**To cite this version :**

Fan LI, Alain ETIENNE, François VERNADAT, Ali SIADAT - Comprehensive Performance Expression Model for Industrial Performance Management and Decision Support - IFAC-PapersOnLine - Vol. 51, n°11, p.558-563 - 2018

# Comprehensive Performance Expression Model for Industrial Performance Management and Decision Support

**Fan Li*. Alain Etienne**. François Vernadat***. Ali Siadat****

**Department of Industrial Engineering, Tsinghua University, Beijing 100084, China*
*(e-mail: lifan026@gmail.com)*
***LCFC, Arts et Métiers ParisTech, 57078 Metz, France*
*(e-mails: alain.etienne@ensam.eu, ali.siadat@ensam.eu)*
****LGIPM, University of Lorraine, 57073 Metz, France*
*(e-mail: vernadat30@gmail.com)*

Abstract: Due to proliferation of evaluation criteria and decision data overflow in nowadays fluctuating industrial environments, it is necessary to build a holistic, easy-to-use and efficient methodology for performance evaluation and decision making. More accurate overall performance expressions should not only prove that the selected decision alternative better fits the evaluator's objective at the time of evaluation, but it should also assume that this alternative remains the best solution in the subsequent evaluation periods. To this end, the benefit-cost-value-risk (BCVR) methodology has been developed for performance evaluation and decision support. The objective of this paper is to propose a comprehensive performance expression model to further ease the application of the methodology.

*Keywords:* Performance evaluation, performance analysis, decision making, decision support systems, project management, industrial systems

## 1. INTRODUCTION

Regarding today's changing global competitive market, companies must simultaneously satisfy multiple stakeholder objectives in industrial projects. However, this endeavour becomes more challenging with the increasing diversity of customer demand (Nudurupati et al., 2011) and emergence of new concept such as Industry 4.0 (Hofmann & Rüsch, 2017) in industrial systems. In addition, objectives and degrees of satisfaction vary among stakeholders. This problem can even be more complicated when some of the objectives contradict each other.

Satisfying objectives requires performance measurement and management methodologies to efficiently evaluate how good the objectives are met (Berrah & Foulloy, 2013). To this end, many methodologies and approaches have been proposed so far, such as Activity-Based Costing (Cooper & Kaplan, 1988), Balanced Scorecard (Kaplan & Norton, 1992), ECOGRAI (Bitton, 1990; Ducq & Vallespir, 2005), QMPMS (Suwignjo et al., 2000) or Performance Prism (Neely et al., 2002), just to name a few.

Performance measurement and management methodologies evolved with business trends (Bititci et al., 2012). Indeed, earlier methods mainly focused on cost or financial evaluation, then later methods integrated financial and non-financial performance measurement and, more recently, new methods turned to integrate performance management systems which take into consideration the multidimensional nature of performance through a wide range of performance indicators. Consequently, performance measurement and management problems become ever more challenging due to the proliferation of evaluation criteria and decision data overflow in nowadays fluctuating environments. In addition, companies must rely on integrated, dynamic and relevant performance information to promote a pro-active management style for efficient and effective decision making.

For this purpose, it is necessary to build a holistic, easy-to-use and efficient methodology for performance management and decision support. Because the dimensions of benefit, cost, value and risk (BCVR) are the most common and important aspects taken into account (including time) while evaluating an industrial system or project, it has been decided that performance of an industrial system can be comprehensively measured and managed using these dimensions (Shah, 2012; Vernadat et al., 2013).

Based on these observations，Li (2017) proposed a BCVR based methodology for performance evaluation and decision support of industrial systems. It consists of four main phases *(identification, quantification, aggregation* and *decision support)* to generate an overall performance, which is qualitatively and quantitatively expressed on each of the four dimensions.

Overall performance expressions should not only prove that the selected decision alternative better fits the evaluator objective at the time of evaluation, it should also assume that this alternative remains the best solution in the subsequent evaluation periods. Therefore, a comprehensive performance expression model is proposed as a supplementary component of the BCVR based methodology.

The first part of the paper introduces the key concepts of BCVR based comprehensive performance expression. The second part presents the concept of performance variation to adjust the overall performance expression. The last part shows the results of an experimental application to illustrate the proposed model.

