Finally, for each performance "$i$", the "actual performance rank" $P_i$ is calculated, according to the formula:

$$P_i = \sum_{j=1}^{M} Z_{ij}.$$

The costs of the activities measure the resource consumption, so it is possible to weigh all the activities. This procedure does not give more importance to the performance objectives that require more resources. It simply permits an activity to contribute to a performance level in relation to the investments that the activity requires. This is the significance of the passage from the matrix $X_{ij}$ to the matrix $Z_{ij}$. In fact, one result of the application of the IP2MS is to re-allocate the production resources in order to obtain the best performances at the minimum cost.

It is important to notice that the obtained performance profile $P_i$ is more accurate than a correspondent profile derived from a direct evaluation of the performances, without the weighted "two-by-two" (or "pair") comparisons.

## Comparisons between the actual and the desired levels of performance

The "desired performance scale" $D'_i$ is constructed. It is constructed in a different way in respect to the columns of the matrix $X_{ij}$: the "desired performance scale" $D'_i$ is obtained utilizing a more sophisticated weighted-ranking technique, with weights: 0, 0.25, 0.33, 0.50, 0.66, 0.75, 1.00. This is because of the lower number of people involved in interviewing (only the top managers and the production managers, not the production workers). In the construction of the "desired performance scale" $D'_i$ some assessments requested by the buyers are also considered, concerning the price, the delivery, the reliability, the innovation degree, the volume and mix flexibility, the quality level and the conformance of the products.

The $D'_i$ scale is then divided by $N*(N-1)/2$ and multiplied by $T = \sum_{j=1}^{M} C_j$, obtaining the "desired performance ranks" $D_i$, in order to compare them with the "actual performance ranks" $P_i$.

Finally, for each performance "$i$", the difference $\Delta_i$ between the actual and the desired levels of performance (in terms of "actual performance costs" $P_i$ and "desired performance costs" $D_i$) is calculated.

## Identification of the activities responsible for the major differences between the actual and the desired levels of performance

### Re-allocation of the production resources between the activities

Furthermore, using the matrix $Y_{ij}$ (which measures the activity importance of each activity for each performance), the activities responsible for the major differences between actual and desired performances can be indicated. If $\Delta_q$ is the greatest value among $\Delta_i$, we look at the row "$q$" in matrix $Y_{ij}$ to find the activities "$j$" with the highest values $Y_{qj}$ (i.e. the activities with the greatest impact on the performance "$q$"). Thus IP2MS permits the redirection of the productive energies and resources, indicating which performances are already satisfactory and which need to be improved, how many and which productive resources to divert from certain specific activities to others.

For example: if activity "A" is very efficient but not very flexible and vice versa activity "B" is flexible but not very efficient and none of the other activities demonstrate evident differences between actual and desired levels of efficiency and flexibility, then it is proposed, all resources being equal, that the efficiency of "B" be improved at the expense of that of "B". If the performances of the activities "A" and "B" are independent of each other, this can be obtained by simply reviewing the performance objectives; otherwise the productive resources must be re-allocated, with a transfer of the workforce or a redefinition of the technological investments in the two activities.

## Empirical findings: an example

Some enterprises of Northern Italy are testing the proposed system and the managerial implications seem to be interesting. We will briefly present an application to an Italian medium-sized mechanical firm, having implemented an ABC system.

In Tables I and II, the "performance rank matrix" $X_{ij}$ and the "activity priority matrix" $Y_{ij}$ are presented: there are eight measured performances and ten value-added activities; the non-value-added activities (such as set-ups, queues, moves, changeovers, reworks, maintenance and inspection) are not

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considered as activities which should be measured, but simply as costs (derived from the ABC system).

As $N = 8$ and $M = 10$, the sum of the values of the columns of the matrix $X_{ij}$ and the sum of the values of the rows of the matrix $Y_{ij}$ respectively value: 8*(8 – 1)/2 = 28 and 10*(10 – 1) = 45.

For example: the first column of the matrix $X_{ij}$ was constructed as, in regard to the activity "A", the following performance priorities exist: most important of all, volume flexibility, then quality conformance, next with the same degree of importance, efficiency delivery and reliability, followed by quality capability and mix flexibility, and finally innovation degree. The first row of the matrix $Y_{ij}$, instead, was constructed keeping in mind the impact that each single activity has on the performance "efficiency"; in order of decreasing importance: "A", "G", "C", of equal importance "B" "I" and "J", next "D" and "E", then "F", and finally "H".

