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SUPPORT TOOL TO ASSIST THE CHOICE OF SKILLS FOR MAINTENANCE INTERVENTION BASED ON EXPERIMENTAL DESIGN

Abstract: *Industrial maintenance occupies a predominant place in manufacturing companies and it effectively contributes to the improvement and the development of the production tool. However, the major concern of industrialists is to carry out efficient interventions in optimal time without penalizing production. Faced with this challenge, maintenance actors often find it difficult to choose the right skills to assign to the different tasks, depending on the complexity and the rapidity required of each task.*

In this article, we present a tool that helps manufacturers to choose the right actors for maintenance interventions. It is based on the practice of the experimental design and the estimation of the levels of competences of each actor in each maintenance level. Such a tool highlights and takes into account two important responses being the rapidity and quality of interventions. The results obtained were simulated on simulation software and examples of treatment of the results were also presented.

Keywords: *Competences, Maintenance levels, Experimental design, Qualification, Decision support tool.*

1. Introduction

The subject of skills plays a vital role and takes a decisive position in companies, especially in an evolving environment where new forms of organization and modes of productive performance have appeared. Human resources are increasingly managed individually, by taking into account their competence; they are no longer regarded as anonymous resources. It is observed that to perform a given task by two operators of the same qualification, performance varies according to the actor (Dakkak & Talbi, 2014). It brings about the concept of competency level, which is relative to each actor. Many studies focus on the sequencing of activities for human resources, but only few approaches take into account the competency level of these resources (Boye Kuranchie-Mensah & Amponsah-Tawiah 2015; Nassazi, 2013; Boumane, 2007; Soulié & Mathieu, 2003; Le Boterf, 2004). And almost all approaches that are aware to human resources' skills are mainly the "able or not" type.

The subject of competence management was treated in several research works and with several ways according to the viewing angle of each author using sometimes managerial and empirical approaches and some other times mathematical models.

Norman et al. (2002) considers the problem of assigning workers to manufacturing cells

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in order to maximize the effectiveness of the organization. The authors assumed that the organization effectiveness to be a function of the productivity, output quality, and training costs associated with a particular worker assignment. Traditionally, these worker assignments have been based only on the technical skills of the workers. The proposed model by Norman et al. (2002) also includes human skills and permits the ability to change the skill levels of workers by providing them with additional training. The problem is formulated as a mixed integer programming problem. A total of 32 test problems were developed and varied with regard to the total training time, the available training time for each worker, the training costs, the productivity coefficients and the quality level coefficients. Results indicate that this model provides better worker assignments than one that only considers technical skills.

Markes (2006) collected the necessary data on the skills required by the engineering and manufacturing employers based on a detailed review of the literature. The author affirmed that it is necessary to understand the needs of the industry to acquire the appropriate engineering skills. This can only be achieved through cooperative, inclusive, transparent and centrally coordinated approaches to skills assessment, monitoring and development.

Gillian et al. (2007) outline an electronic research skills audit tool that has been developed to map both transferable and discipline-specific skills teaching and assessment within individual modules, the results of which can be collated and analyzed across entire degree programmers'.

Arsovski et al. (2008) proposes the use of information and communication technologies to improve the quality of the maintenance process.

Hong (2015) presented a study on the identification of skills required for geographic information systems (GIS) posts. This study was based on the analysis of 946 GIS announcements from 2007 to 2014. Such analysis permitted to identify the key competences for improving the employability of GIS majors.

Mendes and Machado (2015) did a structural equation modelling applied to data collected from 144 manufacturing firms in the automotive industry from several countries. Findings provide evidences that workforce' skills may foster manufacturing flexibility as an effective approach to cape with uncertain environments and turbulent markets. More precisely, results show that employees' skills directly influence new product, volume and mix flexibility, which in turn directly influence business performance.

Carvalho and Rabechini Junior (2014) presented a study to elucidate the relationship between risk management and the success of the project given the potential impact of the complexity of the project. The authors have shown that any approach or approach is doomed to failure without taking into account two aspects of skills: soft and hard.

Moutinho and Oliveira (2015) affirm that the logistics and information systems assume relevant rolls to consolidate global performance. Beside efficiency, effectiveness productivity and flexibility, field teams need skills on autonomy responsibility and proactivity.

