Towards a Quantitative Performance Measurement Model in a Buyer-Supplier Relationship Context

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1. Introduction - problem statement

In the current industrial context, it is generally difficult for manufacturing companies to produce all the components of the products they propose. Thus, they either buy a large proportion of these components from suppliers or subcontract their manufacturing with other companies. This exchange of physical and informational flows between buyers and suppliers is then considered as a network. In terms of manufacturing and logistics, this network can be seen as a Supply Chain (SC) which connects the ultimate customer (buyer) to the ultimate supplier (Ayers, 2000) (Barut et al., 2002). On the other hand, the SC management requires an effective cooperation between suppliers and buyers. In this sense, the whole SC from raw material suppliers to the final customer can be seen as a set of buyer-supplier relationships. It means that the buyer-supplier relationship is the cornerstone of the SC management (Kelle et al., 2007).

One important point in the SC management concerns the measurement of the performance (Gunaserakan et al., 2008). Indeed, according to Deming's wheel, SC management requires performance indicators which handle:

- on the one hand the objectives, to be defined consistently with the capabilities of the considered system,
- on the other hand the measures of the achievement of the assigned objectives, in order to asses the achieved improvement and define the next actions to implement.

The performance measurement remains a difficult problem for companies as well as SC's. We choose here to subscribe to the performance vision based on the ISO 9000 standard. In this sense, the current scorecards generally collect sets of performance measurements about the main processes of the SC, usually according to the SCOR model (SCOR, 2000). Nevertheless, the question of the overall performance resulting from the process performances is rarely considered. Indeed, performance indicators are associated to each process. However, the provided performances are independently defined, as each process is evaluated separately from the others. This partitioned vision does not allow to consider SC as a whole and thus to efficiently control it. In this sense, the involved indicators must be supplemented by the knowledge of the links between them. Therefore, the interest for an overall performance expression for all or a part of the SC is acknowledged, as is the case for

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process control in individual companies. Indeed, for a SC considered as a whole, this expression can help decision-makers in many situations.
The aim of our proposition is the overall performance quantification in a SC context, through the handled set of buyer-supplier relationships. The work here presented is based on the synthesis of previous studies in this field (Clivillé & Berrah, 2005), (Berrah & Clivillé, 2007). More precisely, the idea is to extend the proposed approaches to the case of individual companies. In this sense, this chapter is organized as follows. In section 2, some generalities about the SC are recalled. Section 3 deals with the industrial performance measurement, first with a review of Performance Measurement Systems (PMS's) from a general point of view. Then we focus on the proposed quantitative performance measurement model. The considered model for the SC is the SCOR one while the process performance quantification is supported by both the multicriteria MACBETH methodology and the 2-additive Choquet Integral operator. Then, in section 4, an overall performance measurement framework is presented through a case study submitted by a bearings manufacturer.

2. Some generalities about the SC

Among the propositions made to model the SC (Villa, 2001) the SCOR (Supply Chain Operations Reference) model (SCOR, 2000) proposes to distinguish 4 abstraction levels, going from the more generic one (level 1) to the more particular (level 4) (figure 1). At level 1, each company of the SC is described through 5 processes: *Plan – Source – Make – Deliver – Return*. At level 2, these processes are specified (e.g. the *Source* process is identified in the S1 process *i.e. Source Stocked Product* process, or the S2 process *i.e. Source Make-to-Order Product* or the S3 process *i.e. Source Engineer-to-Order Product*). At level 3, the processes of level 2 are deployed into sub-processes according to the company organization. At level 4, the activities which constitute the sub-processes are defined specifically w.r.t. the organization of the company. According to the previous definitions, the SCOR model takes the different SC flows into account in a common manner. Indeed, the set of categories of processes and sub-processes is able to represent the different types of manufacturing organisation. So, it is easier for the decision-makers to consider the whole SC, which is a necessary condition for the management to consider the consequences of their decision (Berrah & Clivillé, 2007).
Besides, the measurement of the SC performance (Beamon, 1998) remains a difficult problem (Angerhofer & Angelides, 2006), which is often handled in two different ways:

- the SC performance is the result of, respectively, the intra-organisational performance of the different companies implied in the SC and, the performance of the interaction between the different companies of the SC (Angerhofer & Angelides, 2006),
- the SC is conventionally seen as a particular process, and its performance is thus expressed w.r.t. the process recommendations of the ISO 9000 standard (Clivillé et al., 2007).

According to the second approach, the current scorecards generally collect sets of performance measurements from the processes of the SC, usually w.r.t. the SCOR model. As an illustration, Gunaserakan collects, in table 1, the main strategic, tactical and operational indicators, according to the *Plan – Source – Make - Deliver* processes of SCOR (Gunaserakan et al., 2004).