## 2. BCVR BASED PERFORMANCE EXPRESSION

The key concepts for BCVR based performance expression framework are presented in this section.

### *2.1 Concepts of benefit, cost, value and risk*

The concepts of benefit, cost, value and risk as well as industrial performance are popular terms that have been widely used in almost all practice and research contexts. Their definitions vary across different fields of application and it is hard to identify standard definitions that can be adapted to universal situations. Therefore, the specific definitions adopted the particular research context must first be presented.

Benefit can be tangible or intangible. Tangible benefits, which are always defined on quantitative monetary measurements, can be estimated before the start of a project and measured at the end. Intangible benefits, which are often related to non-financial and subjective aspects, may either be measurable or qualitative. They can be listed before the project starts and can only be ascertained at the end. Because any kind of benefits cannot be systematically expressed in measurable units to become an estimation indicator, they will be expressed in the form of literal expressions. In this paper, benefit is defined as a qualitative list of potential advantages or gains for a stakeholder compared to an objective that is set beforehand for the realisation of an industrial system.

The cost of an industrial project is usually quantitatively expressed and evaluated in monetary terms. In this paper, cost refers to total expenses for the production, distribution and acquisition of the final result (a product, service or deliverable) of an industrial system. The challenging point regarding this evaluation axis is not the proposition of an adapted definition, but the identification of the different measurable elementary costs that can comprehensively represent the overall cost.

The dimension of value is considered as a non-financial term in the proposed methodology. Therefore, value is described as the degree of satisfaction of a set of stakeholder expectations or needs, expressed by the appreciation level of a number of performance indicators.

Regarding the context of project management, risk means the likelihood and consequence of an event occurrence impacting the achievement of some stakeholder objectives.

According to these definitions, the concept of benefit has been defined as a non-monetary term and it is assumed that benefits are expressed as literal expressions in the current approach. The global performance of an industrial project can be quantitatively and independently expressed by following the other three dimensions (cost, value and risk). In addition, it is assumed that all dimensions are independent at a broad level because they are analysed and evaluated separately. However, they can interact at the basic level by sharing common elementary variables. For instance, project delay can be a factor that can negatively impact user satisfaction and budget overrun risk, thus impacting the value and risk axes. The individual model of each dimension should be developed on the basis of a common logic to ease performance measurement.

The concepts of benefit, cost, value and risk will be developed on the basis of individual conceptual models. The objectives are: (1) description of the relations among the different key concepts used in each dimension for the purpose of evaluation and (2) establishment of a basis for software development in the future work to ease the evaluation process.

Figure 1 shows the proposed model of risk with different elements and their interactions using UML (Unified Modelling Language) class diagrams. The global project risk can result from a set of risk components that are related to elementary risk expressions. These components can be further classified into different types and at different levels. A risk component can also be expressed by several sub-components at the lower level for the purpose of risk assessment. A risk component is impacted by several risk drivers that influence the result of risk measurement. The elementary expressions of risk components should be aggregated into an overall result by using a selected bottom-up aggregation method in order to help the stakeholder in making a risk evaluation. The overall expression should also be normalised into a real number between 0 and 1 to make the decision making easier on a normalised scale.

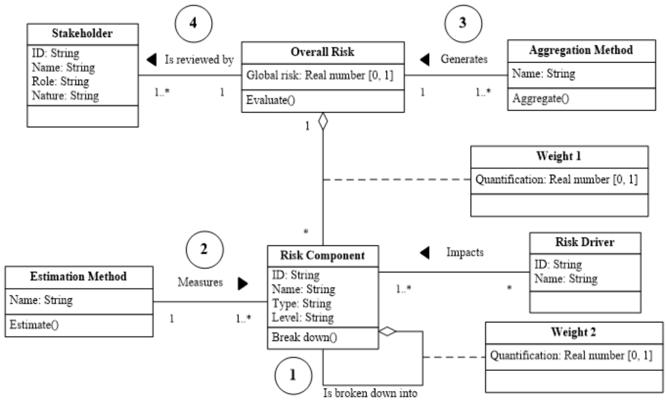


Fig. 1. Individual model for the dimension of risk

The numeric numbers in Fig. 1 indicate the main operations used to process risks. They are: (1) identification of the risk structure regarding the project context, (2) risk assessment with selected estimation methods, (3) generation of the overall risk expression with adapted aggregation methods and quantitative weights and (4) risk evaluation based on the evaluator's preferences.