Campos Ciro et al. (2016) affirm that production resources usually represent an important constraint in a manufacturing activity, specially talking about the management of human resources and their skills. They consider an open shop scheduling problem based on a mechanical production workshop to minimize the total flow time including a multi-skill resource constraint. Then, they count with a number of workers that have a versatility to carry out different tasks, and according to their assignment a schedule is generated. In that way, they have formulated the problem a linear as and non-linear mathematical model which applies the classic scheduling constraints, adding some different resources constraints related to personnel staff competences and their availability to execute one task. In addition, they introduce a genetic algorithm and an ant colony optimization (ACO) tool to solve large size problems. The best tool (ACO) has been used to solve a real industrial case.

Pancholi and Bhatt (2017) use a multi-attribute decision making (MADM) approach. The primary findings of this research work are to enhance quality in planning the maintenance activities of critical components.

Therefore, the main factors related to the right choice of human resources for a given intervention are the availability of individuals, their number, their suitability for tasks and, finally, their level of competence, which directly influences the performance of a given intervention. The research papers show that the human resource competency levels are poorly integrated into scheduling models. The notion of competence level to quantify the rapidity and performance of a person in relation to a task to be performed is little taken into account.

In this paper, we pay greater attention to the choice of human skills for a given maintenance intervention according to the level of competence of each actor and the complexity of each task. In other words, it is a question of coming up with a tool based on the experimental design to help the industrialists to choose, from the available competences, the actors who might intervene in a given maintenance task taking into account both the actors' qualification level, the desired rapidity and quality of intervention.

For this purpose, this paper is organized as follows. First, we begin by definitions of the competence concept. In this section we present the different definitions and the main studies that have been carried out in this field in order to gain a clear understanding of the task. Second, we define the objectives, the hypotheses of the study and the responses to achieve them. Third, we search the factors that could influence the responses and we define the low and high levels of the factors used. Thus, we choose the right experimental design for each response. Finally, we conclude with a practical study to test the validity of the established models.

2. Definitions

The competence is the capacity of a person (actor) to act and react with the pertinence required to perform an activity in a work situation. The actor is at the heart of a process, which consists in selecting, combining and mobilizing knowledge, know-how, abilities and behaviors on the one hand and environmental resources on the other, in order to accomplish a mission defined by the organization (Boumane et al., 2006).

On one hand the competence can be considered as a process but also as a disposition to act (Le Boterf, 2004). The competence is a process that builds or adapts action strategies by mobilizing resources to accomplish a given mission. Through this process the subject learns and develops his professional practices. On the other hand, to consider competence solely as a disposition to act is a risk of reducing it to personal resources.

The competence is finalized; it is linked to a mission defined by the work organization. The competence consists in carrying out a mission within the framework of the company's strategy and in the spirit of its culture (Lévy-Leboyer, 1997). Faced with a situation of work, the subject is led to take the initiatives and the decisions necessary to achieve the expected performances. Thus, the competence must be clearly described and formalized in relation to a specific mission.

Classically, the competence is defined as the combined implementation of knowledge, know-how (mastered practices) and know-how (attitudes and behaviors). A competency model proposed by (Harzallah et al., 2006) (Figure 1) is based on four characteristics related to the type of competency, skill category, the context in which the competency is used, and the mission associated with that skill.

