Using competencies in performance estimation: 
From the activity to the process

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Abstract

Performance estimation of enterprise processes generally involves models focused on a particular viewpoint (temporal, financial, etc.). This estimation rarely takes the impact of the human factor into account. It is now fully understood that it is important to include this factor when modelling and analyzing enterprise processes. In this paper, a conceptual approach to human resource modelling is proposed on the basis of an analysis of human integration in enterprise process models. The human entity is described through individual and collective competencies, which are needed to implement a process activity and assess its performance. The proposed formally built model provides a new approach to correlating some qualitative and quantitative aspects of the human influence on industrial performance. This model formalizes and generalizes performance estimation by linking human capacities and process performance. This approach is illustrated on an industrial process example.

Keywords: Human resource; Competence; Performance estimation

1. Introduction

For several years, market saturation has forced industry to develop new production. Flexibility, ability to react, innovation, and anticipation are a few of the many parameters that must now be integrated by industrial management. These changes have again placed the human entity at the core of the enterprise. Human resources – with their implicit cognitive and decision-making capacities – represent a key element of industrial performance. Often overlooked human skills, as described through individual and/or collective aspects, must now be integrated in enterprise process analysis. This project, which is based on a large-scale academic survey and an industrial project, describes the enterprise model MOVES (Model for the Organization and the Validation of Enterprise Structures). This model is specifically geared towards competence modelling and performance estimation. The identified and proposed concepts integrate the human entity, perceived through its characteristics, as an essential process performance vector. An analysis of the competence concept through its characterization and links with performance is first examined through several studies. Then the MOVES model is formally built by considering the underlying concepts of both competence modelling and the enterprise process performance estimation approach. It can link qualitative aspects associated with competence classes and quantitative aspects such as competence patterns or performance evaluation. Once the model is established, the underlying activity and enterprise process performance formulations are described from different viewpoints (temporal, financial and quality) with an industrial process example. Then the main potential contributions of the developed model and performance estimation approach are discussed and some research applications are proposed. Finally, the limitations of this work are identified and we suggest several possible for improvement.

2. Performance and competence

2.1. Link between competence and performance

The link between the human entity and industrial performance is underlined in many scientific disciplines. In economics, the human capital theory has been developed, thus
showing the importance of training on performance [1,2]. In the social sciences, where research is focused on human behaviour, authors are interested in the link between performance and the human entity through its individual [3], management [4] and environmental [5] dimensions. Most industrial engineering approaches consider human resources as material resources, and do not take the impact of their competencies on performance into account [6,7]. However, industrial engineering currently tends to give human resources their rightful status and new industrial management approaches based on the competence concept are emerging. This is founded on the fact that the competence of employees and the organization develop jointly and account for the performance of the enterprise [8,9]. Through the competence concept, i.e. both individual and collective, the industrial process must take the human entity into account.

2.2. The competence concept

The competence concept is multifaceted and no commonly accepted definition exists. In industrial engineering, the concept is often presented as involving the implementation of combined knowledge (theoretical, contextual, procedural), know-how (practical empirically controlled), and behaviour (relational or cognitive attitudes and behaviours) [10–12]. This competence concept is broken down into individual and collective competencies, with the latter viewed as a coordinated combination of individual competencies [13,14].

2.3. From competence to performance

Several studies have highlighted the importance of human resource management in controlling enterprise performance [15], but few industrial engineering studies have sought to formalize the link between competence and performance. Although some authors have explicitly referred to this link [6,16], the formalism is lacking, even though the different models strive to describe this relation. Some authors recognized the “human entity” in enterprises, but only in terms of availability or capacity [9,17–20]. Others have sought to model the influence of this factor by recognizing the importance of its training and learning capacities [21–23]. The complex nature of humans has led researchers to develop the competence concept. In addition to individual personality facets, researchers have introduced a collective dimension to encompass the human relational faculties. However, only a few studies have proposed such complex models. The lack of interdisciplinary aspects [24] of the adopted approaches and their empiricism should be noted. The developed approaches generally neglect the collective dimension [25] of work and overlook the competency dynamics.

After underlining the importance of the link between the human entity and performance, the next paragraph presents how enterprise modelling uses these various concepts (human resources, competence, and performance) to integrate the human entity in the analysis of enterprise processes. Once again, this highlights the importance of the human entity and the way in which it is taken into account in enterprise modelling.