Using the same logic, the individual model of cost and value can be developed. These individual models show that each dimension is directly measured at the elementary levels to get quantitative expressions for the purpose of performance management and, then, these elementary expressions can be aggregated into one global result per dimension to support the decision making process performed by the evaluator or analyst.

Based on the conceptual models, the main operations (identify, quantify, aggregate and decide) involved in performance evaluation can be identified as the basis for the methodological framework. However, besides the multiple aspects of the selected dimensions, performance expression should also meet other characteristics of performance. Therefore, an analytical framework for BCVR based performance expression is developed in the next section.

### *2.2 BVCR based performance expression*

The concept of "industrial performance" is multidimensional and relative in nature (Li et al., 2016). On one side, the performance of an industrial project can be assessed from multi points of view, multi levels and multi-criteria. Performance excellence in one aspect of cost, value or risk cannot guarantee the success of an industrial project. In addition, a performance expression depends on the objective to be met. It is also influenced by the time, the way and the conditions under which it is measured and interpreted. From a generic level, industrial performance can be defined by three perspectives: *stakeholders*, *evaluation periods* and *evaluation variables*. The definition is summarised using (1).

$$P = (S, T, VA) \qquad (1)$$

Where,

- $P$ is the overall performance of an industrial system;
- $S$ is a set of viewpoints from selected stakeholder(s) involved in the performance evaluation process;
- $T$ is the time period over which the performance evaluation is carried out. It can be an instant, a life cycle phase or the whole duration of the system or project;
- $VA$ is the set of evaluation variables to be considered. It is assumed that these variables can be categorised along the four dimensions: benefit, cost, value and risk.

Based on the particular context of the problem at hand, the evaluator selects the relevant performance components (i.e. key stakeholders, specific time periods and adequate evaluation variables) to define the scope of the performance evaluation problem. For a decision maker and a specific industrial system or project, an overall performance measure of one decision alternative can be quantitatively expressed as shown in (2).

$$\mathrm{P} = (\mathrm{C}, \mathrm{V}, \mathrm{R}) \qquad (2)$$

Where, $C$, $V$ and $R$ are the overall cost, value and risk of one specific decision alternative. They are expressed with a single quantitative expression within a range [0, 1]. Bigger numeric result represents better performance in a specific cost, value or risk dimension.

In the BCVR methodology (Li, 2017), a visualisation tool is proposed to help the decision maker to graphically evaluate the overall performance compared to the predefined preferences (Fig. 2). This representation is based on the performance measurement of one specific decision alternative for one particular evaluation period.

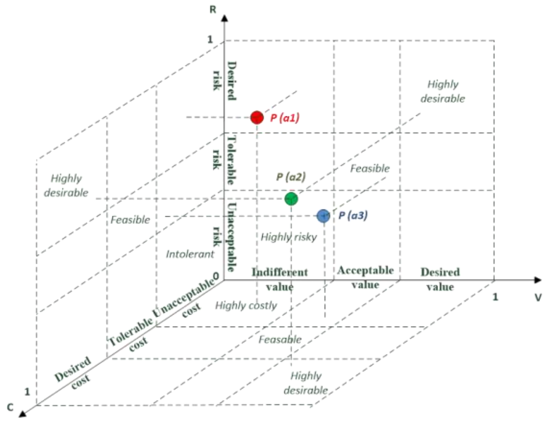

Fig. 2. Performance expressions in a cost-value-risk graph

With such a 3D graph, the overall cost, value and risk of one decision alternative or more can be presented in a cost-value-risk space to assist the decision maker to evaluate the performance of different decision alternatives denoted $P_{(an)}$ (with n=1,2,…n) (for example, different solutions or candidate projects) according to their preferences.

