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Aggregation of performance measures for supporting decision makers

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Abstract

This work has presented and analysed three methods (Aggregation of information, aggregation of performance metrics and quantitative model for performance measurement systems based on ANP) for aggregating performance measurement information in order to provide decision-makers with additional information. The analysis has shown that the most complete method by far is the ANP, as it enables an easy modification of the initial structure of the performance measurement components, as well as a good performance regarding simplicity, visibility and presentation of information.

Keywords: performance measures; decision; information; aggregation.

1. Introduction

Nowadays, organisations have to compete in a pretty fast and fierce environment, which forces them to adopt management methods that effectively and efficiently help them to evaluate their performance at both the internal and the external level. More concretely, the measurement of key business processes of an enterprise is a vital task for properly managing an organisation. In this sense, the adoption of performance measures is a very good alternative as these facilitate to monitor and control an organisation's performance.

However, one of the biggest drawbacks when using performance measures is the high number of them that is possible to define at the operational level for each of those key business processes. Consequently, and from a decisional point of view, it raises the need of having them aggregated, facilitating therefore operations of control, as the decision-maker is enabled to focus only on a reduced number of key aggregated performance measures. Such an aggregation process should be supported by a methodology that provided the most economical and simple approach for carrying it out.

2. Information aggregation regarding performance management

Organisations should have an efficient and effective tool for managing their performance. Such a tool must be kept as simple as possible becoming a quick facilitator of decision-making processes. Then, when managers are asked to make a decision, the key issue is to clearly identify and assess the existing trade-offs among the different performance criteria (Mapes and Szewjczewski, 1997). For doing so, numerous multi-criteria decision aid (MCDA) methods have been developed, aiming to rank the different alternatives by weighting them regarding their importance.

Other important point is that Performance Measurement Systems (PMS) are dynamic in nature (Neely, 1999), as they change or may change quite often due to either internal or external factors. This is a crucial issue to take into account when assessing models for aggregating information of performance management components, as the more flexible such models are to introduce changes the more useful they will become to decision-makers.

According to Da Silveira (2001), it is possible to classify the most relevant of these MCDA methods into: goal programming, which solves conflictive objectives by using linear programming models; scoring methods, where regarding several criteria, different decision alternatives are evaluated and ranked; methods based on analytic hierarchical process model, which are based on pair-wise comparisons, weighting and ranking the different decision alternatives; and finally deployment techniques, such as the House of Quality included inside the quality function development (QFD) model.

In terms of giving a clear picture of how these techniques might help organisations to achieve consistent and useful aggregated performance management information in a simple way, and as these are the most extended within the academic literature, we have considered that it is important to further explain and apply three frameworks that are inside these MCDA methods: the information aggregation method (Berra et al., 2004); the method for aggregating performance metrics (Alfaro et al., 2001); and the alternative quantitative model for performance measurement systems (Suwignjo et al., 2001). The three of them follow a systemic view where the first step is to establish levels and identify priorities among the components of the system.

3. Mathematical techniques

In this point we shall present the three mathematical techniques used for aggregating information at the PMS context analysed in this paper.

3.1. Aggregation method

This method is based on Choquet's 2-additive integral compromise operators, which considers only pair-wise interactions (Guh, 1997). Choquet's 2-additive integral is based on two main compromise parameters:

1) *The Shapley parameters v_i,:* Satisfy equation 1, and whose objective is to quantify the weights of each performance criterion.

$$\sum_{i=1}^{n} v_i = 1 \tag{1}$$

2) The *interaction parameters I_{ij}:* between pairs of performance criterions and whose range is [-1, 1], where a value of 0 means no interaction, a value of 1 means positive interaction and a value of -1 means negative interaction.