3. Competence concept and enterprise modelling: integration framework

3.1. Positioning the competence concept

Enterprise modelling [26] is an essential tool to capitalize the knowledge of the enterprise. This understanding of the existing knowledge allows its analysis to improve performance [27]. An enterprise model must integrate the representation of all or part of the enterprise, including human resources, by adapted models and methodologies. In studies like [28], human or material resources are only characterized by a set of capacities, and they contribute to implementation of the activities to which they are allocated. More recently, UEML [29,30] implemented the resource concept, where resource is characterized by the role notion. The roles that resources must have to execute an activity can thus be defined, while specifying those allocated to a resource. A resource is described by a set of attributes which generate information on its capacities and, in the case of a human entity, its competencies.

UEML 1.0, i.e. one of the most accomplished languages for enterprise modelling, introduced the role with a more conceptual dimension, but it lacks any noteworthy advances in the definition and use of competence for process analysis. Although enterprise models do not necessarily try to describe and integrate human resources, most refer to these resources using a more or less detailed description, depending on the targeted outcome.

The next section proposes a description of an enterprise model dedicated to enterprise process performance estimation. Developed with an industrial partner, it defines all the constructs needed to model human competencies and to integrate them in the performance estimation method used.

3.2. Formalization of the competence model

The presented work was developed within the framework of an industrial contract associating the LIRMM and LGI2P laboratories with the industrial enterprise Merlin Gerin [31,32]. Firstly, the way the competence concept is integrated into a global view of the description of enterprise processes is precisely outlined. Secondly, the way this concept is broken down, by modelling competence through its individual and collective aspects in order to estimate the performance of the analyzed processes, is detailed.

3.2.1. Target process

One process of the Merlin Gerin enterprise, termed the production authorisation process (PAP) (Fig. 1), is used to illustrate the competency integration method for performance estimation. The goal is to allow or disallow the production of a new industrial product.

The process presented in Fig. 1 is broken down into three activities ($A_1$, $A_2$, and $A_3$) and requires stakeholders from the
technical (that build a working prototype of a product) and production (that produce the product for the market) teams. A battery of tests for the product is defined during activity $A_1$. These tests are then carried out in activity $A_2$. Depending on the test results, either the necessary corrective actions before conformity are carried out or a production order is generated. The production order is then examined during activity $A_3$ for a final decision.

3.2.2. Activity, task, resource and competence

The proposed human resource modelling is close to that developed by Pourcel and Gourc [33] and Jia [16]. The competence concept is linked to the activity, task, and human resources (Fig. 2). However, contrary to the work of [16,33], several tasks can coexist in the same activity. The task remains inseparable from the material and human resources allocated to it. A stakeholder can represent a single resource as well as a group of entities. However, the stakeholder concept is not necessarily defined by the presence of the individual. The proposed competence concept is multi-form because it recovers, as for [11], knowledge, know-how and behaviour. It is also multi-level because it can be described using an individual or a collective aspect. The activity is characterized by all competencies necessary for its implementation. The human resources may or may not have, from various levels, a set of acquired competences. These change over time, with experience (know-how), training plans (behaviour–motivation), etc. Having clarified the proposed view of the competence concept, the following part discusses its classification.

3.2.3. Main competencies: the breakdown

Implementation of an activity can be constrained by the availability of various business domains BD, which necessitates a set of required competencies. As Franchini noted [34], the number of considered competencies is limited by characterising employees by their main competencies (Fig. 3). The latter are broken down into two classes: first, the individual main competencies relative to each of the human entities considered independently, and secondly, the collective main competencies which characterize the organization of human relations between the different individuals within and between business domains. These relations take the collective dimension of the work of a group of employees into account. Table 1 shows the considered main competencies. It also outlines existing links with the criteria used by our industrial partner to evaluate their workers.
3.2.4. Required individual competence: the link with performance

3.2.4.1. Principle of performance estimation. The idea developed by Covès [31,32], and based on the observations of our industrial partner, is that it is possible to quantitatively estimate the influence of human resource skills on the performances (quality, cost, time, etc.) of the process. The competency assessment study is based on a set of interviews with an industrial expert. The competencies are linked to criteria used by the industrial stakeholder to characterize process activities [35]. The developed approach supposes that any activity is characterized, according to every viewpoint, by a nominal performance. During the implementation of activities, the influence of human resources on the performance estimation explicitly takes the impact of their competencies into account (Fig. 4). These competencies then modulate the performance, to increase or to reduce the nominal performance of an activity via dedicated laws developed with the industrial partner.