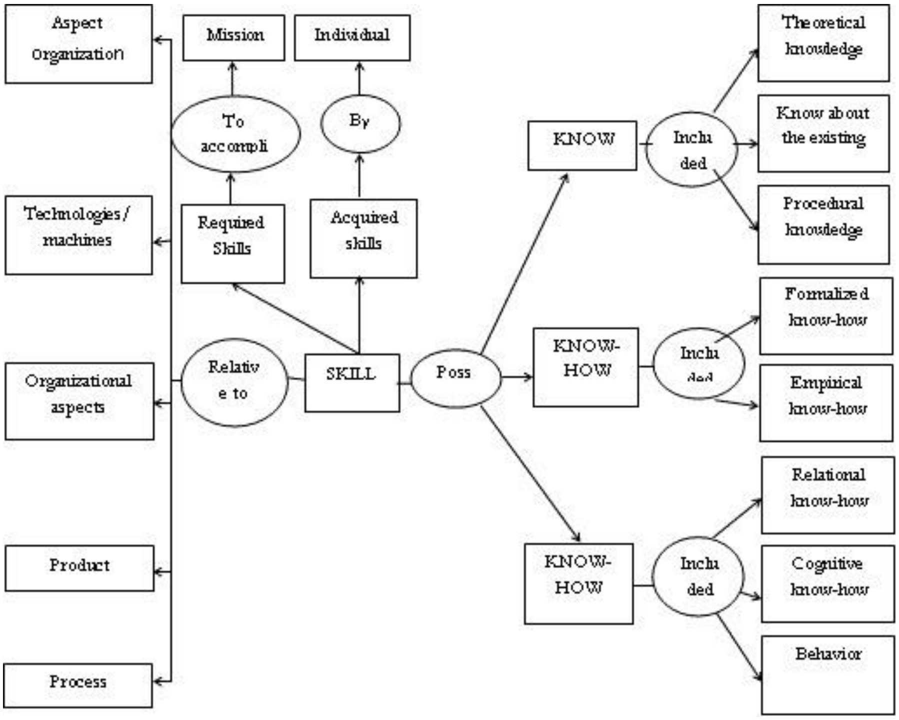

Figure 1. Skill model (Harzallah et al., 2006)

Competence management (CM) refers to how competence is managed with respect to organizations, groups and individuals (Berio & Harzallah 2005). The organizational view has shifted from using the term qualifications to the broader term competence (Boucher et al. 2007). Much research emphasises the organisational perspective related to strategic planning, involving identification of competence gaps and strategies to fill these gaps (Lindgren et al., 2004). They found that for organisational CM activities, skill-based competence descriptions are appropriate and often used. For individual CM activities, job-based descriptions are common. There is a tension between these two views: i) skill-based, as personal descriptions with a present and future focus and; ii) job-based, as positional descriptions with a focus on the past.

3. Conceptual and theoretical framework

3.1. Experimental design

Experimental design is the process of planning a study to meet specified objectives. Planning an experiment properly is very important in order to ensure that the right type of data and a sufficient sample size and power are available to answer the research questions of interest as clearly and efficiently as possible.

Experimental design is a careful balancing of several features including “power”, generalizability, various forms of “validity”, practicality and cost. A thoughtful balancing of these features in advance will result in an experiment with the best chance of providing useful evidence to modify the current state of knowledge in a particular scientific field. On the other hand, it is unfortunate that many experiments are designed with avoidable flaws. It is only rarely in these circumstances that statistical analysis can rescue the experimenter (Seltman, 2018).

Experimental design is part of the set of quality tools that allow companies to progress in mastering the design of new products and in mastering manufacturing processes. Together with other statistical tools such as SPC and multiple regression analysis, they form a coherent set of formidable efficiency to solve many quality problems. Ignoring these's today, would deprive oneself of a significant potential for improvement for the company. Whatever the sector of activity and whatever the industry, the latter is always required to conduct tests. But these tests are unfortunately too often conducted without methodology. We proceed by trial and error, without rigorously planning the tests to obtain a plethora of results that we do not always know very well exploit. And yet, the experimental design makes it possible to rigorously conduct the tests with a view to a perfectly defined objective. It will also allow a considerable reduction in the number of tests compared to traditional techniques. More importantly, it will allow a quick and unequivocal interpretation of test results by providing an experimental model of the system under study (Goupy & Creighton, 2006).

In fact, this is exactly what the technician is looking for in a problem. The method, once understood, is an irreversible step in the career of the latter who can no longer consider conducting tests without using a plan of experiments.

In this article, we will lead another way of applying the experimental design. It is a question of designing a tool in form of abacuses to help the choice of human skills for maintenance interventions.