Then, the resultant combined function is given by equation 2.

$$CI_g(P_1, P_2, ..., P_n) = \sum_{i=1}^{n} P_i (v_i - \frac{1}{2}\sum_{j \neq i} |I_{ij}| + \sum_{Iij>0} \min(P_i, P_j) I_{ij} + \sum_{Iij<0} \max(P_i, P_j) |I_{ij}| \tag{2}$$

with the property that

$$(v_i - \frac{1}{2}\sum_{i \neq j} |I_{ij}|) \geq 0 \tag{3}$$

Hence, it is necessary to identify how these two parameters are linked together, providing then to decision-makers a guideline for knowing how these combined coefficients are affecting to the aggregated performance evaluations. Therefore, the model defines the following:

- A positive I_{ij} implies that the simultaneous satisfaction of objectives O_i and O_j is significant for the aggregated performance evaluation, whereas that unilateral satisfaction has no effect.

- A negative I_{ij} implies that the satisfaction of either O_i or O_j is sufficient to have a significant effect on the aggregated performance evaluation.

- A null I_{ij} implies that no interaction exists; thus v_i acts as the weights in a common weighted mean.

Then, if there is no interaction between performance criteria, the v_i values are the weights of a combination by the weighted mean, enabling a better achievement of the commensurability issue.

This methodology has got two main phases:

1) *Top-down objective decomposition*: Where the strategic or first level objectives are broken down into second level or tactical ones and these into operational ones, where each operational objective must be expressed through a performance measure. At this point all the weights and interactions are identified, being the latter ones a result of managers' experience.

2) *Bottom-up performance combination*: At this point, Performance Indicators have been developed, being possible to aggregate them by common operative areas. Then, the methodology starts a two steps process, which firstly carries out a combination from operational to tactical levels and secondly a combination from tactical to strategic levels. In the latter, the combination to be made is of decisional nature and therefore, for avoiding the commensurability problem, it is necessary to build up interval scales between [0,1] for all the tactical criteria.

3.2. Method for aggregating performance metrics

This method takes as initial point the enterprise's objectives, developing then its methodology, which is broken down into the next four phases:

1. Description of the main objective to be analysed.

2. Definition of the hierarchical structure of both objectives and sub-objectives: Allocation of the relative importance to each sub-objective (weight) for achieving the immediately anterior.

3. Establishment of the parameters that enable the most concise evaluation of each of these sub-objectives: Allocation of the relative importance to each one (weight).

4. Searching and establishment of reference standards for every parameter.

It is important to point out that the weights given to each level of objectives, sub-objectives and parameters must sum up to 1 to assure consistency within the hierarchical network. The general expression is shown in equation 4.

$$N_aO_{ijk} = N_{a1}I_{ijk}*Pr_1I_{ijk} + N_{a2}I_{ijk}*Pr_2I_{ijk} +.....+ N_{av}I_{ijk}*Pr_vI_{ijk} \quad (4)$$

The nomenclature used by this method is the following:

$N_aO_{i,j,k}$,...up to as many levels as necessary (usually 3), being N_a the level reached by the objective $O_{i,j,k}$.

The sub-index 'i' means first level objectives; the sub-index 'j' means second level objectives; the sub-index 'k' means third level objectives, etc. It is possible to have as many levels as necessary at both hierarchical level and objectives level within the same level.

$PrO_{i,j,k}$ …. being Pr the relative importance in this particular case of the objectives $O_{i,j,1}$, $O_{i,j,2}$, ………

$tI_{i,j,k}$ … The symbol I means parameter used for measuring the objective $O_{i,j,k}$. The t distinguishes among the different parameters that serves to evaluate the objective $O_{i,j,k}$.

Consequently, this is a simple and effective method for aggregating performance management systems components. Its main drawback lies on its hierarchical structure as medium-big hierarchies considerably increases complexity, making it very difficult to introduce changes within the network.