3.2.4.2. Performance estimation. In the following, the PAP industrial process will be used to illustrate the performance modulation principle. An activity is supposed to be characterized by a nominal performance (cost, quality and time). So activity $A_2$ has a nominal time, a nominal financial cost and a nominal quality. In the proposed approach, an individual’s skills are characterized by a set of knowledge, behaviour and know-how that influence the main competencies. Their impact is modelled by empirical and common sense laws (histogram, function continues by fragments, etc.), as established with the industrial partner, to estimate the rate of modulation of part of the nominal performance attached to a given main competence in the activity context. The proposed laws stem from industrial expertise, which considers that about ten classes of laws are enough to model connections between competence and performance. For each class, if the shape of a curve remains the same, the modulation depends, for an activity, on the type of work and on the competence profile of workers. This profile is defined during worker evaluations and interviews.

For example, the technicality main competence can be connected to the duration of an activity by the graph of Fig. 5 that is empirically drawn up with the industrial partner. Note that the modulation coefficient evolves with the person’s experience (hence his/her level of expertise). A novice will increase the duration, an expert will reduce it. For a given training, knowledge, and with time, the know-how can appear on the curve (Fig. 5). Furthermore, the motivation (behaviour) of the person can locally modify the slope of the curve.

In the same way, for the decision-making main competence, a histogram graph as in Fig. 6 allows estimation, in a given context, of the decision-making capacity of a person. The histogram form depends on the activity context. For example, for a technical task, a senior manager belonging to the administrative department (director) is not adapted. However, in a technical context, an engineer is more adapted to decision making. Experience can invert this rule by preferring a technician with substantial experience to a novice engineer. Behaviour is closely tied to the relational capacities of a person (relational MC_C). These are broken down into six levels,

![Fig. 4. From competence to performance: the proposed mechanism.](image)

![Table 1]

<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Criteria of merlin gerin ales</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC_I</td>
<td>Technicality</td>
<td>To realise</td>
</tr>
<tr>
<td></td>
<td>Decision making</td>
<td>To decide—to supervise—to manage</td>
</tr>
<tr>
<td></td>
<td>Autonomy</td>
<td>To undertake</td>
</tr>
<tr>
<td></td>
<td>Innovation</td>
<td>To create</td>
</tr>
<tr>
<td>MC_R</td>
<td>Management</td>
<td>To negotiate—to organize—to animate</td>
</tr>
<tr>
<td></td>
<td>Relational</td>
<td>To communicate—to cooperate</td>
</tr>
</tbody>
</table>

![Fig. 5. Modulation coefficient and MC_I technicality.](image)
ranging from “inferior” to “excellent” (Fig. 7), describing the behaviour of a person in a group, and estimated during interviews.

All the defined laws only characterize individual aspects of the human resource. In the presence of working groups, contextual laws are used to aggregate and take the influence of all employees on the performance of the activity into account. Intra-business (inside a business domain) and inter-business (between business domains) behaviours are distinguished (Fig. 8). The context is taken into account by considering the activity tasks and also the curves and aggregating laws. For example, a histogram is used to evaluate the impact of the decision-making capacity but the modulation coefficient is not the same for an engineer and the director if a technical or a management task is considered. Depending on the task, the impact of collaborative work is not always evaluated in a standard way by using a mean aggregation law, but instead max, min or integer part laws can be used, for example [36].

The proposed modelling of the competence concept is then integrated into a wider framework to derive a modelling language. This language is oriented towards the analysis of enterprise process performance.

3.3. Meta-model (MOVES) proposal to support enterprise performance estimation

An enterprise meta-model was built to go further into the various concepts introduced previously (human resources, competence, activity, process, etc.). It integrates human resources via the notion of competence. Contrary to most of the works, it allows to develop a more realistic and objective analysis of a process by actually integrating the impact of competencies on performance. The MOVES meta-model, which is briefly presented hereafter is only a simplified view of the modelling work. The proposed meta-model is the result of an analysis of a set of enterprise meta-models (IDEF3, GRAI, CIMOSA, MECI, UEML) and a collaboration with our industrial partner.

