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Performance Indicators for Training Assessment of Control-Room Operators

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The performance assessment of industrial operators is a challenge faced by the scientific community in last decades on account of the subjectivity involved, lack of quantitative methods and complex trainer-trainee- relation. This paper presents a methodology to evaluate the performance of a control room operator according to operator performance indicators based on relevant human factors, which allows a quantitative and as well as qualitative assessment. The proposed methodology can be used not only for the assessment of operators but also for scheduling training courses, future recruitments, and insurance evaluations.

1. Introduction

Operator Training Simulators (OTSs) for industrial processes are available in the market since years. On one hand, the availability of high performing computers at low prices and of robust dynamic simulators has lowered the entry threshold. On the other hand, OTSs are more frequently required by the Industry to take the training level of future operators to both acceptable and safe values, and to increase and refresh the knowledge of the process by existing operators. Actually, OTSs allow facing not only programmed operations but also abnormal situations that can be even singular. Rare events such as process startups and shutdowns can be simulated virtually a number of times, thus enhancing the degree of knowledge and experience of operators (Brambilla and Manca, 2011).
Shared understanding and operation of the plant, among workers, allow increasing the safety of the process and may even improve its efficiency. Finally, OTSs allow keeping the knowledge and understanding of the process shared and within the company. These training tools avoid losing the expertise of workers who, after a long career, retire.
The structure of common OTSs is based on the paradigm of trainer-trainee(s) interaction. Usually, a training room replicating the control-room devices and Human Machine Interphase (HMI) sees the trainer assigning some duties to one or more trainees that are evaluated according to their actions, decisions, timings and coordination with other operators. The trainer can either assign predefined exercises and observe the operator performance or modify *ad libitum* some process parameters to monitor how the trainee(s) respond to unexpected events and/or abnormal situations.
Once the exercise comes to an end, the trainer assesses the performance of the operator(s) and outlines both correct and wrong/missing actions. During the assessment phase, the only means the trainer has to come up with a judgment on the trainee(s) performance is to refer to some process values recorded by the dynamic process simulator during the simulation session (replacing the real plant behavior in the OTS); but typically the final judgment, strongly depends on the personal opinion of

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the trainer. The intrinsically subjective assessment produced by the trainer raises some problems. As a matter of fact, the final subjective judgment used as a basis to producing the performance assessment, changes according to the trainers involved in the judgment. Moreover, under the hypothesis of a single trainer, the assessment is subject to the trainee(s) involved and on when the training session is done. Put it differently, the risk for the same operator performance to be assessed differently by the same trainer according to the involved trainee is really high as it strongly depends on the biases the trainer has on the trainee's capabilities and potential. Also under the hypothesis of the same trainer, the same trainee, and the same performance repeated in different training sessions, the subjective evaluation of the trainer might reasonably produce different assessments of the trainee.
In order to reduce the subjectivity of the trainer for the performance assessment, it is fundamental to identify and develop effective means to enable grounding the operator's performance assessment on objective and measurable parameters that, under the same circumstances, would give the same performance marking. In addition, an automatic assessment procedure, based on intrinsically objective parameters and sequence timings, would allow running both the training and assessment sessions without the, otherwise necessary, trainer's support. This would increase the automation of the training activity and would allow trainees practicing alone, repeating the same training session to track any improvements before taking the final assessment with the trainer. The possibility to repeat an indefinite number of times the same exact assessment procedure with a large number of operators would also produce some valuable data of statistic relevance. The large number of objective and repeatable assessments would allow identifying some kind of averaged learning-curve and threshold among teams of operators, thus understanding aseptically whether an operator is ready for the real-world operations and whether a team of operators, involved in a work-shift, would be well balanced and represented to face with possible abnormal situations.

2. Performance Indicators

Moving the attention from a subjective evaluation towards an objective judgment calls for indentifying and finally implementing a performance assessment procedure. Such a procedure should be based on performance indexes capable of describing quantitatively the training level and process understanding of industrial operators. This paper focuses the attention on control-room operators (CROPs) but the same remarks can be spent for field operators (FOPs). The call for a quantitative assessment tool is due to the fact that only quantitative values allow tracking either the improvement or the worsening of operator's performance. In addition, a quantitative mark is akin to both school-grade reports and serious-game scoring, therefore to well-known and recognized features.