3.2. Methodology of experimental design

The different steps of the experimental design are as follows (Vanot & Sergent, 2005):

1) Clear definition of the problem being studied: proposed targets, consequences of a wrong decision, budget (in time, cost, means, etc.).
2) Compilation of the current local and bibliographical knowledge. If some necessary information is not available, experiments must be undertaken. Therefore, a complete and precise list of the factors likely to be influential, the responses, and the constraints must be established. The area of the experimental domain in which the missing information is to be sought has to be defined. It is referred to as the experimental domain of interest.
3) Setting up an experimental strategy (or experimental design) (i.e., to choose the experiments to be carried out according to the defined targets, the means available, and the desired information). The researcher seeks a relationship of cause and effect between some parameters of the phenomenon (called factors), which are supposed to influence the behavior of the phenomenon and other parameters (called responses) that define the result of the phenomenon. The planning of experiments consists in forcing the factors (input) to vary in a precise way, measuring the induced variations of the answers (output) and then deducing the relationships between causes and consequences.
4) Carrying out the experiments that will give us the values of the studied responses.
5) Deduction of the answers to the questions either directly or with the help of a mathematical model.

4. Experimental set-up and the used method

In this section, we will follow the steps of the experimental design to design a model to help the selection of human skills for carrying out industrial maintenance interventions. To do this, the concepts listed below represent the expected results of the application of the tool:

- Execution of maintenance interventions in optimal time, respecting production requirements and available skills;
- The maintenance intervention must meet the performance requirements imposed in terms of quality, safety and environment. They will be called subsequently the requirement of quality.

The study will be successful if the competences for a given intervention can be identified knowing the desired duration and quality of the intervention.

4.1. The responses to achieve the objectives

- The first answer matches the first objective. We will therefore choose the rapidity of the intervention.
- The second answer matches the second objective. So we will choose the desired quality as second response.

4.2. Hypotheses of the study

This study will be valid if the following considerations are taken into account:

- For reasons of simplification, we will consider only the first three maintenance levels. However, the study may be generalized later.
- Get the collaboration of the staff so that the work done during the experimentation phase is the true reflection of what really happens
- All members of the stuff are able to perform the three maintenance levels. Only the rapidity and the quality of interventions differ from one actor to another.
- The worksheets are written and formalized.

4.3. Investigation of factors expected to affect responses

What are the factors that may impact the quality and the rapidity of maintenance intervention?

To try not to forget factors, we have to proceed methodically. It is necessary to analyze all the major sectors that may involve factors impacting the chosen responses:

- Maintenance levels;
- Work atmosphere;
- Noise and olfactory disamenities;
- Production pressure;
- Availability of tooling;
- Availability of spare parts;
- Accessibility to place of intervention;
- Season (summer, winter…);
- Day (i.e., the day of the intervention corresponds to an ordinary day, weekend, public holiday, beginning of the week, end of the week…);
- Intervention time (morning, afternoon or night. Because, the performance of operators depends on the intervention time), etc.

To illustrate the approach, we have given a first list of some factors that may have an impact on responses.

From this list, the factors that are expected to be influential are selected and divided into two categories: the factors that will be studied through the experimental design and the factors that will not be studied during the experiment but their levels will always be set at the same value. In this study, three factors were chosen to develop the experimental design: the 1st, the 2nd and the 3rd maintenance level.

4.4. Levels of input factors

It is a question of choosing the high and the low levels of the three factors selected. To do this, we will link each factor with a closed questionnaire where we will correspond to each question asked a grid of answers with four affirmations: yes, rather yes, rather no and no. Each assertion is associated with a weighting coefficient 1; 0.7; 0.3 and 0 respectively as illustrated in Table 1.

Table 1. Questionnaire model

Questions	Affirmation			
	Yes	Rather yes	Rather no	No
Question 1				
...				
Question n				

The questions of such questionnaire must summarize the tasks and the maintenance interventions to be carried out on the equipment and the means of production. It is then necessary to share them according to the first three maintenance levels.

Once the questionnaire is established, the level of each actor is the sum of the scores obtained in each level of maintenance. Therefore, the high and the low level of each factor can be determined. The low level corresponds to the lowest score and the high level represents the highest score.

It is interesting to summarize these levels in a table (Table 2).

Table 2. Factors and field of study.

Factor	Low level (-)	High level (+)
1st maintenance level		
2nd maintenance level		
3rd maintenance level		

4.5. Choice of the experimental design Q

In the case of this study, we considered three factors. The low and the high level of each factor have been defined. We assume that the levels of the factors to be kept constant during the experiment are already specified.