The costs of the (value-added) activities, derived from the ABC system and utilized by the IP2MS, are listed in Table III, so the "performance weighted-rank matrix" $Z_{ij}$ can be constructed (Table IV).

$$\text{For example } Z_{11}\frac{5.352\times 4.0}{8(8-1)/2} = 0.764.$$

Using the formula: $P_i = \sum_{j=1}^{M} Z_{ij}$, the "actual performance ranks" $P_i$ can be calculated (Table V). The "desired performance scale" $D'_i$ is constructed ($\sum_{i=1}^{N} D'_i = N*(N-1)/2 = 8*(8-1)/2 = 28$), and then all the values $D'_i$ are divided by N*(N – 1)/2 and multiplied by $T = \sum_{j=1}^{M} C_j$, obtaining the "desired performance ranks" $D_i$ ($\sum_{i=1}^{N} D_i = T = \sum_{j=1}^{M} C_j = 35.398$, the total cost of all the activities), in order to compare them with the "actual performance ranks" $P_i$. The differences between $P_i$ and $D_i$ are $\Delta_i$. Obviously: $\sum\Delta_i = 0.000$.

It can be seen, from the column on the right in Table V, that the major differences in the level of performance concern quality conformance, efficiency and reliability (less than the desired levels), and quality capability and innovation (more than the desired levels). Through the matrix $Y_{ij}$, the activities that are more responsible for these performances can be indicated:

**Table I**
The "performance rank matrix" $X_{ij}$

| | A: Raw materials purchased | B: Nuts and bolts purchased | C: Part purchase | D: Milling | E: Lathing | F: Drilling | G: Gear cutting | H: Other works | I: Sub assembly | J: Final assembly |
|---|---|---|---|---|---|---|---|---|---|---|
| **Efficiency** | 4.0 | 6.5 | 3.5 | 5.0 | 6.0 | 6.0 | 6.0 | 0.5 | 6.5 | 6.0 |
| **Delivery** | 4.0 | 6.5 | 5.0 | 1.5 | 1.5 | 2.0 | 1.5 | 3.0 | 5.0 | 6.0 |
| **Reliability** | 4.0 | 2.0 | 6.5 | 1.5 | 1.5 | 6.0 | 1.5 | 4.5 | 6.5 | 6.0 |
| **Innovation** | 0.0 | 0.5 | 6.5 | 0.0 | 0.0 | 0.0 | 1.5 | 6.5 | 0.0 | 0.0 |
| **Volume flexibility** | 7.0 | 3.0 | 1.5 | 3.0 | 4.0 | 2.0 | 1.5 | 0.5 | 3.0 | 2.0 |
| **Mix flexibility** | 1.5 | 5.0 | 0.0 | 4.0 | 4.0 | 2.0 | 6.0 | 4.5 | 3.0 | 3.5 |
| **Quality capability** | 1.5 | 0.5 | 3.5 | 7.0 | 7.0 | 6.0 | 6.0 | 6.5 | 1.0 | 1.0 |
| **Quality conformance** | 6.0 | 4.0 | 1.5 | 6.0 | 4.0 | 4.0 | 4.0 | 2.0 | 3.0 | 3.5 |