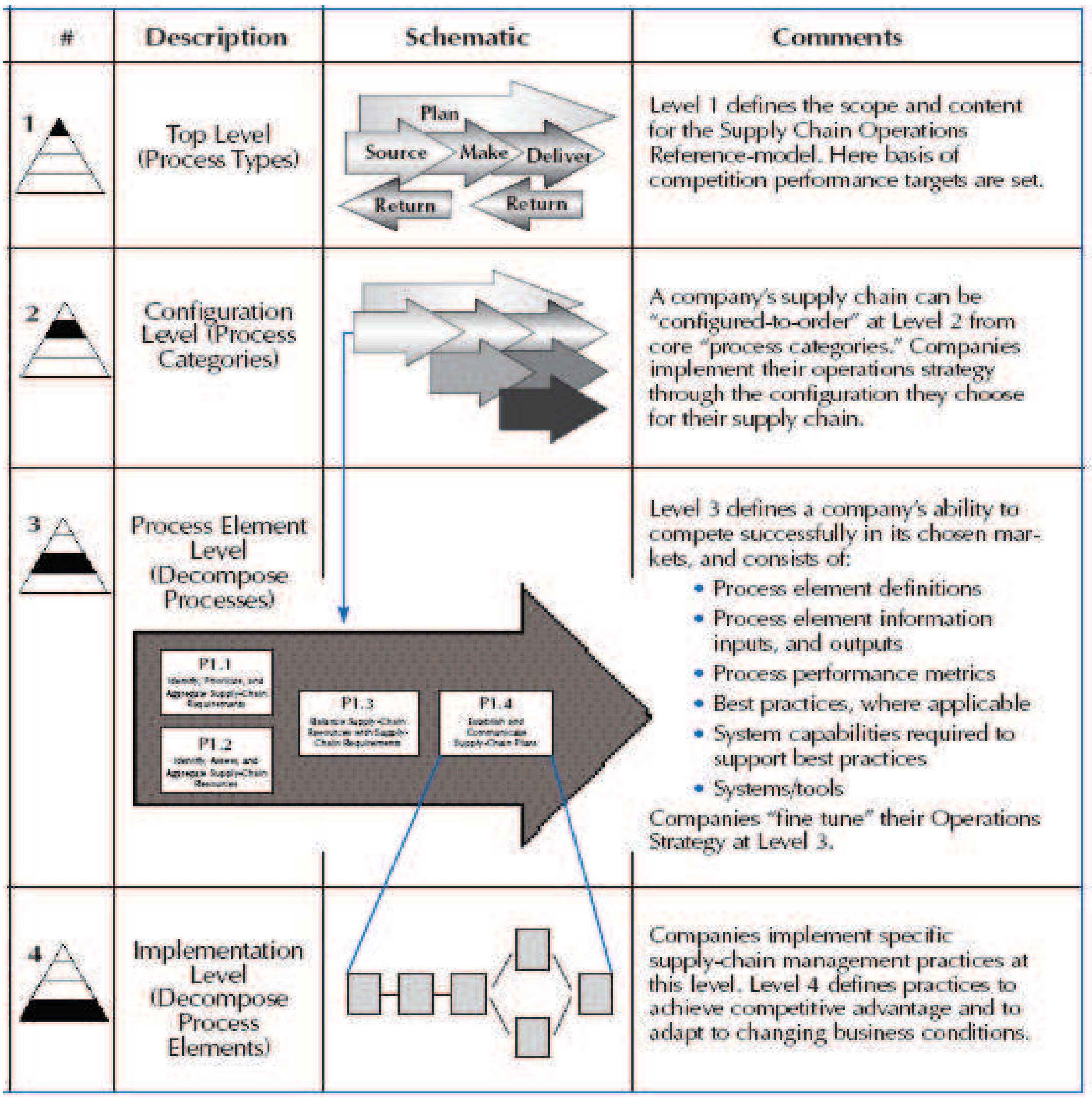


Figure 1. The SCOR model (SCOR 80, 2007)

Note that in this case, no strategic indicators are associated to the *Source* process. Nevertheless, we can imagine similar measures as for the tactical level, such as delivery, lead time, pricing… Moreover, the question of the overall performance resulting from the process performances is rarely approached. Indeed, performance indicators are associated to each process of SCOR, thus providing information for the control. As viewed before, this practice induces a risk because each process is separately evaluated from the others.

This partitioned vision does not allow to consider SC as a whole and thus to efficiently control it. In this sense, the involved indicators must be implemented by information concerning the links between them (Lohman et al., 2004) (Blanc et al., 2007). Therefore, the interest for an overall performance expression for all or a part of the SC is acknowledged, as is the case for process control in individual companies. Indeed, for a SC, this expression can help decision-makers (Chan, 2003):

- to compare different organizations (e.g. the location of the warehouses),
- to manage and improve the whole SC (e.g. a change of supplier, the transition from *make-to-stock* to *assembly-to-order*…),
- to diagnose the main causes of an unsatisfactory overall performance,
- to benchmark all or a part of the SC (e.g. the delivery reliability is worse than the median of the class).

SC activity/ process	Strategic	Tactical	Operational
Plan	Level of customer perceived value of product, Variances against budget, Order lead time, Information processing cost, Net profit Vs productivity ratio, Total cycle time, Total cash flow time, Product development cycle time	Customer query time, Product development cycle time, Accuracy of forecasting techniques, Planning process cycle time, Order entry methods, Human resource productivity	Order entry methods, Human resource productivity
Source		Supplier delivery performance, supplier lead time against industry norm, supplier pricing against market, Efficiency of purchase order cycle time, Efficiency of cash flow method, Supplier booking in procedures	Efficiency of purchase order cycle time, Supplier pricing against market
Make/ Assemble	Range of products and services Percentage of defects, Cost per operation hour, Capacity utilization	Utilization of economic order quantity	Percentage of Defects, Cost per operation hour, Human resource productivity index
Deliver	Flexibility of service system to meet customer needs, Effectiveness of enterprise distribution planning schedule	Flexibility of service system to meet customer needs, Effectiveness of enterprise distribution planning schedule, Effectiveness of delivery invoice methods, Percentage of finished goods in transit, Delivery reliability performance	Quality of delivered goods, On time delivery of goods, Effectiveness of delivery invoice methods, Number of faultless delivery notes invoiced, Percentage of urgent deliveries, Information richness in carrying out delivery, Delivery reliability performance

Table 1. SC performance indicators.

Our study is based on the SCOR model. We look for the overall performance quantification of a SC on the one hand and the explanation of the different involved links on the other hand. In the following sections, we are going to formalize this performance, by making first a literature review.

3. The industrial performance measurement

3.1 A brief literature review

The purpose of performance indicators is, on the one hand, to give pieces of information about the satisfaction of the assigned objectives and on the other hand to link the current measures to the improvement actions to launch (Berrah & Mauris, 2002) (Bitton, 1990) (Fortuin, 1988). In this sense, so-called Performance Measurement Systems (PMS's) are the instruments to support decision-making (Bititci, 1995) (Ghalayini et al., 1997) (Globerson, 1985) (Kaplan & Norton 1992) (Neely, 1999) (Clivillé, 2004) in continuous improvement processes.

From a global point of view, a PMS can be seen as a multi-criteria instrument, made of a set of performance expressions (also referred to as metrics by some authors (Melnyk 2004)), *i.e.* physical measures as well as performance evaluations, to be consistently organized with respect to the objectives of the company (Berrah et al., 2000) (Clivillé et al., 2007a). A PMS is defined w.r.t. a global objective and at the end, provides one or a set of performance expressions in order to quantify the satisfaction of this objective.

Generally, the considered global objective is broken down into elementary ones along organizational levels (strategic, tactical or operational) (Grabot, 1998) (Gomez et al., 2001), while the elementary performance expressions associated to the broken-down objectives can be aggregated, providing information about the global satisfaction. As will be seen later, such a quantitative break-down/aggregation performance measurement model (Berrah et al., 2004) (Clivillé et al., 2007a) has been proposed for the performance improvement process control, being thus a support for decision-making. Indeed, there are limits to the decision-maker's ability to process large sets of performance expressions. So, a more synthesized piece of information completes the numerous considered scorecards, leading thus to a global vision of the involved processes. More particularly, the established links between overall and elementary performance expressions allow explanation and diagnosis of the objective's satisfactions according to the different reached performances, leading thus to choose or launch improvement actions (Bititci, 2001) (Clivillé, 2004). More precisely, it is well known that one challenge of control is to identify "coalitions" of improvement between different areas in as efficient as possible a way (Clivillé & Berrah, 2007b).

More particularly, in this sense, one major problem in PMS modelling concerns two points:

- the identification of the performance structure, *i.e.* on the one hand the elementary criteria which contribute to the global objective and, on the other hand, the coherent expression of the performances which reflects the objective's satisfactions according to the different criteria,
- the identification of the links between the elementary expressions and the overall one in order to express the global objective's satisfaction.

The performance structure is widely considered in the literature. Indeed, most of the PMS proposals are logical frameworks for linking strategic objectives and structuring the tactical and operational criteria affecting them as shown in table 2.