The MOVES modelling language is adapted to a trans-functional enterprise representation. It integrates an accurate competency-based perception of the human entity to support the performance estimation methodology. Fig. 9 gives a simplified representation of this meta-model, while also highlighting the relations between the various previously enumerated constructs.

As in most modelling languages, MOVES considers that an enterprise cannot be described without the environment with
which it is in constant interaction. It is composed of enterprise objects, representing all the stakeholders and technical objects involved in the process implementation. The process can be broken down into a set of activities, which in turn can be broken down into a set of tasks. Implementation of an activity requires one or more stakeholders, which can be material or human resources. In the case of human resources, it can involve one individual or a group of individuals.

To build MOVES, these different very general and consensual concepts used in enterprise modelling have been enriched. Firstly, the constructs considered as pertinent in other works were added. Secondly, this model integrates concepts needed to describe the human entity and develop a performance estimation approach.

The organizational vision was initially overlooked in the MOVE enterprise representation. A construct for an organizational unit has been added. It represents the hierarchical structure of the enterprise. The role concept has also been introduced but its conceptual significance has been limited relative to the UEML definition. It is restricted to a set of main competencies and certifications necessary to implement an activity which itself is broken down into a set of business domains. As other modelling languages, the capacity concept is used but it is specifically connected to the material resources. The human entity is identified by its skills expressed by a distinct concept and not by attributes.

The impact of the main competencies is evaluated simple and common sense laws defined with the industrial partner. The performance estimation result is obtained by aggregating the performances of all business domains involved in the implementation of an activity.

The main advantage of this new enterprise model is that it provides a link between quantitative modelling of the human resources and qualitative performance evaluation. It is based on a more detailed model of the human competencies than those currently used and it clearly distinguishes human and material resources. However, the competence model has limited complexity so as to be really useful for performance simulation.

After having presented the MOVES meta-model and integrating the human resources via the competence concept and its relation to performance, the following paragraph proposes a mathematical formalization of the relation between competence and performance. The results obtained with the performance estimation method will be presented for activity $A_2$ of the PAP process.

4. Computing activity performance

4.1. General activity formalization

The proposed methodology assumes that, for a given viewpoint, the performance of an activity is characterized by its nominal value $P_N$ different from 0. The approach can be broken down into two different parts (Fig. 10). First, independently of the assigned staff (employees), the nominal performance of the considered activity is broken down according to business domains (Mi) and the necessary competencies (Stage E1) required to implement the activity.
Secondly, individual and collective dimensions of the work are considered to estimate the impact of the competencies of the involved employees on the performance of the activity (from Stage E2 to Stage E4).

4.1.1. Computation of business performances

$P_N$ is broken down into nominal business performance $P_{Nm}$ that takes the contribution of each of the $m$ business domains necessary to carry out an activity into account. A weight factor $\beta_m$ translates the relative importance of each of the business domains in this performance. This allows us to write the following Eq.(1):

$$P_{Nm} = \beta_m P_N, \quad 1 \leq m \leq M$$

(1)

It is then easy to express the relation between the nominal business performance and the nominal performance using Eq. (2):

$$P_N = \sum_M P_{Nm} \sum_{M} \beta_m P_N \quad \text{with} \quad \sum_M \beta_m = 1$$

(2)

Competencies are integrated at the business domain level by evaluating the impact of each of the $k$ competencies relevant to the business. We then get the nominal business performance by competence $P_{Nmk}$ as shown in Eq. (3):

$$P_{Nmk} = \alpha_{mk} P_{Nm} \quad \text{with} \quad \sum_k \alpha_{mk} = 1$$

(3)

The chosen laws depend on the type of activity and on the individual or collective nature of a business. This determines, for each competence, a modulation coefficient $\gamma_{mk}$ that takes the influence of the chosen human entities on the performance into account. This method allows to establish the final expression of a business performance by competence $P_{mk}$ (Eq. (4)):

$$P_{mk} = P_{Nmk} + \gamma_{mk} P_{Nmk} = (1 + \gamma_{mk})P_{Nmk}$$

(4)

Then globally the business performance could be expressed by Eq. (5) when the human competencies are integrated.

$$P_m = \sum_k P_{mk} = \sum_k \alpha_{mk}(1 + \gamma_{mk}) P_{Nm}$$

$$= P_{Nm} \sum_k \alpha_{mk}(1 + \gamma_{mk}) = \beta_m P_N \sum_k \alpha_{mk}(1 + \gamma_{mk})$$