**Table II**
The "activity priority matrix" $Y_{ij}$

| | A: Raw materials purchased | B: Nuts and bolts purchased | C: Part purchase | D: Milling | E: Lathing | F: Drilling | G: Gear cutting | H: Other works | I: Sub assembly | J: Final assembly |
|---|---|---|---|---|---|---|---|---|---|---|
| **Efficiency** | 9.0 | 5.0 | 7.0 | 2.5 | 2.5 | 1.0 | 8.0 | 0.0 | 5.0 | 5.0 |
| **Delivery** | 8.5 | 0.0 | 8.5 | 6.0 | 2.0 | 6.0 | 1.0 | 3.5 | 6.0 | 3.5 |
| **Reliability** | 6.5 | 0.5 | 9.0 | 3.0 | 3.0 | 6.5 | 0.5 | 3.0 | 6.5 | 6.5 |
| **Innovation** | 3.0 | 3.0 | 8.5 | 7.0 | 3.0 | 3.0 | 3.0 | 8.5 | 3.0 | 3.0 |
| **Volume flexibility** | 7.5 | 0.5 | 7.5 | 4.5 | 7.5 | 0.5 | 2.5 | 2.5 | 4.5 | 7.5 |
| **Mix flexibility** | 2.5 | 5.0 | 8.0 | 5.0 | 0.5 | 0.5 | 8.0 | 8.0 | 2.5 | 5.0 |
| **Quality capability** | 0.5 | 0.5 | 8.5 | 6.5 | 4.5 | 6.5 | 4.5 | 8.5 | 2.5 | 2.5 |
| **Quality conformance** | 5.0 | 2.5 | 8.0 | 8.0 | 0.0 | 8.0 | 5.0 | 5.0 | 1.0 | 2.5 |

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**Table III**
The cost of the activities $C_j$ (data from the ABC system)

| | A: Raw materials purchased | B: Nuts and bolts purchased | C: Part purchase | D: Milling | E: Lathing | F: Drilling | G: Gear cutting | H: Other works | I: Sub assembly | J: Final assembly |
|---|---|---|---|---|---|---|---|---|---|---|
| **Activity cost*** | 5.352 | 1.724 | 9.080 | 3.665 | 2.908 | 1.240 | 2.565 | 2.150 | 1.937 | 4.780 |

Notes
* mld. of Italian lire (total cost of all the activities $T = 35.401$)

**Table IV**
The "performance weighted-rank matrix" $Z_{ij} = \dfrac{C_j X_{ij}}{N(N-1)/2}$

| | A: Raw materials purchased | B: Nuts and bolts purchased | C: Part purchase | D: Milling | E: Lathing | F: Drilling | G: Gear cutting | H: Other works | I: Sub assembly | J: Final assembly |
|---|---|---|---|---|---|---|---|---|---|---|
| **Efficiency** | 0.764 | 0.400 | 1.135 | 0.654 | 0.623 | 0.266 | 0.550 | 0.038 | 0.450 | 1.024 |
| **Delivery** | 0.764 | 0.400 | 1.621 | 0.196 | 0.156 | 0.089 | 0.137 | 0.230 | 0.346 | 1.024 |
| **Reliability** | 0.764 | 0.123 | 2.108 | 0.196 | 0.156 | 0.266 | 0.137 | 0.346 | 0.450 | 1.024 |
| **Innovation** | 0.000 | 0.031 | 2.108 | 0.000 | 0.000 | 0.000 | 0.137 | 0.499 | 0.000 | 0.000 |
| **Volume flexibility** | 1.338 | 0.185 | 0.486 | 0.393 | 0.415 | 0.089 | 0.137 | 0.038 | 0.207 | 0.341 |
| **Mix flexibility** | 0.287 | 0.309 | 0.000 | 0.524 | 0.415 | 0.089 | 0.550 | 0.346 | 0.207 | 0.598 |
| **Quality capability** | 0.287 | 0.031 | 1.135 | 0.916 | 0.727 | 0.266 | 0.550 | 0.499 | 0.069 | 0.171 |
| **Quality conformance** | 1.147 | 0.246 | 0.486 | 0.785 | 0.415 | 0.177 | 0.366 | 0.154 | 0.207 | 0.598 |
| | 5.351 | 1.725 | 9.079 | 3.664 | 2.907 | 1.242 | 2.564 | 2.150 | 1.936 | 4.780 |

**Table V**
The "actual performance ranks" $P_i$, the "desired performance scale" $D'_i$, the "desired performance ranks" $D_i$, the differences $\Delta_i$ between the actual and the desired performance ranks

| | Actual performance ranks $P_i$ | Desired performance scale $D'_i$ | Desired performance ranks $D_i$ | $P_i - D_i = \Delta_i$ |
|---|---|---|---|---|
| **Efficiency** | 5.904 | 6.08 | 7.686 | –1.782 |
| **Delivery** | 4.963 | 4.42 | 5.588 | –0.625 |
| **Reliability** | 5.570 | 5.50 | 6.953 | –1.383 |
| **Innovation** | 2.775 | 1.17 | 1.479 | +1.296 |
| **Volume flexibility** | 3.629 | 2.08 | 2.630 | +0.999 |
| **Mix flexibility** | 3.325 | 2.08 | 2.630 | +0.695 |
| **Quality capability** | 4.651 | 1.17 | 1.479 | +3.172 |
| **Quality conformance** | 4.581 | 5.50 | 6.953 | –2.372 |
| | 35.398 | 28.00 | 35.398 | 0.000 |