A quantitative score is linked intrinsically to quantitative indexes based on industrial processes. The most natural and consolidated reference to quantitative indicators concerns the category of Key Performance Indexes. KPIs are well-known in the scientific literature (Cox, *et al.*, 2003; Steele, *et al.*, 2010; Hřebíček, *et al.*, 2011;) where the evaluation of process/plant performance plays a significant role in the on-line optimization of operating conditions. Such indexes allow measuring the production efficiency by taking into account a number of process variables that play a major role. Industrial KPIs try to summarize and convey either in a number or in a diagram the multifaceted representation of the plant by accounting on the dynamic response of the process subject to production variability and external disturbances. Although the evaluation of a KPI is usually based on taking into account several process variables, its evaluation is rather easy once the process variables are stored in a historical repository. Multidimensional statistical methods allow calculating the desired KPIs. In case of operator assessment, the performance indicators are referred to the decisions and actions of human beings and consequently to their complex behavior. For the sake of clarity, it is appropriate to speak of Operator Performance Indicators, *i.e.* OPIs, rather than KPIs when human factors are concerned. Although the mutual relation between KPIs and OPIs remains valid, the human attribute, intrinsic to OPIs, plays indeed a significant role in increasing the evaluation complexity of OPIs. It is also worth adding that, before evaluating an OPI, it is necessary to define the OPI nature and analyze its consistency and feasibility. The consistency feature deals with human factors and intangible attributes that are rather distant from both extensive and intensive variables of industrial processes. Once a single OPI has been evaluated, it is necessary to find a methodology capable of reassembling the set of OPIs that are devoted to assessing the comprehensive performance of the operator. Actually, the operator assessment is quite complex due to the fact that s/he is usually examined respect to a wide range of capabilities and skills. Some key OPIs may depend from sub-OPIs, which, on they turn, may depend on other lower-level OPIs. All these OPIs can be arranged according to a hierarchical structure. At the end, an overall OPI summarizes the whole performance of the operator. Categorization of the OPIs for CROP requires the understanding of the tasks handled by him during normal and as well as abnormal situations. Therefore, a very well defined but complex hierarchy is defined for the CROP as shown schematically in Figure 1.

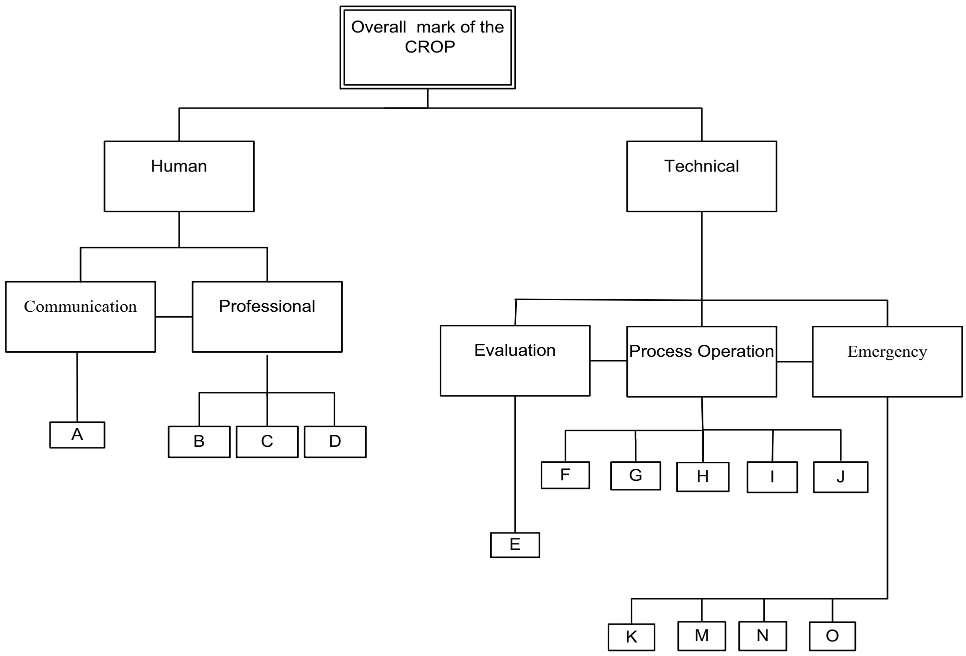

Figure 1 – Categorization and classification for CROP.