(5)

To finish, the intra-business relational aspect is taken into account by a single coefficient $\delta_m$ for a given business domain. The final expression of business performance with relational $P_{mr}$ is then:

$$P_{mr} = P_m + \delta_m P_m = (1 + \delta_m)P_m$$

(6)

4.1.2. Activity performance computation

It is now possible to express the performance of an activity $P_A$. It suffices to sum the expressions $P_{mr}$ derived for each business (Eq. (7)):

$$P_A = \sum_M P_{mr}$$

(7)

This expression does not take the impact of inter-business relations into account. This can be done by introducing of a single coefficient $\lambda_A$ per activity. It permits us to express the final performance of an activity $P_{FA}$ as follows:

$$P_{FA} = P_A + \lambda_A P_A = (1 + \lambda_A)P_A$$

(8)

Expressing each of the terms in Eq. (8), the formulation developed for the final performance of an activity is given by Eq. (9):

$$P_{FA} = (1 + \lambda_A)P_N \sum_M \left[ (1 + \delta_m)\beta_m \sum_k \alpha_{mk}(1 + \gamma_{mk}) \right]$$

(9)

4.2. Experimental results

All the carried out experiments concern activity $A_2$ of the PAP process. The performance estimation is strictly connected to the resources required to implement the process activities. These resources, by their characteristics and competencies, will influence the performance involved, i.e. the temporal, financial or quality performance.

4.2.1. Temporal performance

All the elements presented permit estimation of the performance of a process activity. In this temporal performance
context, Eq. (9) becomes:

\[
T_{FA} = (1 + \lambda_{TA})T_N \sum_M \left( (1 + \delta_{Tm})\beta_{Tm} \sum_k \alpha_{Tmk}(1 + \gamma_{Tmk}) \right)
\]

where \(\lambda_{TA}, \delta_{Tm}, \beta_{Tm}, \alpha_{Tmk}\) and \(\gamma_{Tmk}\) are characteristics of the temporal viewpoint \(T\).

Fig. 11 presents, according to a temporal aspect, an example of the performances obtained when executing activity \(A_2\) of the PAP process. For the chosen configuration, the nominal value \(T_N\) of the duration of the activity \(A_2\) is 1170 min. In Fig. 11, the temporal performance is widely dispersed according to the chosen employees executing \(A_2\). Even though the mean activity duration of 1562 min is relatively close to the nominal value, the duration can range between 900 and 2600 min according to the competence profiles used and the inter-business behaviour. Note also that a step-curve is obtained. Each performance level pools a set of human resources with similar performances.

4.2.2. Financial performance

According to the financial viewpoint, the performance is characterized by a nominal cost (\(C_N\) not null). Eq. (9) can be transformed to establish the expression of the final cost of an activity. Eq. (11) integrates the human dimension and is expressed as follows:

\[
C_{FA} = (1 + \lambda_{FA})C_N \sum_M \left( (1 + \delta_{Fm})\beta_{Fm} \sum_k \alpha_{Fmk}(1 + \gamma_{Fmk}) \right)
\]

where \(\lambda_{FA}, \delta_{Fm}, \beta_{Fm}, \alpha_{Fmk}\) and \(\gamma_{Fmk}\) are characteristics of the financial viewpoint \(F\).

Fig. 12 presents, according to a financial aspect, an example of the performances obtained when executing activity \(A_2\) of the PAP process. In Fig. 12, as for the temporal viewpoint, the financial performance is widely dispersed depending on the employees chosen to implement activity \(A_2\). Even though the mean implementation cost is 48,611 (financial units), the cost can range between 30,000 and 80,000 (financial units), depending on the profiles of the human resources involved in implementing the activity. The same step-curve as that obtained for temporal viewpoint is observed.

Note that the financial performance can also be practically evaluated by considering the material costs, the human costs and the duration of the considered activity, which thus must first be computed. The proposed formulation (Eq. (11)) allows us to define a global approach for different performance viewpoints. The links between these two financial performance calculation approaches are detailed in [35].

4.2.3. Quality performance

Considering that an activity is characterized by a nominal quality (\(Q_N\) not null), Eq. (9) can be written using a quality viewpoint to express the final quality of an activity:

\[
Q_{FA} = (1 + \lambda_{QA})Q_N \sum_M \left( (1 + \delta_{Qm})\beta_{Qm} \sum_k \alpha_{Qmk}(1 + \gamma_{Qmk}) \right)
\]

where \(\lambda_{QA}, \delta_{Qm}, \beta_{Qm}, \alpha_{Qmk}\) and \(\gamma_{Qmk}\) are characteristics of the quality viewpoint \(Q\).