The link identification problem is handled w.r.t. the aggregation of the elementary performance expressions. The performance aggregation is often defined as the corollary step of the break-down of the objectives. This operation deals with the combination of all the associated performance expressions. In this sense, two PMS types are distinguished, the mono-criterion PMS and the multi-criteria PMS, as shown in table 3.
Note that the performance expressions are generally considered independently from one another. They are usually provided from the comparison of the assigned objectives and the measures which describe the considered processes or activities' enactment. These measures usually come from physical sensors or human operators. Nevertheless, according to Taylorian local control, performances can be simply quantified by physical measures or by productivity ratios. But in a multi criteria vision, the coherence between elementary and aggregated performances becomes necessary.

PMS model	Focuses
SMART (System Measurement Analysis and Reporting Technique) model (Cross & Lynch, 1988-89)	Break-down of the objectives of the company along 4 levels – company, business units, business operating units and departments and work centres - according to 10 measures such as delay, quality, customer satisfaction…
ABC/ABM (Activity Based Costing/Activity Based Modelling) model (Brimson, 1991)	Identification of the activities and processes which generate value in the company and the factors which induce this value production.
Balanced Scorecard BSC (Kaplan & Norton, 1992, 1996)	Definition of 4 axes (criteria) - processes, organisational learning, financial and customers - in order to express company performance.
PPMS (Process Performance Measurement System) (Kueng & Krahn, 1999)	Measurement of the company performance according to 5 aspects - financial, innovation, customer, societal and employee.
ECOGRAI (Bitton 1990) (Ducq et al., 2001)	Identification of 3 criteria - delay, quality and cost – for all the processes/activities of the company.
Quantitative Breakdown/Aggregation Performance Measurement model (Clivillé et al. 2007a)	Identification of the performance indicators and their organization for a reactive control according the systemic approach

Table 2. The major PMS models

According to the measurement theory (Kranz et al., 1971), ensuring the coherence requirement in the performance quantification process implies that:

- the elementary expressions must be «commensurate», *i.e.* two identical values (e.g. 0.8) according to two different criteria (e.g. *Lead_time* and *Quality*) must have the same meaning for the decision-makers,
- the aggregation operator must be «significant» w.r.t. the elementary expressions. For example, if the aggregation operator is the arithmetic mean, the significance condition is translated into the following proposition: for each criterion, the same difference between two values must have the same meaning (e.g. [0.8 - 0.5] and [0.4 - 0.1]). This condition ensures that an elementary performance can be compensated by another one.

Now, if the aggregation operator is the product, the condition will not concern the difference but the ratio.

PMS model	Type	Aggregation mechanism
Accounting (Johnson, 1975)	Mono criterion	Addition of elementary costs
ABC (Berliner & Brimson, 1988) (Cooper & Kaplan, 1988)	Mono criterion	Addition of elementary costs according to company Activity Based Model
Time based performance measures (Azzone et al., 1991)	Mono criterion	Addition of elementary durations
PCS (Performance Criteria System) (Globerson, 1985)	Multi criteria	Aggregation of "critical" performances thanks to the Weighted Arithmetic Mean (WAM)
ECOGRAI (Bitton 91) (Ducq et al., 2001)	Multi criteria	Aggregation of 3 criteria - delay, cost, and quality – thanks to specific aggregation operators - *min, max, sum* – w.r.t. both the involved criterion and the combination type of the activities - *or, and, sequence* – in processes
QMPMS (Quantitative Model Performance Measurement System) (Bititci 1995) (Suwignjo & Bititci, 2000),	Multi criteria	Identification of the criteria to be considered thanks to a cognitive map and aggregation thanks to the WAM operator. Integration of a corrective factor to take interactions between criteria into account. Using of the AHP methodology to define weights.
Quantitative Breakdown/Aggregation Performance Measurement model (Clivillé et al. 2007a)	Multi criteria	Identification of the criteria to be considered thanks to a cause-effect diagram and aggregation thanks to the Choquet Integral (CI) operator. Using of the MACBETH methodology to identify both elementary expressions and CI parameters

Table 3: The different aggregation approaches

The Analytic Hierarchy Process (Saaty, 1977, 2004) methodology was the first to deal with this awkward task. Ratio scales[1] are built from human expertise in order to quantify the weights of the WAM operator. In this approach, the required determination of an "absolute" null performance remains a difficult task in an industrial context where the performance is particularly relative. In the same way, the MACBETH (Multi Attractiveness Categorical Based Evaluation TecHnique) methodology (Bana e Costa et al., 2003) (Bana e Costa et al., 2004) (Clivillé, 2004) (Clivillé et al., 2007a) has been used to coherently express both the elementary and aggregated performance expressions. In MACBETH, these conditions are ensured thanks to the building of particular scales, well adapted for the family of arithmetic

[1] For the sake of conciseness, the scale aspect is not developed in this article. It is possible to find more information about ordinal, interval, ratio scales in (Bane e Costa et al., 2003) (Kranz et al., 1971).

mean operators (in accordance with the measurement theory). Moreover, in a context where the criteria are interdependent, the Choquet Integral (CI) operators can be used. This operator family generalizes the WAM operator by taking mutual interactions between criteria into account (Berrah et al., 2004) (Grabisch, 1997) (Grabisch & Labreuche, 2004) (Marichal, 2000).
Let us now focus on the mechanism of performance quantification, as it is adopted in the quantitative breakdown-aggregation performance measurement model mentioned before, and which is based on the MACBETH methodology illustrated by the figure 1.