The categorization to obtain overall mark for CROP is initially divided into human and technical skills, which are further divided into subsequent categories. Each sub-category is divided into OPI(s) and thereafter each OPI is classified into some human factors. For example, the “Emergency” consists of four OPIs which are: information interpretation, abnormal situation management, emergency handling, and alarm system evaluation; presented as K, M, N and O in Figure 1. As far as a specific OPI is concerned, Figure 2 shows how the “Abnormal Situation Management” OPI depends on five human factors that allow deepening and saturating its different features. Since the hierarchically structured OPIs play an important role in the final operator’s assessment, a suitable weighing procedure must be developed to quantify the relative importance of each human factor which constitutes a single OPI. Once the structure is defined topologically and quantitatively, it is time to measure the features and attributes that contribute to the OPIs of the assessment structure. The measurement may be quite challenging since it can deal with a qualitative appraisal that on its turn must be transformed into a quantitative value. Likewise, contributes from psychology, human and behavioral sciences, ergonomics, and the like, play a significant role in defining and then measuring the constituents at the basis of the OPIs.

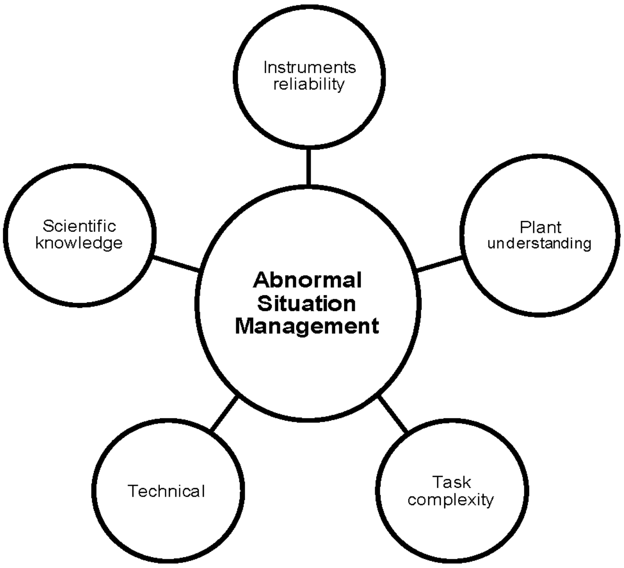

Figure 2 – An OPI with relevant human factors.

The measurability issue is not only referred to the feasibility of the measure and to the possible measuring devices, tools, and methodologies, but it comprises further features such as the definition of reference values and robust and acknowledged algorithms to convert any qualitative appraisals into quantitative values.

3. A workable hierarchy of OPIs

Nazir *et al.*, 2011, discussed extensively the situation awareness of CROPs in industrial plants. Their findings about individual and team situation awareness can be used as a reference for defining a suitable set of OPIs. Among the features that contribute to the definition of OPIs we have:

- The process understanding in terms of equipment, operations, cause-effect relations, dynamics and controllability;
- The role played by inlet flowrates, process streams, recycles, and utilities on the response of the process;
- The role played by the heat exchange network on thermal balances and control of equipment;
- The capability to drive the process to new operating conditions or to reject external disturbances;
- The capability to forecast the process evolution subject to unexpected malfunctions;
- The capability to deal with startups, shutdowns, grade changes, alarms, abnormal situations, incidents, and accidents;
- The achievement of a safety culture;
- The capability to coordinate the actions throughout a work-shift with both the control room colleagues and the field operators.

Once the OPIs are defined and their measurability is assessed, then it is time to organize them in a hierarchical structure capable of grouping different categories from a bottom-up perspective. As shown in Figure 1, the OPIs belong to different groups and occupy three levels of the hierarchical pyramid where the vertex summarizes the overall performance of the CROP. The overall performance indicator of the CROP gathers contributes from the human and technical features. Each OPI of the hierarchy must be weighed according to an accepted methodology which is shared by assessment experts. As aforementioned, an OPI is based and depends on some Human Factors. These HFs are defined according to the perspective of process industry. Eq. 1 shows the correlation used for the evaluation of an OPI:

$$OPI = \sum_i \frac{r_i w_i}{r^i_{max}} \tag{1}$$

where: r_i is the performance measure of the ith HF, w_i is the weight of ith HF, r^i_{max} is the maximum value of r_i.