Fig. 13 presents, according to a quality aspect, an example of the performances obtained when implementing activity \(A_2\) of
the PAP process. The quality performance is also widely dispersed depending on the employees chosen to implement A2. The mean quality value is \(-11.8\) (without units), and can range between \(-99.6\) and \(+93\) (without units) according to the profiles of the human resources used to implement the activity. Our industrial partner requires that the quality performance of an activity range between \(-100\) and \(+100\). Contrary to the two previous viewpoints, the curve seems to have a quasi-linear distribution for the performance obtained when implementing this activity. Negative values show the influence of stakeholders with weak competencies.

5. Computing the process performance

5.1. General process formalization

Defining composition rules of local performances estimated for each activity allows us to calculate the global performance of a process for a given human resource distribution and for a specific process behaviour \(s\). The composition laws used depend on the analyzed viewpoint. For example, an additive law is used for the financial and quality performance axes. The max law is used for the temporal aspect.

Four performance classes have been distinguished:

- The previously defined activity performance \(AP_i\), which estimates the performance of a particular activity \(A_i\).
- The upstream performance \(UP_i\), which corresponds to the performance of the part of the process, which is implemented before activity \(A_i\) for the considered behaviour \(s\).
- The feedback performance \(FP_i\), which is introduced in the model to account for the possibility that, for some viewpoints like quality, an iteration of an activity in the behaviour \(s\) could arbitrarily influence the performance.
- \(AP_i\), \(UP_i\) and \(FP_i\) are combined to obtain the output performance of an activity (Fig. 14).

The output performance \(OP_i\) of an activity \(i\), for a performance viewpoint \(v\), can be estimated with Eq. (13).

\[
OP_{iv} = AP_{iv} + UP_{iv} + FP_{iv}
\]  

(13)

Table 2
Calculation elements for the temporal performance of an activity

<table>
<thead>
<tr>
<th>Element</th>
<th>Modulation ((T_{Nom}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(AP_{iT})</td>
<td>Modulation ((T_{Nom}))</td>
</tr>
<tr>
<td>(UP_{iT})</td>
<td>(\text{Max}{\text{perf}(A_{i1}), \ldots, \text{perf}(A_{iT})}) (A_{i1}, \ldots, A_{iT}) activities upstream to (A_{iT})</td>
</tr>
<tr>
<td>(FP_{iT})</td>
<td>0</td>
</tr>
<tr>
<td>(OP_{iT})</td>
<td>(AP_{iT} + UP_{iT})</td>
</tr>
</tbody>
</table>

The performance associated with a particular process behaviour can then be estimated by using the proposed approach.

In the following, for the temporal, financial and quality viewpoints, a table summarizing the rules used for performance estimation is presented. Two typical performance curves are shown for the PAP process for a behaviour represented by sequence \(\sigma = \{A_{1}, A_{2}, A_{1}, A_{2}, A_{1}, A_{2}, A_{3}\}\). Each curve is linked to the human resources implementing the process, first qualified and secondly inadequate for the task implementation.

5.2. Experimental results

5.2.1. Temporal performance

Table 2 summarizes the elements required to compute the temporal performance of the PAP process. Fig. 15 presents variations in the duration of the PAP process for a given human resource allocation. Fig. 15 shows two curves: one plotted for human resources with high competencies to implement the activity, the other plotted for human resources with low competencies to implement the activity. For this viewpoint, the feedback performance is null because the temporal penalty is naturally taken into account. This means that the process duration increases each time an activity is implemented. The vertical axis corresponds to variations in the estimated temporal performance during implementation of the sequence \(\sigma\). The activities are plotted on the horizontal axis associated with their implementation.

5.2.2. Financial performance

Table 3 gives the elements required for the estimation of financial performance. As for the temporal aspect, the financial

![Fig. 14. The four identified types of performance.](image)

![Fig. 15. Temporal performance of the PAP process for \(\sigma\).](image)
penalty due to iteration of the process is directly taken into account. Fig. 16 presents variations in the performance of the PAP process for a given human resource allocation. In this case, the feedback performance is also null because each time an activity is implemented, the associated cost is added to the financial cost of the process. The vertical axis corresponds to variations in the estimated financial performance during implementation of the sequence $s$. The activities are plotted on the horizontal axis. Each of the curves in Fig. 16 shows variations in the implementation of the process activities for a set of human resources presenting competence more or less adapted to the work.