- concerning efficiency, in order of importance the activities "A", "G", "C";
- concerning reliability, first of all the activity "C" and then the activities "A", "F", "I", "J";
- concerning innovation, first the activities "C" and "H", and then the activity "D";
- concerning quality capability, first the activities "C" and "H", and then the activities "D" and "F";
- concerning quality conformance, the activities "C", "D", "F".

Multiplying the differences $\Delta_i$ by the elements of the matrix $Y_{ij}$, it is possible to quantify the "performance objectives" for each activity, and to re-allocate the productive resources so as to respond better to the required performances. For example: about the efficiency, the activities held to that have the greatest impact (in terms of cost) on the performance "efficiency" are "A", "G" and "C", with respective values of –16.038, –14.256, –12.474 (i.e. –1.782*9.0, –1.782*8.0, –1.782*7.0); about the reliability, the impact of the activities "C", "A", "F", "I", "J" is respectively equal to –12.447, –8.989, –8.989, –8.989 –8.989 (–1.383*9.0 and –1.383*6.5); about the innovation degree, the impact of the activities "C", "H", "D" is respectively equal to +11.016, +11.016, +9.072 (+1.296*8.5 and +1.296*7.0); and so on.

For lack of space, we will only summarize some of the observations that emerged from the case examined, and not enter into any analytical details:

- activity "A" first of all must become more efficient and then more reliable;
- activity "C" must produce parts with better conformance and in second place be more efficient and reliable, even to the detriment of the already good quality capability and the high rate of innovation;

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- those responsible for the activities "D" and "F" must concentrate more on the quality conformance than on the quality capability;
- activity "G" must have greater efficiency in its performance;
- activity "H" does not need to have such a high level of innovation and quality, at least until the other performances have reached a higher level than at present.

## Conclusions

The proposed model can be considered innovative because it uses MPCS and ABC data in order to obtain the production performance levels and to re-allocate the productive resources of the firms on the basis of the difference between the actual and desired levels of performance. It is a method for evaluating performances and for productive resource management.

The soundness of the results depends on the reliability of the ABC data and the accuracy with which the $X_{ij}$ and $Y_{ij}$ matrices are constructed. As the only accounting data used are the cost of the activities, it could be that it is not necessary for the firm to have an ABC system, provided that the costs localized where the activities are carried out are calculated and accurate: these costs are the sum of the real costs of the activities themselves and those arising from the overhead costs distribution. In regard to the construction of the matrices $X_{ij}$ and $Y_{ij}$, which express assessments of the reciprocal importance of performances and activities, it is necessary to have quantitative measures available for the complete evaluation of each single performance by means of the measurement of basic components furnished by the MPCS (for example: the reliability of delivery by means of the completeness of the orders, the percentage of late orders, the average delay, the maximum delay, etc.). The list of basic components to be measured varies from firm to firm.

In conclusion, the model is proposed for evaluating company production performances in contexts where competitive advantages derive from both cost, time and quality performances, performances that are heterogeneous and not easily estimated. Thus an integrated examination of the performances and a quantitative and homogeneous appraisal are obtained.

## Note

1 ABC recognizes that costs originate from, and are driven by, factors other than volume; only raw materials and direct labour costs can be directly allocated to products. ABC is based on five steps:

1. identify the major activities performed, independently from the location in the firm;
2. determine the cost of those activities, as a consequence of the consumption of resources by the activities (first-stage drivers are used to trace the costs of inputs to the activity cost pool);
3. identify what drives those activities (second-stage drivers or simply "drivers", for instance, number of components, number of purchase orders, number of engineering changes);
4. combine each second-stage driver with every product;
5. compute activity-based product costs.

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