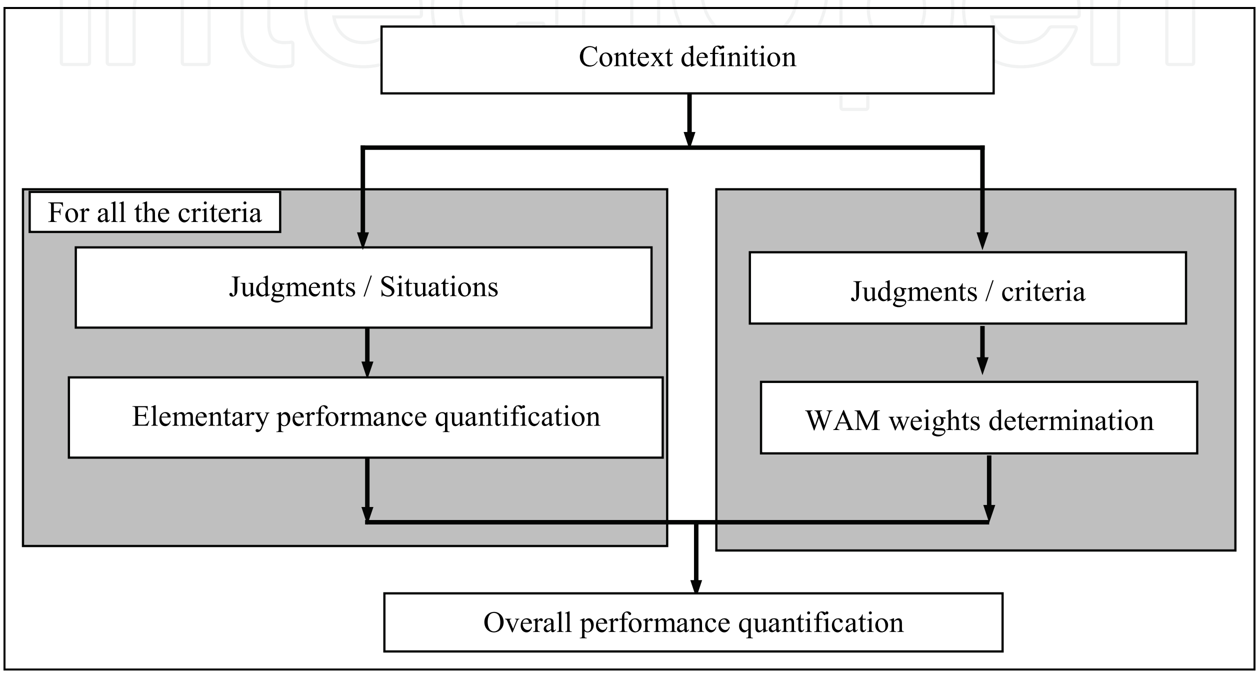


Figure 1. The MACBETH methodology.

3.2 The mechanism of performance quantification

3.2.1 Description of the problem

The quantification of the performance expressions can be viewed as a procedure which, in a first step, quantifies the elementary performances. The second step then consists in their synthesis in an overall performance expression, generally thanks to an aggregation operator. Hence, the performance aggregation can be formalized by the following mapping (Berrah et al., 2004):

$$Ag: \quad E_1 \times E_2 \times ... E_i \times ... E_n \times \rightarrow E$$

$$(p_1, p_2 ..., p_i ..., p_n) \rightarrow p_{Ag} = Ag(p_1, p_2 ..., p_i ..., p_n)$$

The E_i 's are the universes of discourse of the elementary performance expressions $(p_1, p_2 ..., p_i ..., p_n)$ and E is the universe of discourse of the overall performance expression p_{Ag}. As the universes E_i's and E can be different, the determination of the aggregation mapping Ag is generally not straightforward.

Example: Let us consider a simple example from (Gunaserakan et al., 2004) with 4 criteria about the *Source* process performance. In order to compare the different suppliers for improving the buyer-supplier relationships, let us imagine that we need to aggregate the performances related to the 4 following criteria: the *Lead_time*, the *Quality*, the *Cost_saving_initiatives* and the *Supplier _pricing* (Figure 2).

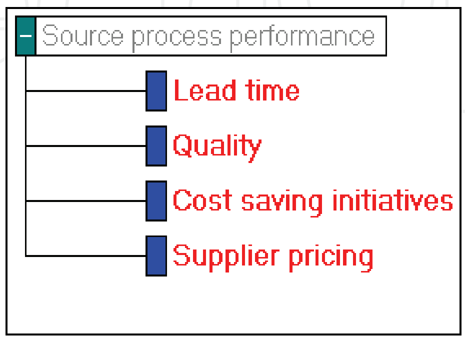


Figure 2. The criteria for the Source process performance

For a given supplier, let us consider it possible to express the following elementary measures: $m_1 = 12 days$ for the *Lead_time*, $m_2 = 99{,}3\%$ for the *Quality*, average_*delay* $m_3 = 30$ K€ for the *Cost_saving_initiatives* and $m_4 = 13.5$ € for the *Supplier _pricing*.

In this case, directly determining the supplier overall performance is an awkward task. One way to simplify this problem is to translate the elementary measures into satisfaction degrees, so called elementary performance expressions, and to define the links between the local satisfactions and the global one by the weighted mean for instance. Indeed, the aggregation operation can be performed if and only if the elementary performances are expressed and the aggregation operator is selected and defined.

3.2.2. Elementary performance expression

Generally speaking, the transformation of physical measures into performance expressions can be given according to the following mapping (Berrah et al., 2004):

$$P: \quad O \times M \rightarrow E$$

$$(o,m) \rightarrow P(o,m) = p$$

O, M and E are respectively the universes of discourse of the set of objectives *o*, of the set of measures *m* and of the performance expression p. The key point in differentiating this kind of performance expression from conventional measurements is the comparison of the acquired measures with an objective defined according to the control strategy considered. Thus, the mapping P denotes a comparison operator such as a distance operator or a similarity operator (Berrah et al., 2004).

But we have already highlighted that the elementary expressions have to be commensurable and the aggregation operator must be significant for this expression (Grabisch et Labreuche,

2004). To respect these two points, rather than using a direct comparison operator, MACBETH proposes to define interval scales on [0,1] elaborated thanks to decision-makers' judgments (Bana e Costa & Vansnick, 1997) (Vansnick, 1984).
Example: Let us consider the previous example. Table 4 gives the judgments of the SC decision-maker concerning the *Lead_time* criteria w.r.t. 3 different steel furniture suppliers, S1, S2, and S3. These suppliers are thus compared. 2 fictive suppliers are introduced for reference: "*Supplier Good*" which entirely satisfies the considered criteria and "*Supplier Neutral*" which does not satisfy them at all.

Lead time

	Good	S2	S1	S3	Neutral	Current scale
Good	no	v. strong	positive	positive	positive	100.00
S2		no	very weak	positive	positive	61.54
S1			no	moderate	positive	53.85
S3				no	strong	30.77
Neutral					no	0.00

Decision-maker **moderately** prefers supplier S1 to supplier S3

Consistent judgements

Table 4. The SC decision-maker judgments about *Lead_time* (M-MACBETH software[2])

The MACBETH software handles these comparisons and delivers elementary expressions, e.g. the performance of the supplier S2 concerning *Lead_time* is 0.62. In the same way, the decision-makers give their judgments about the other criteria, which allows them to establish the Table 5. At this stage, the results are the same as a scorecard. The decision-maker is able to identify the strengths and the weaknesses of the potential suppliers but he cannot decide which is the best, because there is no Pareto dominance between them. That is why an overall performance associated to each supplier is useful.

	p_1	p_2	p_3	p_4
Supplier S1	0.54	0.55	0.20	0.56
Supplier S2	0.62	0.64	0.50	0.44
Supplier S3	0.31	0.82	0.20	0.67