5.2.3. Quality performance

Table 4 presents the elements required for evaluation of the quality performance of the PAP process. For this viewpoint, the penalty (if there is one) induced by an iteration is artificially taken into account by $FP_{Q}$. It is expressed by the law $FP_{Q} = g(r)$, where $r$ corresponds to the number of iterations associated with the activity. For example, when $r = 0$, a null value can be chosen for $FP_{Q}$, and when there is an iteration, the function $g(r)$ leads to a penalty. For example, it can be considered that each iteration explains a lack of quality, which has not been identified and can be artificially integrated with the feedback performance law. The additive law was chosen by the industrial partner to aggregate the different performance classes in order to highlight, for a considered behaviour, points where an abnormal lose of quality can be observed.

Fig. 17 presents variations in the performance of the PAP process for a given human resource allocation. The vertical axis corresponds to the estimated quality performance pattern during $s$. The activities are plotted on the horizontal axis. Each curve in Fig. 17 shows variations in the implementation of process activities for a set of human resources with high and low competence (as indicated on the curves).

5.3. Advantages and applications of the proposed methodology

The links between competence and performance seem logical and have been tackled for many years in the soft sciences, but the formulation of these links has not yet been proposed. In industrial engineering, few works have tried to really model in detail the impact of human resources on performance. Most of the time a worker is just considered as a simple resource that is available or not, or to have some competence levels, without trying to explain the relations between these competencies and the process performance. The proposed performance estimation approach has several advantages compared to these previously published proposals:

- It allows specific integration of the impact of human resources on enterprise process performance while actually trying to quantify it. This is possible thanks to the development of the MOVES enterprise model. The link between qualitative aspects related to the human entity (more or less good competence) and its influences on the activity performance can thus be modelled. To our knowledge, no studies have formalized this competence/performance link with this kind of approach.

| Table 3 |
| Calculation elements for the financial performance of an activity |

<table>
<thead>
<tr>
<th>$AP_{i,T}$</th>
<th>Modulation ($F_{Nom}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$UP_{i,T}$</td>
<td>$\sum [\text{perf}(A_{1,T}), \ldots, \text{perf}(A_{n,T})]$</td>
</tr>
<tr>
<td>$FP_{i,T}$</td>
<td>0</td>
</tr>
<tr>
<td>$OP_{i,T}$</td>
<td>$AP_{i,T} + UP_{i,T}$</td>
</tr>
</tbody>
</table>

| Table 4 |
| Calculation elements for the quality performance of an activity |

<table>
<thead>
<tr>
<th>$AP_{i,T}$</th>
<th>Modulation ($Q_{Nom}$) $\in [-100, +100]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$UP_{i,T}$</td>
<td>$\sum [\text{perf}(A_{1,Q}), \ldots, \text{perf}(A_{n,Q})]$</td>
</tr>
<tr>
<td>$FP_{i,T}$</td>
<td>Defined by the user</td>
</tr>
<tr>
<td>$OP_{i,T}$</td>
<td>$AP_{i,T} + UP_{i,T} + FP_{i,Q}$</td>
</tr>
</tbody>
</table>
It makes it possible to simultaneously integrate aspects related to the individual as well as collective work. It also highlights the importance of the activity implementation context to define aggregation laws or modulation coefficients according to individuals.

- It makes it possible to address several performance viewpoints. It is well known that enterprise performance cannot be reduced to its temporal or financial dimension. In fact, to our knowledge, few studies have sought to simultaneously address several enterprise performance dimensions.

- It is based on a unified approach with a single formalization of a performance expression, irrespective of the addressed viewpoint.

This model and the developed formulation have permitted us to develop a simulator using C language and the Matlab® tool. Using a worker database characterizing their competencies, it allows the user to evaluate, for a given behaviour, the performance of an enterprise process. For a considered set of assigned workers, each activity performance is evaluated with the proposed formulation and aggregated, depending on the performance viewpoints, by using the corresponding process performance laws.