This visualisation and the estimation of overall performance expression can help in the following types of problems: (1) decision support based on benefit, cost, value and/or risk evaluation, this could be *a priori* analysis such as opportunity assessment of different alternatives while selecting the most appropriate one at the preliminary phase of an industrial system or *de facto* analysis such as decision making; (2) performance evaluation at any stage of an industrial system, process or project (*a priori*, *de facto* or *a posteriori*) and (3) monitoring and control of an ongoing industrial project requiring performance evaluation steps at different phases along the life history of the project.

However, it should be noticed that the overall performance expressions for a selected evaluation period may not be accurate enough for the decision maker to compare different decision alternatives. Better performance results can only prove that the selected decision alternative is closer to the evaluator's objective at the time of evaluation, but it cannot assume that this alternative can always be the most performing solution in the subsequent evaluation periods along the project life history. Therefore, the concept of "performance variation" should be introduced to assess the evolution of performance over time.

## 3. PERFORMANCE VARIATION

For the purpose of prognosis, an adapted comprehensive performance expression is first introduced in this section. Then, definitions on the concept of performance variation are presented. Finally, the process for decision support by using the comprehensive performance expression is described.

### *3.1 Adapted overall performance expression*

It is assumed that the performance expression for decision support should include two parts: (1) performance measurement for one specific time interval and (2) gap of performance variations (GA). The former is the overall value, cost and risk, which are obtained from the aggregation computation in the BCVR based methodology (Li, 2017).

The latter is the difference between two overall expressions for one specific alternative in one certain performance dimension over the relevant time interval along a project life history. Finally, the overall performance expression for decision support can be adjusted as shown in (3).

$$P(A) = \{(C, GA_c), (V, GA_v), (R, GA_r)\} \quad (3)$$

Where, $GA_c$ , $GA_v$ and $GA_r$ are gaps of performance variations of the three dimensions: cost, value and risk. They should be computed based on different overall performance expressions.

To explain the process to generate the gap of performance variations, a set of concepts are proposed in the following section.

*3.2 Proposed definitions*

*Definition 1:* Performance variation (PV) is the difference between two results of performance measurement regarding the same alternative in terms of one dimension: cost, value or risk. It is computed by using (4).

$$PV_c = \left(\frac{C_i - C_j}{t_i - t_j}\right), PV_v = \left(\frac{V_i - V_j}{t_i - t_j}\right), PV_r = \left(\frac{R_i - R_j}{t_i - t_j}\right) \quad (4)$$

Where,

- $PV_c, PV_v$ *and* $PV_r$ are performance variations in terms of cost, value and risk;
- $t_i$ *and* $t_j$ are two instants when the performance measures are generated;
- $C_i - C_j, V_i - V_j$ *and* $R_i - R_j$ are the differences between two performance measures of the same dimension at the selected moments. In most cases, it is supposed that the numeric expressions of the initial time, cost, value and risk in a decision making problem equal to 0, that is, the results of these elements $t_0, C_0, V_0, R_0$ are set to 0.

Based on the type of performance measures, performance variations can be categorised in two types: desired and estimated variations.

*Definition 2:* Desired variation (DV) is the difference between two measures: (a) the desired quantitative measures at the end of the evaluation period – They are predefined by the decision maker; and (b) the performance expression at the initial instant of the relevant time interval. The mathematical expressions are given by (5).

$$DV_c = \left(\frac{C_d - C_0}{T - t_0}\right) = \frac{C_d}{T}, DV_v = \left(\frac{V_d - V_0}{T - t_0}\right) = \frac{V_d}{T},$$
$$DV_r = \left(\frac{R_d - R_0}{T - t_0}\right) = \frac{R_d}{T},$$
$$\text{with } t_0, C_0, V_0, R_0 = 0 \quad (5)$$

Where,

- $DV_c, DV_v$ *and* $DV_r$ are the desired variations in terms of cost, value and risk;
- $t_0, t_i$ *and* $T$ are the initial time, measurement moment and the end time of the performance evaluation period;
- $C_d - C_0, V_d - V_0$ *and* $R_d - R_0$ are the differences between the performance measure at time $t_i$ and the initial performance measure of the same dimension.