Among the methodologies that allow weighing the relative importance of distinct attributes the Analytic Hierarchy Process is one of the most well-known (Saaty, 1980). Such methodology is based on pairwise comparisons among indexes belonging to a square matrix whose row and column labels are the OPIs. Such matrix is reciprocal (*i.e.* $a_{ji} = 1/a_{ij}$) and its coefficients are obtained by transforming the qualitative assessments into quantitative ones according to Saaty's scale. A dedicated algorithm allows outlining possible inconsistencies in the pairwise comparisons due to human discrepancies in the judgments. The normalized eigenvalues of the Saaty's matrix are the weights of the OPIs at each level of the hierarchy. By adopting the same approach for weighing the HF contributes of each OPI it is possible to get a hierarchical weighed structure that can be used eventually to perform automatically, the CROP assessment. For the sake of correctness, once the weights have been evaluated and the hierarchy is defined, both in terms of structure and relative importance, the most challenging task remains the transposition of the operator performance (usually based on qualitative judgments) into quantitative values. This quantitative values represent the input values that enter the bottom of the hierarchical pyramid as shown in Figure 1. To make the task even more challenging and complex is the procedure is expected to run automatically then it is necessary to identify a methodology to measure the performance of the operator(s) without the human interventation so to produce those input values that allow finalizing the assessment procedure. Anyhow, the automatic measure of the operator performance for any OPIs goes beyond the scope of this manuscript. The steps involved to reach the overall mark for CROP are shown in Figure 3.

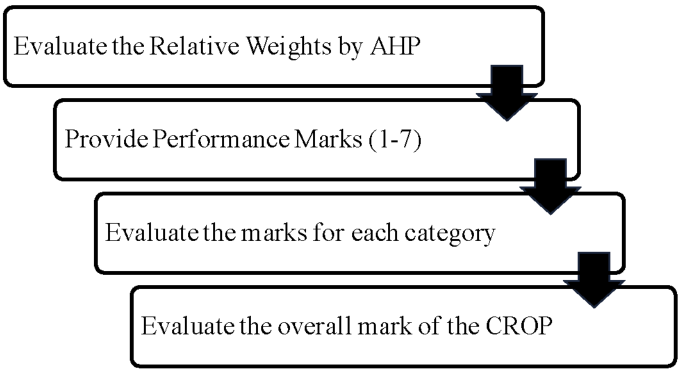

Figure 3 – Systematic steps to evaluate the overall mark for CROP.

4. Results and Discussions

Once the pairwise comparison is deployed according to the AHP methodology and the subsequent steps are performed according to Figure 3, not only a an overall quantitative value is obtained for the CROP, but also the evaluation is made at each category and subcategory, which are shown in the hierarchy of Figure 1. Table 1 shows a weighing matrix for the OPI “Operator Carefulness”, where the qualitative assessments are converted into quantitative ones according to the Saaty’s scale (Saaty, 1980). The normalized eigenvalues as reported in Table 2, are the weights for each human factor of that OPI.

Table 1 – Weighing matrix based on pairwise comparisons and final normalised weight.

Operation carefulness	**M**	**WE**	**P**	**TR**	**CP**	**Final Weights (Normalised)**
Motivation (M)	1	0.5	0.5	0.5	2	0.079
Work environment (WE)	2	1	2	0.5	0.3	0.15
Personality (P)	2	0.5	1	0.5	0.3	0.11
Task rotation (TR)	2	2	2	1	0.3	0.20
Company policy (CP)	5	3	3	3	1	0.44
						1 (Sum)

Similarly, all the OPIs and relevant HFs are evaluated within the defined hierarchy to obtain a value out of 100 as the overall mark of the CROP and as well as for each well-defined category.

5. Conclusions

The proposed mathematical approach overcomes the deficiency of subjectivity, personal experience and likings/disliking of the trainer, thus, providing the decision makers with a reliable, objective and reusable tool for the evaluation of operators. The authors are involved in some training assessment of industrial operators to validate the proposed methodology and expand the adaptability and application of the software.

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