This accuracy of this new competence integration approach for performance evaluation, based on industrial expertise, is largely based on the relevance of the performance modulation laws and of the proposed formulation. The performance modulation laws are presently built empirically with the industrial partner. Their validation requires a large-scale and long scientific study using statistical or factorial analysis. The different parameters of the proposed performance formulation can be identified on the basis of well known multi-criteria methods. The observed performance profiles have presented, for our industrial partner, a good approach to real process performance. However, achieving good accuracy requires substantial work to validate the aggregation and formulation laws.

This work can lead to many practical applications for enhancing enterprise competency management. One of the problems that can be addressed concerns decision-making aid for human resource allocation to enterprise processes. Currently, despite the many studies, the human entity is generally reduced to an available or unavailable resource. It is obviously interesting to know, for a given process, the possible assignments to achieve the required performance goals. Then the performance estimation issue becomes a performance evaluation issue. If only one process and performance viewpoint are considered, the developed approach shows that all assignments are not equivalent and that some of them must be excluded even if the workers initially seem to be qualified. When several viewpoints are simultaneously addressed, as in real situations when the cost and time have to be minimized while maximizing quality, it becomes a multi-criterion problem. It is then harder to simultaneously meet several performance objectives, which independently lead to assignment solutions with few common solutions. Bennour proposes [36,37] a study, based on the proposed performance estimation approach, that allows the user to efficiently find (time, quantity) some assignment solutions.

Finally, if several enterprise processes are simultaneously addressed, it is possible to develop an affectation algorithm based on the proposed performance estimation and evaluation approaches. This makes it possible to consider real operational control of the process based on dynamic management of workers’ competencies.

6. Conclusion

This article presents a panorama of studies correlating competence with process performance. The relation between these two concepts is often pointed out but has rarely been formalized in the few studies in which the human entity is integrated. A detailed competence model is proposed. It is based on concepts used to describe the industrial world and focuses on the human entity and its links with the activity. A classification that breaks down competence into individual and collective main competence is proposed. The latter categories refer to criteria used by industrial stakeholders and are connected to performance by empirical and common sense laws defined with our industrial partner. The collaborative facet of the work is taken into account by contextual laws concerning the implemented task, and also by including the essential influence of the relational dimension of the work. This approach is generalized and formalized.

This human entity modelling according to individual and collective dimensions goes further into the logic of human integration in the analysis of enterprise processes. This perception of the human entity, which is based on the defined competence concepts, is integrated in a wider MOVES model dedicated to the analysis of enterprise process performance. It permits the operator to make use of the proposed performance estimation methodology, which integrates individual and collective dimensions of human resources and their dynamics into performance estimation.

The main advantages of the proposed work, based on industrial expertise, are to have developed an enterprise model that involves a detailed and dedicated modelling of human resources, and which is also oriented towards enterprise performance estimation. It is based on a medium level of complexity for human resource modelling, higher than usual enterprise models but allowing practical use for performance estimation. It specifically links common qualitative aspects of the human entity (competence model) to quantitative performance estimation. Furthermore, it proposes one formulation of activity performance, which can be projected to several performance viewpoints.

The proposed competence model and performance estimation method obviously have some limitations. In industrial engineering, several studies have tried to formalize the human impact on performance by trying to model competencies that characterize the individual intrinsically, and in terms of his/her learning capacities and social behaviour. The developed human resource model, although it takes some human dimensions into account, still has to be substantially improved. It would be necessary to integrate other important socio-emotional parameters such as motivation, personal ambition, etc., in the individual
competencies. The competence concept should not only be the focus of rough studies, but it should also estimate personality traits of the human resources [3,38,39], thus allowing their classification and evaluation according to criteria beyond simply professional competencies. The collective dimension must be enriched by adding cohesion factors more than a simple relational aspect. For example, the attraction of collective action, the distribution of power or leadership can be used. This dimension is studied, for example, in [40] and allows estimation of an employee’s integration in team work. These various concepts can always be classified, but the evaluation and formalization of their links within the competencies is a more ambitious objective. Besides, the proposed performance estimation approach is based on empirical and common sense laws that link competencies to performance. It will be necessary, in the activity context, to retain only the most pertinent facets of competence in order to simplify the proposed integration model. However, it would be important to more rationally formulate links between knowledge and competence. Studies aimed at modelling human resource capacities and behaviours at work in more detail as well as their impact on process performance are essential to develop pertinent decision-making support tools.

References

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