*Definition 3:* Similarly, the estimated variation (EV) is the difference between two expressions: (a) the performance measures which are the outputs of the aggregation computation and (b) the performance expression at the initial instant of the relevant time interval, as shown in (6).

$$EV_c = \left(\frac{C_i - C_0}{t_i - t_0}\right) = \frac{C_i}{t_i}, EV_v = \left(\frac{V_i - V_0}{t_i - t_0}\right) = \frac{V_i}{t_i},$$
$$EV_r = \left(\frac{R_i - R_0}{t_i - t_0}\right) = \frac{R_i}{t_i},$$
$$\text{with } t_0, C_0, V_0, R_0 = 0 \quad (6)$$

Where,

- $EV_c, EV_v$ *and* $EV_r$ are the estimated variations in terms of cost, value and risk;
- $C_i - C_0, V_i - V_0$ *and* $R_i - R_0$ are the differences between the performance measure at time $t_i$ and the initial performance measure of the same dimension.

Because the performance measures are influenced by the decision maker subjective judgment, the estimated variation should be adjusted.

*Definition 4:* The estimated variation after adjustment (EVA) is defined to take into consideration the random events which can influence the evaluation of the overall expression of one specific performance dimension along the life history of the system or project. The mathematical expression of the term EVA is given by (7).

$$EVA = EV \times \varepsilon \times c \quad (7)$$

Where,

- $\varepsilon$ is a random number that represents the happening of random events. For the dimension of cost, the number is between -1 and 0, because the overall cost is always accumulated over time and the performance expression is decreasing. However, this number is between -1 and 1 for the dimensions of value and risk, because the overall value and risk can be increased or decreased over time.
- $c$ is a positive constant number between 0 and 1 which represents the degree of variance of one particular performance dimension according to the decision maker estimation.

In some cases, the decision maker needs to predict future performance of the project or process in order to improve the management control and generate more effective action plans for future steps. Hereby, the proposed terms can also be used to forecast the overall performance after a considered time interval. The predicted performance can be expressed as shown in (8).

$$P(A') = P(A) \times (1 + EVA) \quad (8)$$

*Definition 5:* To describe the uncertainty of the overall performance in one specific dimension, the term gap of variation (GA) is proposed. It is defined as the absolute value of the difference between desired variation and the maximum absolute value of estimated variation, as shown in (9).

$$GA = |DV - \max|EVA|| = |DV - \max|EV \times \varepsilon \times c|| \quad (9)$$

Higher GA means the selected overall performance expression will have higher variation (it may lead to over performance or underperformance) regarding the desired result. However, it depends on the evaluator preference to define the acceptable level of the GA in a particular case.

The overall performance expression can be further applied to ease the decision making process in an industrial system. The detailed information is presented in the following section.

### *3.3 Decision support process*

From the previous definitions, a process for decision support based on the comprehensive performance expression can be proposed as shown in Fig. 3.

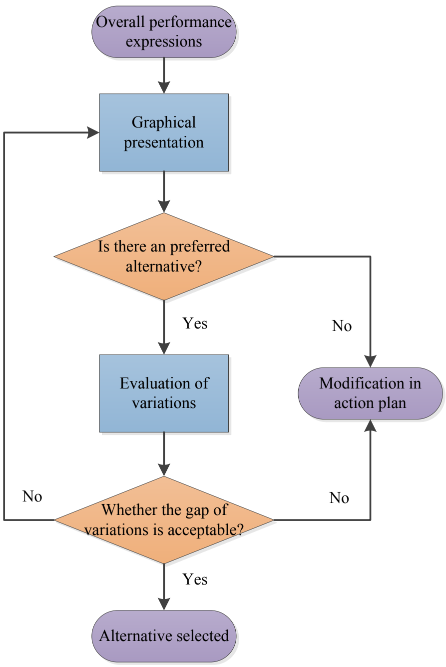


Fig. 3. Overall performance expression for decision support

Thanks to the graphical presentation, the decision maker evaluates whether the overall performance obtained is acceptable. If there is no preferred solution, the action plan should be modified and a new performance measurement should be generated. If the answer is positive, the aim of the following step is to evaluate the GA to ensure this alternative can have a stable performance in the future phases of the project. With an acceptable GA, the alternative can be considered as a solution with reliable performance along the life history of a system or project. Otherwise, it means that even if the selected decision alternative has the preferred overall performance at the moment of evaluation, strong possibility may exist that the performance be subject to large variation in future phases of the project.