Table 5. The elementary performance expressions

3.2.3 Determination of the aggregation operator parameters

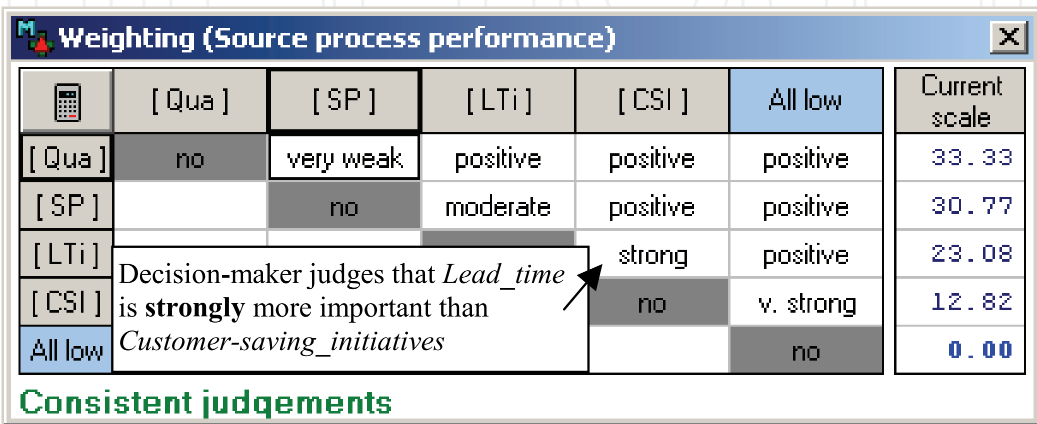
The elementary performances being available, this step concerns the choice of the aggregation operator and thus the determination of its parameters. The most frequently used operator is the WAM (1).

$$\sum_{i=1}^{n} w_i \times p_i \quad (1)$$

[2] A free academic version is available on http://www.m-macbeth.com/

where w_i represents the relative importance of the criteria *i* in the overall performance.

To determine w_i, the decision-maker is asked about the importance of the criteria w.r.t. the overall performance. In this order, he has to express judgments where the relative importances of the criteria are compared. Note that MACBETH also handles this information and allows the SC decision-maker to quantify the weights.
Example: Let us consider our example once again. The decision-maker expresses his judgments about the four identified criteria (Table 6).



	[Qua]	[SP]	[LTi]	[CSI]	All low	Current scale
[Qua]	no	very weak	positive	positive	positive	33.33
[SP]		no	moderate	positive	positive	30.77
[LTi]				strong	positive	23.08
[CSI]				no	v. strong	12.82
All low					no	0.00

Table 6.The decision-maker's judgments about criteria

He considers that the *Quality (Qua)* criterion is more important than the *Supplier pricing (SP)* criterion in a supplier selection process. The difference between the 2 criteria is for him "very weak". He also expresses enough comparisons to compare all the criteria. These pair-wise comparisons are considered in a global system by the MACBETH software. The following weights are thus provided (Table 7).

	w1 Lead_time	w2 Quality	w3 Cost_saving_initiatives	w4 Supplier_pricing
Value	0.23	0.31	0.13	0.33

Table 7. The criteria weights

3.2.4 Overall performance expression

By applying the weighted mean operator, an overall performance of each supplier, for the *Source* process, can be expressed as shown in Table 8.

	p1	p2	p3	p4	PAg
Weights	0.23	0.31	0.13	0.33	
Supplier S1	0.54	0.55	0.20	0.56	0.50
Supplier S2	0.62	0.64	0.50	0.44	0.55
Supplier S3	0.31	0.82	0.20	0.67	0.57

Table 8. The aggregated performance expressions

The decision-maker can now rank the suppliers S1, S2, S3. After a validation of his quantification model, he can draw many conclusions:

- retain the best supplier with regards to the overall performance,
- discuss with the best supplier in order to remedy its weaknesses,
- ask the other suppliers to improve their performances,
- launch a new consultation for a better supplier selection.

The decision will be made w.r.t. other supplementary aspects such as, e.g. the previous relations with the suppliers, the portfolio of products outsourced, the perspectives of new product development… in other words the company policy.

3.2.5 The case of imprecise performance expressions

In the previous table, both the elementary and the aggregated performances were precisely expressed. In the industrial decision-making, according to the complex encountered situations, information can be uncertain or imprecise, even linguistically expressed (Berrah et al., 2000). For a selection problem, this imprecision is not necessarily awkward. Indeed, the ranking between the considered solutions is kept if sufficient information is given in another way by the decision-makers. In this sense, MACBETH allows the handling of of imprecise judgments, in both the weights determination and the elementary performance expression. Imprecise aggregated performance is thus provided. The process of quantification of the decision-makers' judgments is modified because the intensities of preferences are translated as, for instance, into fuzzy values (MACBETH scale) instead of crisp values (cardinal scale).
Figure 3 gives an illustration for imprecise handling of the decision-makers' judgments considered before (§ 3.2.2 & 3.2.3).

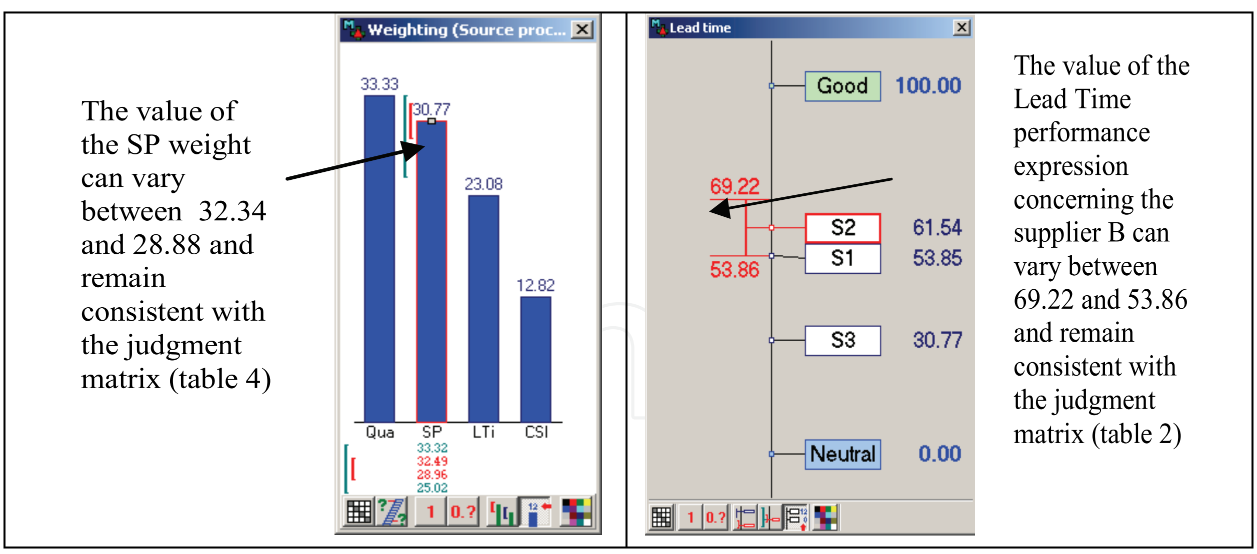


Figure 3. The results of imprecise judgments

Is it possible to compare imprecise aggregated performances? The answer to this question naturally depends on the available information. MACBETH indicates in this sense the necessary information (precise or imprecise) to have w.r.t. the elementary expressions and the weights (Figure 4). For example, to be sure that C supplier is better than A supplier, it is sufficient to have imprecise information concerning the elementary expressions and a ranking of the criteria. On the opposite side, to be sure that supplier C is better than supplier B, it is necessary to have precise values.