Therefore, it is advisable to choose a complete factorial design 2^3:

$$R = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_{12}x_1x_2 + a_{13}x_1x_3 + a_{23}x_2x_3 + a_{123}x_1x_2x_3 \quad (1)$$

This design can be represented by a figure (Figure 2), indicating the field of study and the points of experiment. The low levels and the high levels of the factors coordinate the points of experience. It can also be represented by the experimental matrix (normal units) or the matrix of experiments (coded units).

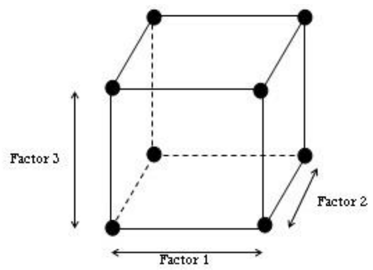

Figure 2. Representation of experimental design

The experimental matrix (Table 3) includes 6 columns: the names of the trails, the three factors and the two responses (output).

The trials must be carried out according to the design of experiments and the results will be recorded in the experimental matrix.

The letters have the following meaning:

- R_i represents the response,
- x_i represents the factor level,
- a_i coefficient represents the factor effect or the first-order effect,
- a_{ij} coefficient represents an interaction between two factors or second-order interaction (binary interaction between xi and x_j),

- a_{123} coefficient represents the interaction between the three factors or third-order interaction (ternary interaction among x_1, x_2 and x_3).

Table 3. Experimental matrix

Trials	Factor 1	Factor 2	Factor 3	Intervention rapidity R_1	Intervention quality R_2
1	-1	-1	-1		
2	+1	-1	-1		
3	-1	+1	-1		
4	+1	+1	-1		
5	-1	-1	+1		
6	+1	-1	+1		
7	-1	+1	+1		
8	+1	+1	+1		
Level -					
Level +					

The rapidity and the quality of the interventions are measured as follow:

First, make an inventory of the maintenance activities and tasks that can be performed on the company's machine park;

- Make an estimate of the completion time of each task taking into account all constraints and opportunities. This leads to distinguish three times:
  - ***Optimistic time*** (T_o): if the maintenance task is performed in very good conditions better than expected;
  - ***Realistic time*** (T_r): if the maintenance task is performed under normal conditions;
  - ***Pessimistic time*** (T_p): if the intervention is carried out under bad conditions, worse than expected
- Weigh intervals of interventions as follow (table 4)
- Weigh the quality of interventions as follow (table 5)

Table 4. Intervention time weighting

Task time	**Weight Value**
$T \leq T_o$	1
$T_o < T \leq T_r$	2
$T_r < T \leq T_p$	3
$T > T_p$	4

Table 5. Intervention quality weighting

Intervention quality	**Weight Value**
Intervention is performed: • With tests, functional checks using additional skills • Without taking into account safety and environmental aspects	1
Intervention is performed: • With tests and functional checks only • Taking into account just some requirements related to safety and environmental aspect	2
The intervention: • Renovates the equipment and it is carried out without any test or verification without calling for additional skills • Takes into account the requirements related to safety and environment.	3

4.5. Experimentation

Once the high and the low levels of each factor are defined, we move to the experimental phase as shown in Table 3. In each trial, the time of the intervention is recorded and compared with what was expected. For example, if the time was between the realistic and the pessimistic time, the value "3" (from Table 4) is recorded in the column "Intervention rapidity". Similarly, a value of intervention quality is chosen from Table 5. The same action is used for the remaining seven trials.

From the achieved results, the coefficients of each factor of equation (1) can easily be calculated for the two chosen responses. Consequently, the model obtained from each response can be graphically represented so that we can come out with graphs to determine which competencies should be chosen for a given maintenance intervention fixing in advance the desired rapidity and quality of the intervention.

To illustrate these theoretical notions, we will present a practical study.

5. Results and Discussion

The case study was conducted in an industrial enterprise. For confidential reasons, we cannot give details about this company. The experimentation must go through the following steps:

- Step 1:Determine the level of each actor based on the questionnaire in Annex 1
- Step 2:Determine the high and low level of each factor in the experimental design;
- Step 3:Choose eight different maintenance tasks that will be called "pilots" to start the experiment
- Step 4:Perform the experimentation;
- Step 5:Calculate the coefficients of each response and generate the final model;
- Step 6: Represent graphically the results.