## 4. EXPERIMENTAL ILLUSTRATION

The application of the proposed model for comprehensive performance expression is illustrated on an application dealing with decision support in construction projects implementation. The main results are presented in this section.

### *4.1 Background*

A building construction company simultaneously implements three construction projects which differ by complexity, duration, budget and variety of works. To make better use of shared material, financial and human resources to achieve higher profits, the company needs efficient performance evaluation for each of these projects during the implementation stage. Therefore, the final objective of the construction company is to achieve higher profit at the end of the implementation phase of the different construction projects. Based on industrial experience, ten evaluation criteria (Li, 2017) are selected to generate the elementary performance expression.

### *4.2 BCVR based performance expression*

Using the BCVR methodology, the benefits in this decision problem are summarised as: (1) increasing efficiency of the construction company in projects implementation and (2) internal and external improvement of the enterprise image. Then, the overall performance of each construction project can be quantitatively expressed on the following dimensions: cost, value and risk. Table 1 shows the results obtained.

Table 1. Overall performance expressions of all projects

| | Project 1 | Project 2 | Project 3 |
|---|---|---|---|
| Overall cost | 0.67 | 0.79 | 0.81 |
| Overall value | 0.25 | 0.60 | 0.63 |
| Overall risk | 0.27 | 0.40 | 0.57 |

To help the decision maker in the comparison of different candidate projects, the overall performance expressions are displayed in the cost-value-risk graph (Fig. 4).

This graph shows that Projects 2 and 3 have much higher value than Project 1, while their cost and risk performance are also better. Regarding Projects 2 and 3, the latter can generate higher value with less risk and cost. Therefore, it can be concluded that the order of priority among these three projects is: Project 3 > Project 2 > Project 1.

### *4.3 Adjusted overall performance expression*

To generate the performance variations, the desired expression for all candidate projects in each dimension are firstly defined by the decision maker based on decision preference. Other data such as the constant numbers *c* are then defined according to previous analyst experience for each dimension (namely, $c_1$, $c_2$ and $c_3$).

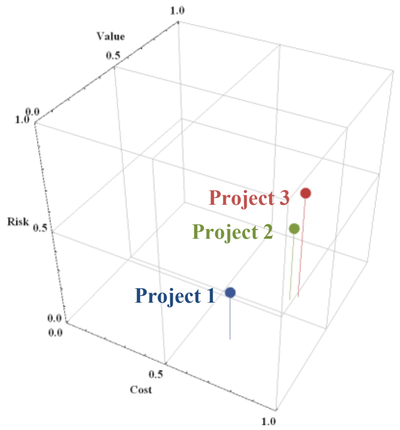


Fig. 4. Plot of overall performance expressions in CVR graph

The implementation phase will last for 12 months. The moment decided for the performance expressions generated with the BCVR methodology is fixed at the end of the third month. It is supposed that the numeric expressions of the initial time, cost, value and risk in this decision making problem equal to 0. Table 2 presents the detailed information of the data used to generate the gaps of performance variations for the preselected Project 3.

Table 2. Gaps of performance variations for Project 3

| $C_d$ | $V_d$ | $R_d$ | $C_i$ | $V_i$ | $R_i$ | $c_1$ | $c_2$ | $c_3$ |
|---|---|---|---|---|---|---|---|---|
| 0.65 | 0.75 | 0.65 | 0.81 | 0.63 | 0.57 | 0.1 | 0.6 | 0.3 |
| $C_0$ | $V_0$ | $R_0$ | $t_0$ | $t_i$ | T | $GA_c$ | $GA_v$ | $GA_r$ |
| 0 | 0 | 0 | 0 | 3 | 12 | **0.03** | **0.06** | **0.05** |

Finally, the adjusted overall performance expressions for Project 3 can be expressed as shown in Table 3.

Table 3. Overall performance expressions for Project 3

| Overall cost | Overall value | Overall risk |
|---|---|---|
| **(0.81, 0.03)** | **(0.63, 0.06)** | **(0.57, 0.05)** |

Therefore, Project 3 has limited performance variations compared to evaluator objective. This alternative can always be the most performing solution in the subsequent evaluation periods along the project life history.