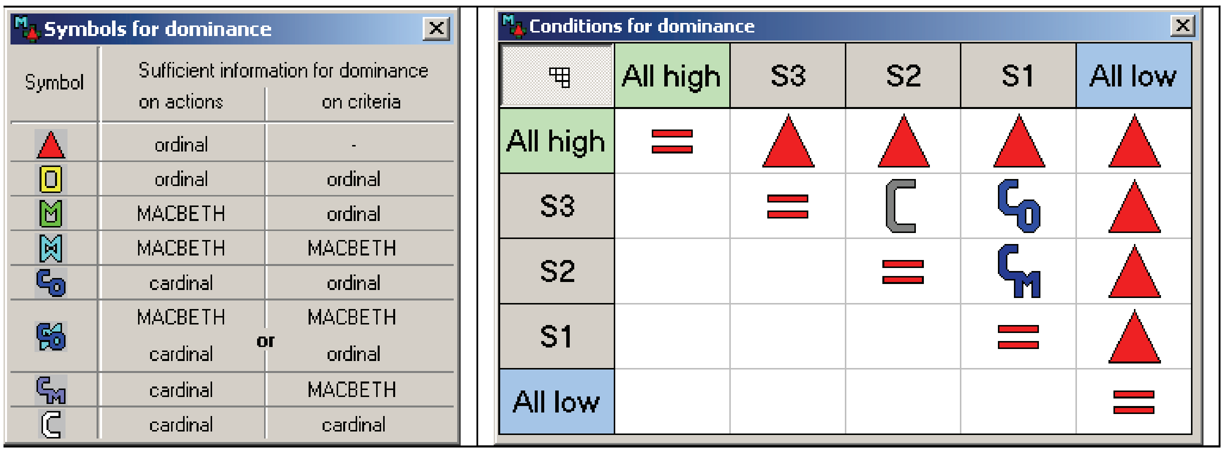


Figure 4. Possible types of comparisons for Suppliers.

4. Case study

The case study concerns a bearings company with its suppliers and deliverers. The company works for automotive and aeronautics companies, spatial and some other high-tech activities. The suppliers are, on the one hand European or Asian steel producers and, on the other hand, SMEs specialized in precision milling and grinding. In order to improve its buyer-supplier relationships, the company overall objective is to subscribe to a total SC point of view and to measure the impact of the defined improvement projects not only on the performance of the company but also on the performance of the SC, namely the 4 main processes according to SCOR, *i.e.* ***Plan, Source, Make, Deliver***[3] (SCOR, 2000) (Gunaserakan et al., 2004) (Figure 5).

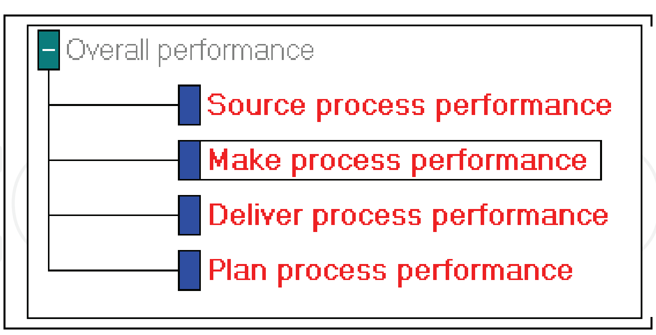


Figure 5. The break-down of the company overall objective

To reach a satisfactory overall performance, the decision-maker defines different improvement projects as alternative solutions:

- the collaboration buyer-supplier relationships (CBS),

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[3] The process *Return* proposed in the recent SCOR model is not retained here, its contribution to the overall performance being more complex to handle.

- the Co-Managed Inventory (CMI),
- the e-business solution (EB),
- the low-cost supplier (LCS),
- the Supplier evaluation procedure (SEP).

4.1 Elementary performance expression

Elementary performances are quantified for all the solutions. The complete results are given Figure 6.

Plan process performance

	Good	ERP	CMI	CBS	EB	LCS	Neutral	Current scale
Good	no	moderate	positive	positive	positive	positive	positive	100.00
ERP		no	weak	strong	positive	positive	positive	81.25
CMI			no	strong	positive	positive	positive	68.75
CBS				no	moderate	positive	positive	43.75
EB					no	moderate	positive	25.00
LCS						no	positive	6.25
Neutral							no	0.00

Make process performance

	Good	ERP	CBS	CMI	EB	LCS	Neutral	Current scale
Good	no	strong	positive	positive	positive	positive	positive	100.00
ERP		no	weak	positive	positive	positive	positive	71.43
CBS			no	strong	positive	positive	positive	57.14
CMI				no	very weak	positive	positive	28.57
EB					no	very weak	positive	21.43
LCS						no	weak	14.29
Neutral							no	0.00

Source process performance

	Good	CBS	CMI	ERP	EB	LCS	Neutral	Current scale
Good	no	very weak	positive	positive	positive	positive	positive	100.00
CBS		no	weak	positive	positive	positive	positive	94.12
CMI			no	strong	positive	positive	positive	82.35
ERP				no	positive	positive	positive	58.82
EB					no	v. strong	positive	52.94
LCS						no	strong	23.53
Neutral							no	0.00

Deliver process performance

	Good	ERP	CBS	CMI	LCS	EB	Neutral	Current scale
Good	no	strong	positive	positive	positive	positive	positive	100.00
ERP		no	weak	positive	positive	positive	positive	69.23
CBS			no	moderate	positive	positive	positive	53.85
CMI				no	weak	positive	positive	30.77
LCS					no	very weak	positive	15.38
EB						no	very weak	7.69
Neutral							no	0.00

Figure 6. Elementary quantification for the buyer-supplier relationships improvement

In order to quantify the overall performance, the decision-maker now has to choose an aggregation operator. But, unlike the case exposed in section 3, the decision-maker believes that the criteria are not independent. Namely, there is a strong synergy between the *Plan* process and the *Source* process performances, while there is no link between the *Source* process and the *Deliver* process performances. In this context, the Choquet integral is useful to consider the mutual interaction between the involved criteria.

4.2 Determination of the aggregation operator parameters

Compromise operators are generally considered for making industrial performance aggregation, *i.e.* the aggregate performance is between the minimum and the maximum of the elementary performances. More precisely, the operators of the Choquet Integral (CI) family (Grabisch, 1997) are relevant because they include a lot of generalized mean operators (*i.e.* those included between the min and the max operators). Moreover, they can be written under the form of a conventional weighted mean modified by the effects coming from the interactions between elementary performances.

More particularly, we briefly present hereafter the 2-additive CI that considers only interactions by pair[4], and that is defined by two types of parameters (Grabisch, 1997):

[4] The propositions made in this paper can be easily extended to the general case of k-additive Choquet integrals.