3.3. Alternative quantitative model for performance measurement systems

The Quantitative Methods for Performance Measurement Systems was first developed by Suwignjo et al. (2000) and it uses the Analytical Hierarchical Process (AHP) (Saaty, 1980) for identifying factors affecting performance and their relationships. More recently, (Sarkis, 2003) developed the QMPMS based on the Analytical Network Process (ANP) (Saaty, 1996), improving the first tentative by introducing a feedback control element and therefore overcoming the rank-reversal problem. The initial point is to identify the performance elements hierarchy, gathering then the relationships among them. This is usually done by managers who fill in a pair-wise comparison questionnaire. Then, through the use of a specific AHP Software called ExpertChoice, these different judgements are integrated and therefore weights for all performance elements are worked out. Then, it is formed the called initial super-matrix for the decision network, which collects all the relationships existing among the different performance elements by filling in all the weights and inter-relationships among such elements. Finally, it is possible to obtain, within this final super-matrix, the combined effects of all performance factors on the main objective under study.

4. Application and analysis of results

These three techniques for aggregating performance measures were applied to real data taken from a Spanish ceramic manufacturer. As Fig. 1 shows, this practical application focuses on the strategic competitive priority of Incrementing Benefits (IB), from which the different sub-objectives at the second level objectives hang down; and from these, the Performance Indicators hang down. The priorities for second level objectives must be sum 1; besides, all the performance indicators coming from the same sub-objective must also sum up to 1. Hence, since the first stage of defining hierarchical objectives and their weighted links is common to all three techniques, as we described above, we will take as initial point for our research the next decision tree.

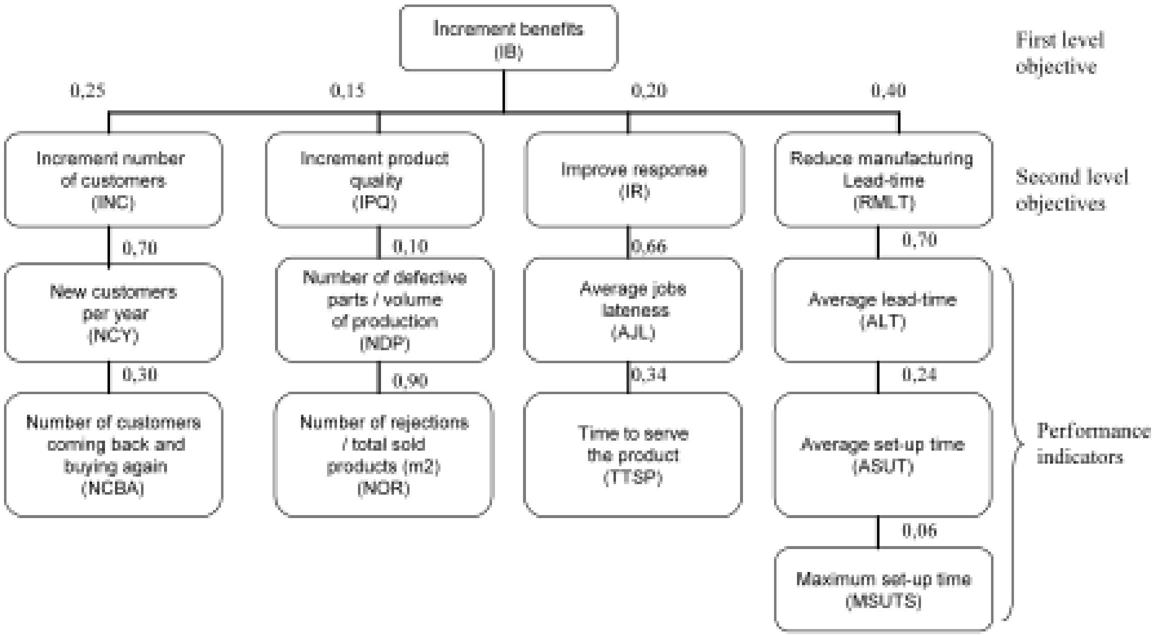

Figure 1. First common step: Initial hierarchical objectives tree

Figure 1 illustrates such a decisional tree, which is the result of introducing the operations managers' opinions into the Expert Choice software. As it is also known, from the managers' experience, there is a negative relationship or interaction between the "Improve Response" initiative and the "Increment Product Quality", which has been quantified as of 20% (0,20).

Next, we will apply the three methods above described.