The questionnaire was largely based on the ISO/IEC 17024 in the sense of properly allocating skills according to three levels of maintenance. This questionnaire was submitted to the head of the company and the results obtained are grouped in Table 6:

Table 6. Factors and field of study

Factors	Low Level (-)	High Level (+)
Level 1 of maintenance	1	10
Level 2 of maintenance	0.3	7
Level 3 of maintenance	2	7

Subsequently, we selected eight maintenance tasks to do the experiment. The results are summarized in Table 7.

Table 7. Experimentation matrix

Trials	Factor 1	Factor 2	Factor 3	Intervention rapidity R_1	Intervention quality R_2
1	-1	-1	-1	4	3
2	+1	-1	-1	4	3
3	-1	+1	-1	3	3
4	+1	+1	-1	2	1
5	-1	-1	+1	3	2
6	+1	-1	+1	2	1
7	-1	+1	+1	1	1
8	+1	+1	+1	1	1
Level -	1	0.3	2		
Level +	10	7	7		

The results of this experiment allowed us to determine the two following models corresponding to the rapidity and quality of intervention respectively:

$R_1 = 2.5 - 0.5x_1 - 0.75x_2 - 0.75x_3 + 0.25x_1x_2x_3$ (2)

$R_2 = 1.875 - 0.375x_1 - 0.375x_2 - 0.625x_3 - 0.125x_1x_2 + 0.125x_1x_3 + 0.125x_2x_3 + 0.375x_1x_2x_3$ (3)

To facilitate the representation of these two models in 2D, four graphs (Figures 3, 4, 5 and 6) corresponding to the four rapidity responses 1, 2, 3 and 4 and three graphs (Figures 7, 8 and 9) corresponding to the three responses of quality of intervention:

From the results of these graphs it is easy to deduce the skills to be chosen for a given intervention. For example, supposing we have arranged a maintenance intervention with a total margin other than zero. In other words, the intervention can be performed between the realistic and the pessimistic expected times. This corresponds to a rapidity of 3 (from Table 4). To do this, according to Fig. 4, it is possible to choose a maintenance actor having at least the following notes in the three maintenance levels:

- In Level 1: 10
- In Level 2: 2.53
- In Level 3: 5.62

Moreover, if we want quality intervention equals to 3, we must choose an actor with at least the following marks:

- In level 1: 2
- In level 2: 1.27
- In level 3: 2.71

If we have a critical maintenance task (total margin of the task = 0), we must choose an intervention rapidity of 1 because a delay on this task can cause losses. To do this, we must use figure 6 corresponding to the rapidity 1. Indeed, the actors that must be assigned to this task must possess, for example, at least the following marks:

- In level 1: 7
- In level 2: 0.5
- In level 3: 4

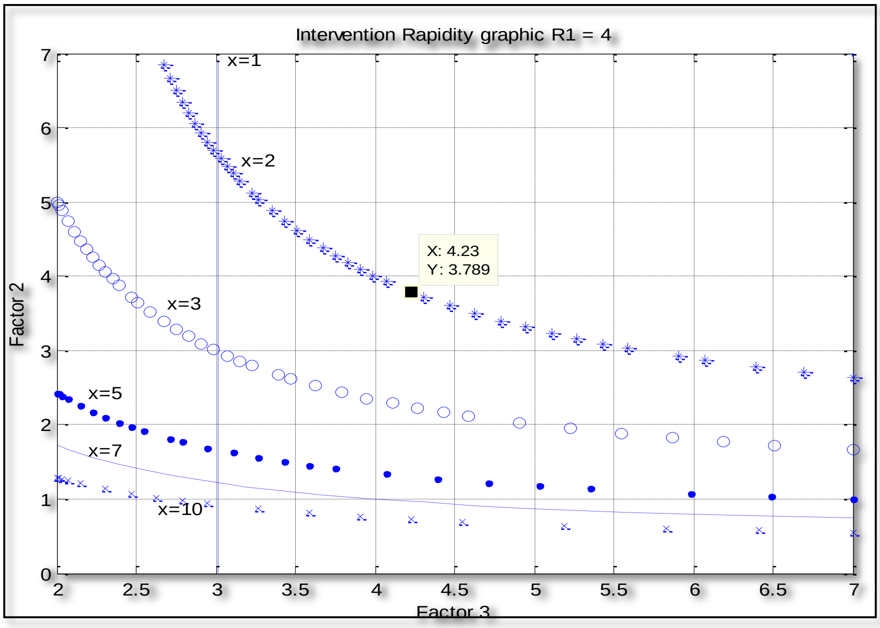

Figure 3. Intervention rapidity graphic R1 = 4

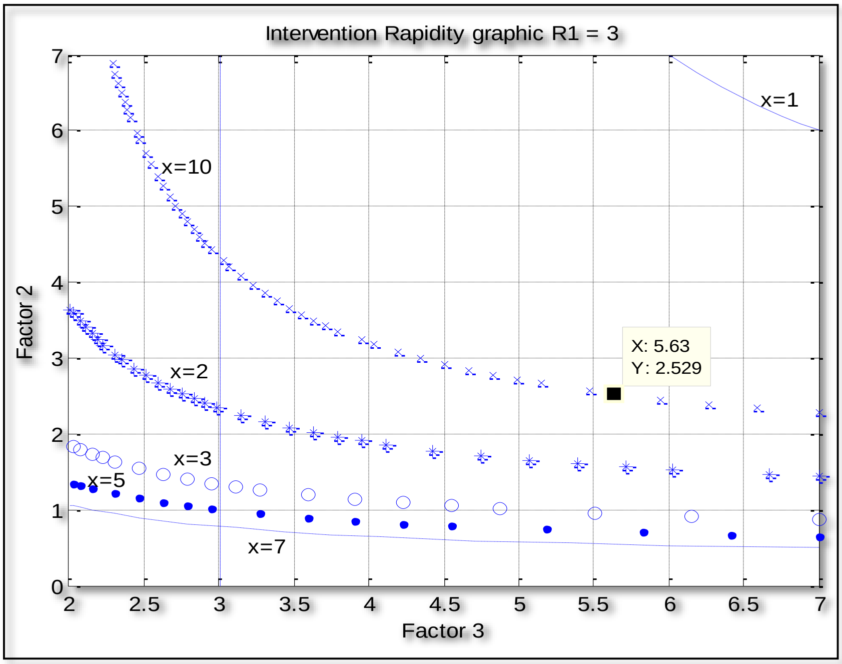

Figure 4. Intervention rapidity graphic R1 = 3