- the weight of each elementary performance expression in relation to all the other contributions to the overall performance evaluation by the so-called *Shapley parameters* v_i's, that satisfy $\sum_{i=1}^{n} v_i = 1$, which is a natural condition for decision-makers,
- the *interaction parameters* I_{ij} of any pair of performance criteria, that range in [-1,1];
  - a positive I_{ij} implies that the simultaneous satisfaction of objectives o_i and o_j is significant for the aggregated performance evaluation, but a 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 WAM.

The associated aggregation function is thus given by:

$$p_{Ag} = \sum_{i=1}^{n} v_i\, p_i - \frac{1}{2}\sum_{i=1}^{n} I_{ij} \left| p_i - p_j \right| \qquad (2)$$

where $(p_1 \ldots, p_i \ldots, p_n)$ is the vector of elementary expressions such that:

$$\left(v_i - \frac{1}{2}\sum_{j=1}^{n} \left| I_{ij} \right| \right) \geq 0, \forall\, i \in [1, n] \text{ et } j \neq i \qquad (3)$$

Thus the meanings of v_i and I_{ij} are clear, providing explanations to decision-makers on how these parameters influence the aggregated performance expressions. If these operators have more parameters than the WAM operator, their determination is based on the same principle. Evidently, more information will be required. For the sake of simplicity, we do not consider here the general case but only deal with our example.

4.3 Overall performance expression

Before computing the overall performance expression from the elementary ones, we need to determine the CI parameters, namely 4 *Shapley parameters* v_i's and 6 *interaction parameters* I_{ij}. In this sense, the decision-maker has to compare some particular situations related to the four main processes (*Plan, Source, Make, Deliver)*. These situations are known through their associated elementary performance vectors $(p_{Plan,}\ p_{Source}, p_{Make}, p_{Deliver})$, more simply denoted (p_1, p_2, p_3, p_4). In order to make such comparisons more realistic and simpler, we propose to consider fictive situations that correspond to particular cases where all the objectives are totally satisfactory, except one. The associated performance vectors will be thus: (0,0,0,1) where $p_4 = 1$ and $p_1 = p_2 = p_3 = 0$, or (1,1,0,1) where $p_1 = p_2 = p_4 = 0$ and $p_3 = 1$. Moreover, in order to identify the ten parameters of the CI, the decision-maker has thus to compare ten fictive situations under the form:

$$p_{\text{Ag}}^{(0,0,1,0)} \text{ is moderately preferred to } p_{\text{Ag}}^{(0,0,0,0)}$$

The full system, the associated matrix (Table 9) and its resolution are given in the appendix.

$$\begin{bmatrix} 0 & 0 & 1 & 0 & 0 & -0.5 & 0 & -0.5 & 0 & -0.5 & -3 \\ 0 & 1 & -1 & 0 & -0.5 & 0.5 & 0 & 0 & -0.5 & 0.5 & -1 \\ 0 & -1 & 0 & 1 & 0.5 & 0 & -0.5 & 0.5 & 0 & -0.5 & 0 \\ 1 & 0 & 0 & -1 & -0.5 & -0.5 & 0 & 0 & 0.5 & 0.5 & -2 \\ 0 & 1 & -1 & 0 & -0.5 & 0.5 & 0 & 0 & 0.5 & -0.5 & -1 \\ 0 & 0 & 1 & -1 & 0 & -0.5 & 0.5 & 0.5 & -0.5 & 0 & -4 \\ 0 & 1 & 0 & -1 & 0.5 & 0 & -0.5 & -0.5 & 0 & 0.5 & -2 \\ 1 & -1 & 0 & 0 & 0 & 0.5 & 0.5 & -0.5 & -0.5 & 0 & -4 \\ 0 & 1 & -1 & 0 & 0.5 & -0.5 & 0 & 0 & 0.5 & -0.5 & -3 \\ 0 & 0 & 1 & -1 & 0 & 0.5 & -0.5 & 0.5 & -0.5 & 0 & -3 \\ 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} v_{Pl} \\ v_{So} \\ v_{Ma} \\ v_{So} \\ I_{Pl\_So} \\ I_{Pl\_Ma} \\ I_{Pl\_De} \\ I_{So\_Ma} \\ I_{So\_De} \\ I_{Ma\_De} \\ \alpha \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

Table 9. Matrix for parameter determination

The results of the parameter determination are synthesized in the Table 10. The decision-maker can naturally correct these values, by reconsidering his judgment. We can now aggregate the elementary performances (§ 3.2.4), according to the different action plans being considered (Table 11).

ν_1	ν_2	ν_3	ν_4	I_{12}	I_{13}	I_{14}	I_{23}	I_{24}	I_{34}
12/34	9/34	7/34	6/34	5/34	3/34	4/34	5/34	0	5/34

Table 10. The Choquet Integral parameters

	p_{Plan}	p_{Source}	p_{Make}	p_{Deliver}	p_{Ag}	Interaction
ERP	0,59	0,71	0,64	0,81	0,63	0,04
EB	0,53	0,21	0,09	0,25	0,32	0,10
CMI	0,82	0,29	0,36	0,69	0,47	0,13
LCS	0,24	0,14	0,18	0,63	0,27	0,07
CBS	0,94	0,57	0,45	0,44	0,47	0,12

Table 11. The overall performance expressions associated to the different solutions

From this result, the decision-maker establishes that:

- the ERP implementation gives the best performance improvement,
- this result is nevertheless moderately satisfying because p_{Ag} is only 0.66,

- taking the interactions into account decreases the overall performance from about 5% to 25% (it is very important for the CMI and the CBS improvement projects) and can modify the ranking.
- the best performance improvement has to balance the interacted elementary performances.

More generally, the company has a systematic tool which allows not only to choose a supplier but also to diagnose the weakness of the buyer supplier relationship and to improve it. This explanation of the reasons of an unsatisfactory overall performance allows managers to adopt a more efficient improvement approach.

Note that other aspects can be handled such as the aggregated performance/investment ratio, the delay associated to the different solutions, or the critical resource utilization.

6. Conclusion and prospects

This study deals with performance measurement in a supply chain context. We have proposed in this sense a global framework to consider, understand and improve the buyer-supplier relationships. The major idea of this work is the overall performance concept. In this sense, decision-makers have one single synthetic piece of information which is, on the one hand, consistent with the new global industrial approach, and on the other hand, allows the comparison of situations conventionally considered as “incomparable”. More precisely, decision-makers cannot only choose the best supplier in a given context and w.r.t the industrial projects under way, but also manage the relationship improvement, by analysing a detailed diagnosis and a quantitative evaluation of the impact of the alternative considered projects.

In the Quantitative Performance Measurement Model, the aggregation concept allows the quantification of an overall performance, in spite of the impossibility to directly measure such a performance. Moreover, the Choquet Integral (CI) operator, which takes the dependencies between criteria into account, highlights the complex relations between the elementary and the overall performance expressions, while the Weighted Arithmetic Mean (WAM) operator does not. In this sense, the MACBETH methodology has been applied to the performance quantification of the four main processes (*Plan, Source, Make and Deliver)* according to the supply chain literature. Indeed, based on human expertise, this methodology gives a structured framework, which links the elementary performance expression to the overall one.