4.1. Aggregation method

The phase one of the methodology, top-down decomposition, is fully covered by the first common step; we then proceed to develop the second phase: the bottom-up performance combination.

At the operative level, we find only physical measures or Performance Indicators (PI), which may also get grouped together into PIs of the same field. For our example, it would be possible to aggregate all the five PIs from the two sub-objectives "Improve Response" and "Reduce Manufacturing Lead-Time" as they apply to a manufacturing line.

For the next tactic level, performance measures are needed, as the combination to be made is of decisional nature. Table 1 shows the aggregated sum of the PIs of the different sub-objectives, which give a total value to be used when working out tactical performance measures.

Table 1. Perception of performance at tactical levels

TABLE I
PERCEPTION OF PERFORMANCE AT TACTICAL LEVELS

TACTICAL OBJECTIVE	PIs	Aggregated sum
Increase number of customers	NCY + NCBA	20%
Increment product quality	NDP + NOR	15‰
Improve response quickness	AJL + TTSP	1000 seconds
Reduce manufacturing lead time	ALT+ASUT+MSUTS	32minutes

The main problem at this stage is commensurability, being necessary to apply an interval scale within [0,1] to every tactic objective. In other words, it is necessary to identify the points for Performance = 0 and Performance = 1, for every tactic objective. Therefore, we will convert the performance evaluation into a linear scale. For instance, and for the Improve Response Quickness, we will consider that for an initial objective of increasing the benefits in a 10%, the improvement target on response quickness is of 630 seconds (this value comes from managers' experience); and over 1800 seconds the improve response quickness performance is null (this value also comes form managers' experience); finally, we see that the aggregated sum of PIs for this tactical objective is of 1000 seconds (this is a physical measure of the indicators); in conclusion, the performance as a linear scale would be:

Presponse = (1800 – 1000) / 1800 - 630, obtaining Presponse = 0,68.

By doing the same for the others three tactical objectives, we obtain their performance expressions as follows:

PINC = 0,5.

PIPQ = 0,5.

PRMLT = 0,6.

In the last step we calculate the strategic performance:

PIB = vINCPINC + vIPQPIPQ + vIRQPIRQ + v4PRMLT + (IIPQ-IRQ)min(PIPQ,PIRQ)

PIB = 0,25 * 0,5 + 0,15 * 0,5 + 0,20 * 0,68 + 0,40 * 0,6 + 0,2 * 0,5 = 0,676.

Therefore, the Performance evaluation of the strategic initial objective of Increasing the Benefits, as an aggregated result of downstream performance measurement components is 67,6%.

This is a good method for achieving compact results and offering a final strategic view of the situation to decision-makers. The main drawback is the difficulty of changing any of the elements it consists of. It would turn in re-calculating the system, which is a highly time-consuming task.

4.2. Method for aggregating performance metrics

Figure 2 shows the data that will be used for developing this example as well as the used nomenclature (already presented above).