In addition, the evolution of the overall performance expressions for Project 3 from the performance evaluation time ($t_i = 3$) to the end of the implementation stage (T=12) can be predicted as shown in Fig. 5.

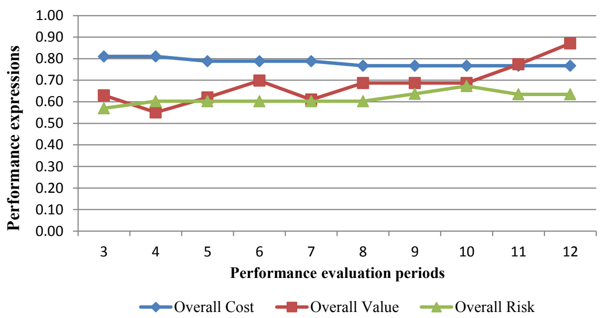


Fig. 5. Overall performance evolution for Project 3

It can be assumed that the overall value of Project 3 can be significantly increased with limited cost and risk variations.

## 5. CONCLUSIONS

The proposed model expresses comprehensively the industrial performance at the time of evaluation, as well as the variation of the measures. It helps the decision maker to evaluate whether the preferred decision alternative can always be the most performing solution in the forth-coming performance evaluation periods. In addition, it improves the application of the BCVR methodology in decision support phase. The current proposal is mainly based on linear functions to generate performance variations. However, it is a fairly complex subject to estimate the deviation and liability of the overall performance expressions. Further experimental applications should be applied to verify robustness and improve the mathematical models if necessary.

## REFERENCES


Berrah, L., & Foulloy, L. (2013). Towards a unified descriptive framework for industrial objective declaration and performance measurement. *Computers in Industry*, *64*(6), 650–662.

Bititci, U., Garengo, P., Dörfler, V., & Nudurupati, S. (2012). Performance measurement: challenges for tomorrow*: performance measurement. *International Journal of Management Reviews*, *14*(3), 305–327.

Bitton, M. (1990). *ECOGRAI : méthode de conception et d'implantation de systèmes de mesure de performances pour organisations industrielles*. Université de Bordeaux 1. (In French).

Cooper, R., & Kaplan, R. S. (1988). Measure costs right: make the right decisions. *Harvard Business Review*, *66*(5), 96–103.

Ducq, Y., & Vallespir, B. (2005). Definition and aggregation of a performance measurement system in three aeronautical workshops using the ECOGRAI method. *Production Planning & Control*, *16*(2), 163–177.

Hofmann, E., & Rüsch, M. (2017). Industry 4.0 and the current status as well as future prospects on logistics. *Computers in Industry*, *89*, 23–34.

Kaplan, R. S., & Norton, D. P. (1992). The balanced scorecard: Measures that drives performances. *Harvard Business Review*, *70*(1), 71–79.

Li, F. (2017). *Performance evaluation and decision support for industrial system management: a benefit-cost-value-risk based methodology* (Ph.D. dissertation). Arts et Métiers ParisTech, Metz, France.

Li, F., Etienne, A., Vernadat, F., & Siadat, A. (2016). Multi-criteria performance management methodology for decision support in industrial project selection problems. Proceedings of the IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), pp. 1096–1100.

Neely, A., Adams, C., & Kennerley, M. (2002). *The Performance Prism: The ScoreCard for Measuring and Managing Business Success*. FT Prentice Hall.

Nudurupati, S. S., Bititci, U. S., Kumar, V., & Chan, F. T. S. (2011). State of the art literature review on performance measurement. *Computers & Industrial Engineering*, *60*(2), 279–290.

Shah, L. (2012). *Value-risk based performance evaluation of industrial systems* (Ph.D. dissertation). Arts et Métiers ParisTech, Metz, France.

Suwignjo, P., Bititci, U. S., & Carrie, A. S. (2000). Quantitative models for performance measurement system. *International Journal of Production Economics*, *64*(1), 231–241.

Vernadat, F., Shah, L., Etienne, A., & Siadat, A. (2013). VR-PMS: a new approach for performance measurement and management of industrial systems. *International Journal of Production Research*, *51*(23–24), 7420–7438.