This study will have to be completed by industrial validation. Indeed, some work is now in progress concerning the application of these ideas in some manufacturing companies, by considering moreover, the impact of the process *Return*, not handled here, on the overall performance in a buyer-supplier relationship context.

Appendix

Notation: $p_{\text{Ag}}^{(0,0,1,0)}$ is the aggregated performance associated to the situation of the SC characterized by the vector of elementary performance (0,0,1,0).

$$
\begin{cases}
p_{\mathrm{Ag}}^{(0,0,1,0)} - p_{\mathrm{Ag}}^{(0,0,0,0)} = 3\alpha & = \nu_{\mathrm{Ma}} - \frac{1}{2}\left[I_{\mathrm{Pl\_Ma}} + I_{\mathrm{So\_Ma}} + I_{\mathrm{Ma\_De}}\right] \\
p_{\mathrm{Ag}}^{(0,1,0,0)} - p_{\mathrm{Ag}}^{(0,0,1,0)} = \alpha & = \nu_{\mathrm{So}} - \nu_{\mathrm{Ma}} - \frac{1}{2}\left[I_{\mathrm{Pl\_So}} - I_{\mathrm{Pl\_Ma}} + I_{\mathrm{So\_De}} - I_{\mathrm{Ma\_De}}\right] \\
p_{\mathrm{Ag}}^{(0,0,0,1)} - p_{\mathrm{Ag}}^{(0,1,0,0)} = 0 & = -\nu_{\mathrm{So}} + \nu_{\mathrm{De}} - \frac{1}{2}\left[-I_{\mathrm{Pl\_So}} + I_{\mathrm{Pl\_De}} - I_{\mathrm{So\_Ma}} + I_{\mathrm{Ma\_De}}\right] \\
p_{\mathrm{Ag}}^{(1,0,0,0)} - p_{\mathrm{Ag}}^{(0,0,0,1)} = 2\alpha & = \nu_{\mathrm{Pl}} - \nu_{\mathrm{De}} - \frac{1}{2}\left[I_{\mathrm{Pl\_So}} + I_{\mathrm{Pl\_Ma}} - I_{\mathrm{So\_De}} - I_{\mathrm{Ma\_De}}\right] \\
p_{\mathrm{Ag}}^{(0,1,0,1)} - p_{\mathrm{Ag}}^{(0,0,1,1)} = \alpha & = \nu_{\mathrm{So}} - \nu_{\mathrm{Ma}} - \frac{1}{2}\left[I_{\mathrm{Pl\_So}} - I_{\mathrm{Pl\_Ma}} - I_{\mathrm{So\_De}} + I_{\mathrm{Ma\_De}}\right] \\
p_{\mathrm{Ag}}^{(0,1,1,0)} - p_{\mathrm{Ag}}^{(0,1,0,1)} = 4\alpha & = \nu_{\mathrm{Ma}} - \nu_{\mathrm{De}} - \frac{1}{2}\left[I_{\mathrm{Pl\_Ma}} - I_{\mathrm{Pl\_De}} - I_{\mathrm{So\_Ma}} + I_{\mathrm{So\_De}}\right] \\
p_{\mathrm{Ag}}^{(1,1,0,0)} - p_{\mathrm{Ag}}^{1,0,0,1)} = 2\alpha & = \nu_{\mathrm{So}} - \nu_{\mathrm{De}} - \frac{1}{2}\left[-I_{\mathrm{Pl\_So}} + I_{\mathrm{Pl\_De}} + I_{\mathrm{So\_Ma}} - I_{\mathrm{Ma\_De}}\right] \\
p_{\mathrm{Ag}}^{(1,0,1,1)} - p_{\mathrm{Ag}}^{(0,1,1,1)} = 4\alpha & = \nu_{\mathrm{Pl}} - \nu_{\mathrm{So}} - \frac{1}{2}\left[-I_{\mathrm{Pl\_Ma}} - I_{\mathrm{Pl\_De}} + I_{\mathrm{So\_Ma}} + I_{\mathrm{So\_De}}\right] \\
p_{\mathrm{Ag}}^{(1,1,0,1)} - p_{\mathrm{Ag}}^{(1,0,1,1)} = 3\alpha & = \nu_{\mathrm{So}} - \nu_{\mathrm{Ma}} - \frac{1}{2}\left[-I_{\mathrm{Pl\_So}} + I_{\mathrm{Pl\_Ma}} - I_{\mathrm{So\_De}} + I_{\mathrm{Ma\_De}}\right] \\
p_{\mathrm{Ag}}^{(1,1,1,0)} - p_{\mathrm{Ag}}^{(1,1,0,1)} = \alpha & = \nu_{\mathrm{Ma}} - \nu_{\mathrm{De}} - \frac{1}{2}\left[-I_{\mathrm{Pl\_Ma}} + I_{\mathrm{Pl\_De}} - I_{\mathrm{So\_Ma}} + I_{\mathrm{So\_De}}\right] \\
p_{\mathrm{Ag}}^{(1,1,1,1)} = 1 & = \nu_{\mathrm{Pl}} + \nu_{\mathrm{So}} + \nu_{\mathrm{Ma}} + \nu_{\mathrm{De}}
\end{cases}
$$

The system resolution gives the following results:

$\nu_1 = 12/34$, $\nu_2 = 9/34$, $\nu_3 = 7/34$, $\nu_4 = 6/34$

$I_{12} = 5/34$, $I_{13} = 3/34$, $I_{14} = 4/34$, $I_{23} = 5/34$, $I_{24} = 0$, $I_{34} = 5/34$

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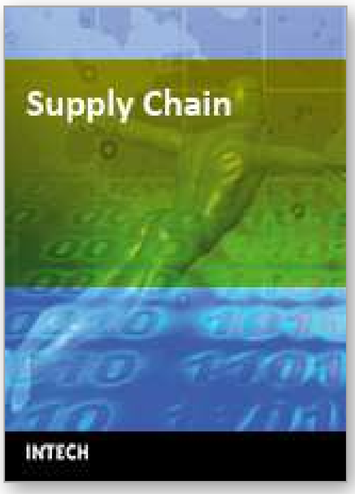

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Traditionally supply chain management has meant factories, assembly lines, warehouses, transportation vehicles, and time sheets. Modern supply chain management is a highly complex, multidimensional problem set with virtually endless number of variables for optimization. An Internet enabled supply chain may have just-in-time delivery, precise inventory visibility, and up-to-the-minute distribution-tracking capabilities. Technology advances have enabled supply chains to become strategic weapons that can help avoid disasters, lower costs, and make money. From internal enterprise processes to external business transactions with suppliers, transporters, channels and end-users marks the wide range of challenges researchers have to handle. The aim of this book is at revealing and illustrating this diversity in terms of scientific and theoretical fundamentals, prevailing concepts as well as current practical applications.

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