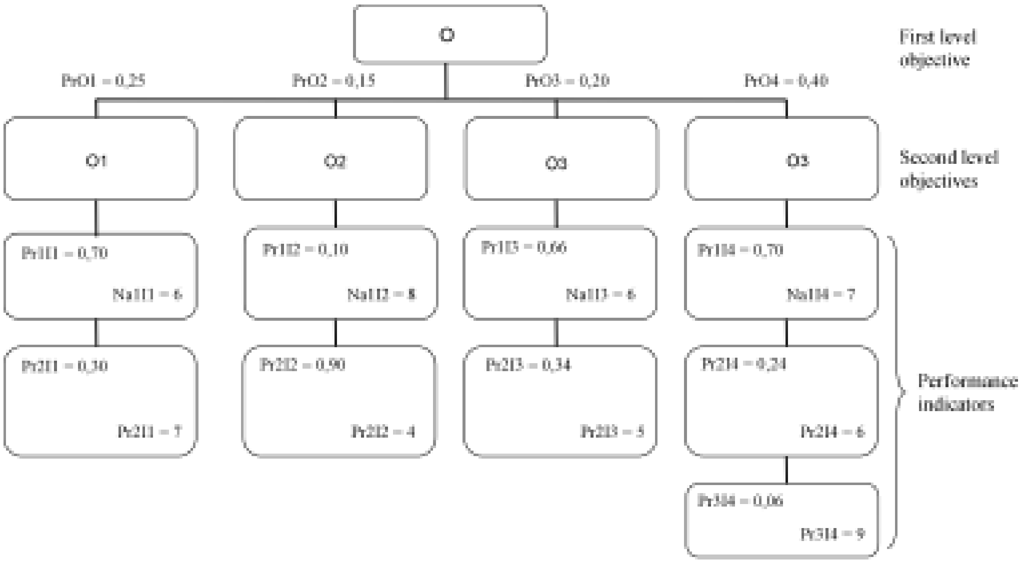

Figure 2. Data for the example and nomenclature

Results achieved at the last level are:

NaO1 = Na 1I1 * Pr 1I1 + Na 2I1 * Pr 2I1 = 6.3

NaO2 = Na 1I2 * Pr 1I2 + Na 2I2 * Pr 2I2 = 4.4

NaO3 = Na 1I3 * Pr 1I3 + Na 2I3 * Pr 2I3 = 5.66

NaO4 = Na 1I4 * Pr 1I4 + Na 2I4 * Pr 2I4 + Na 3I4 * Pr 3I4 = 6.8

Finally, the results reached at the first level are:

NaO = NaO1 * PrO1 + NaO2 * PrO2 + NaO3 * PrO3 + NaO4 * PrO4 = 6.119

Figure 3 graphically shows the final results.

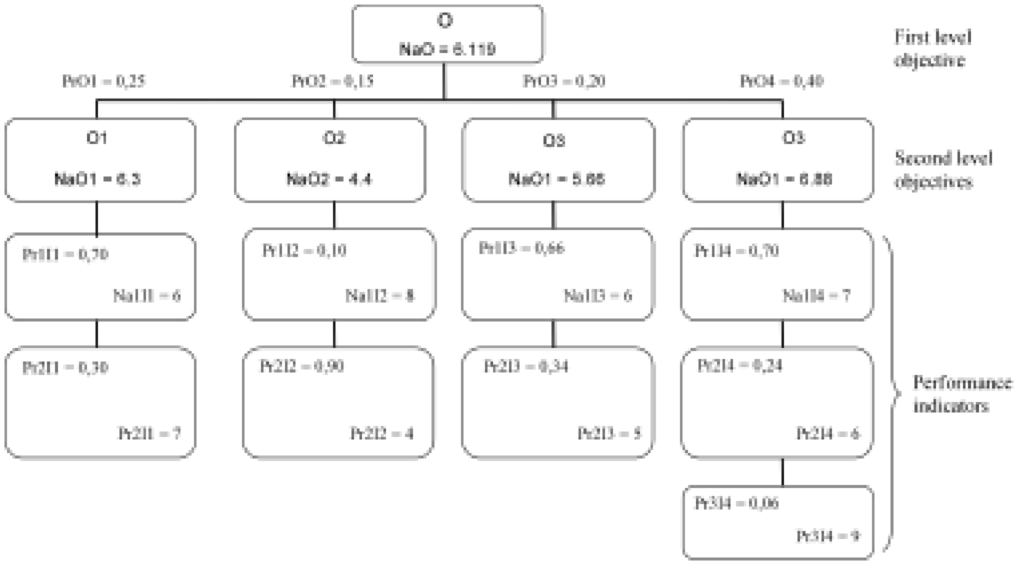

Figure 3. Results of the example

4.3. ANP (Alternative quantitative model for performance measurement systems)

The first step is to build up the initial supermatrix, which relates all the different objectives and sub-objectives from all levels. Once the initial supermatrix is been formed, it is time to work out the final supermatrix (Figure 4) following the appropriate transformation for which Matlab 7.0.1 has been used.

	IB	IR	INC	IPQ	RMLT	TTSP	AJL	NCY	NCBA	NDP	NOR	ALT	ASUT	MSUT
IB	1,00	0	0	0	0	0	0	0	0	0	0	0	0	0
IR	0,23	1,00	0	0,20	0	0	0	0	0	0	0	0	0	0
INC	0,25	0	1,00	0	0	0	0	0	0	0	0	0	0	0
IPQ	0,15	0	0	1,00	1,00	0	0	0	0	0	0	0	0	0
RMLT	0,40	0	0	0	0	0	0	0	0	0	0	0	0	0
TTSP	0,07	0,34	0	0,06	0	1,00	0	0	0	0	0	0	0	0
AJL	0,15	0,66	0	0,13	0	0	1,00	0	0	0	0	0	0	0
NCY	0,17	0	0,70	0	0	0	0	1,00	0	0	0	0	0	0
NCBA	0,06	0	0,24	0	0	0	0	0	1,00	0	0	0	0	0
NDP	0,01	0	0,06	0	0	0	0	0	0	1,00	0	0	0	0
NOR	0,01	0	0	0,10	0	0	0	0	0	0	1,00	0	0	0
ALT	0,10	0	0	0,70	0	0	0	0	0	0	0	1,00	0	0
ASUT	0,35	0	0	0	0,89	0	0	0	0	0	0	0	1,00	0
MSUT	0,04	0	0	0	0,11	0	0	0	0	0	0	0	0	1,00

Figure 4. Final supermatrix

The combined effects of all the factors over IB are showed in the first column of Table III. For instance, it is possible to observe that the performance indicator ASUT has an important effect over such a first level priority or IB. Besides, this supermatrix shows clearly all the interactions, in a pair-wise basis, between the different performance measurement components, providing a very good graphical picture of the system.

Additionally, it would be very easy to replace any of these performance components by others ones, forming a new initial supermatrix and calculating then the final supermatrix.

4.4. Presentation of results

As a consequence of the research above presented, it could be possible to affirm that, regarding to the assessment of information aggregation for performance measurement systems, the main variables to take into account are: simplicity of the system; flexibility (easy to introduce changes); visibility of all relationships of the system; and final presentation of information (level of aggregation). For evaluating the performance of these methods we have ranked them against these four main variables, from 1 to 5, being 1 the worst value and 5 the best one (see Table 2).

Table 2. Comparisons of methods

TABLE IV
COMPARISON OF METHODS APPLIED TO PMS

	Simplicity	Flexibility	Visibility	Information presentation	Total
Information aggregation	2	2	3	4	2,75
Aggregation performance metrics	4	3	3	3	3'25
Quantitative model for PMS	4	5	4	3	4

For evaluating the performance of these techniques we ranked them against four main variables -simplicity of the system; flexibility (easy to introduce changes); visibility of all relationships of the system; and final presentation of information- from 1 to 5, being 1 the worst value and 5 the best one. Then, the most complete method by far is ANP, as it enables an easy modification of the initial structure of the performance measurement components, as well as a good performance regarding simplicity (calculus through a mathematical software), visibility and presentation of information. On the other hand, the worst method is the Aggregation of information. Finally, the Aggregation performance metrics model has achieved a medium-high score in all the key variables.

5. Conclusions

This work has presented and analysed three methods (Aggregation of information, aggregation of performance metrics and quantitative model for performance measurement systems based on ANP) for aggregating performance measurement information in order to provide decision-makers with additional information. The analysis has shown that the most complete method by far is the ANP, as it enables an easy modification of the initial structure of the performance measurement components, as well as a good performance regarding simplicity (calculus through a mathematical software), visibility and presentation of information. On the other hand, the worst method is the Aggregation of information, as it is not very simple to use, and it does not enable easy changes among performance components. Finally, the Aggregation performance metrics method has achieved a medium-high score in all the key variables, being considered as the second more recommended method, out of the three studied, to be used for presenting aggregated information of performance measures to decision makers

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