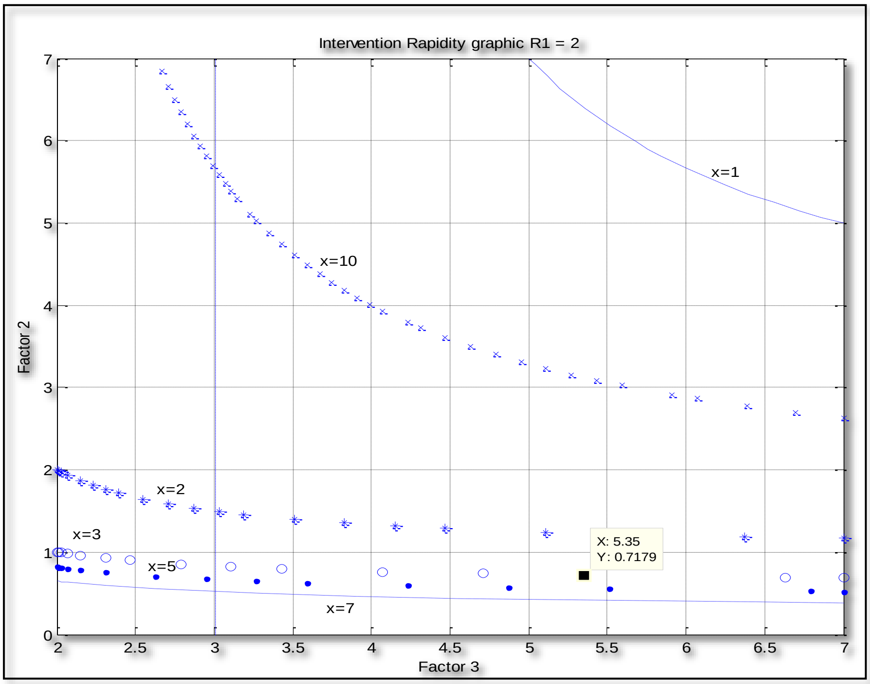

Figure 5. Intervention rapidity graphic R1 = 2

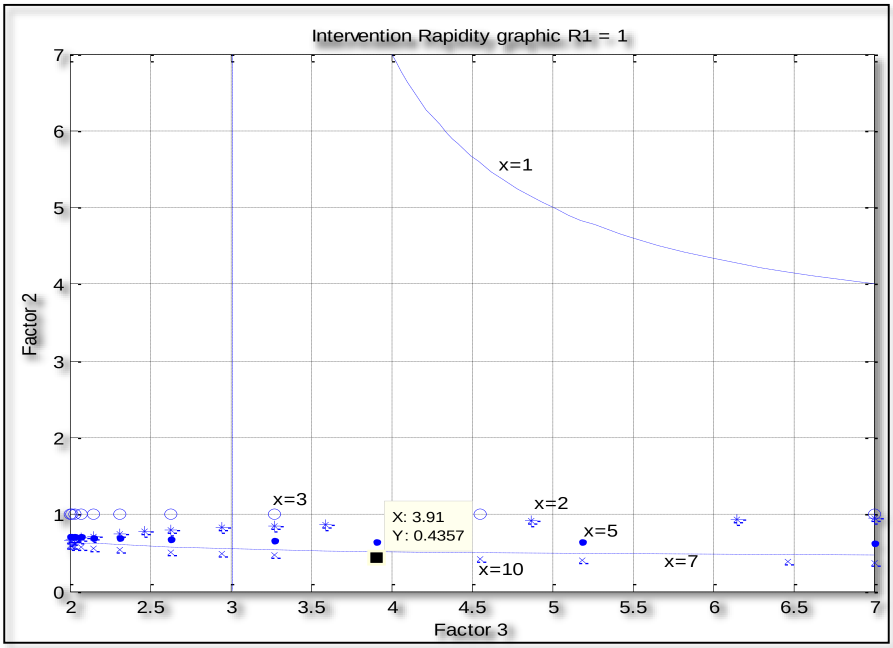

Figure 6. Intervention rapidity graphic R1 = 1

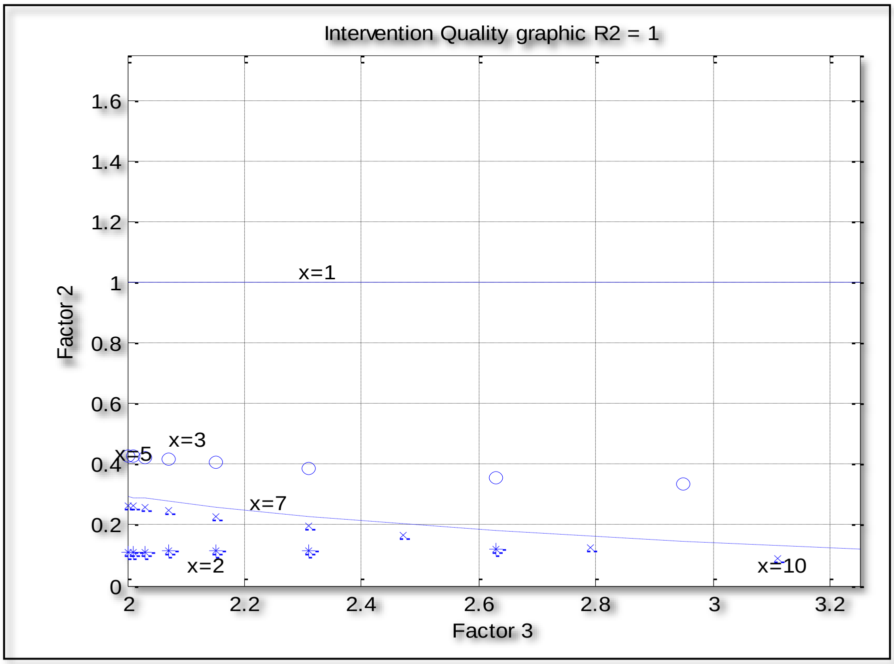

Figure 7. Intervention quality graphic R2 = 1

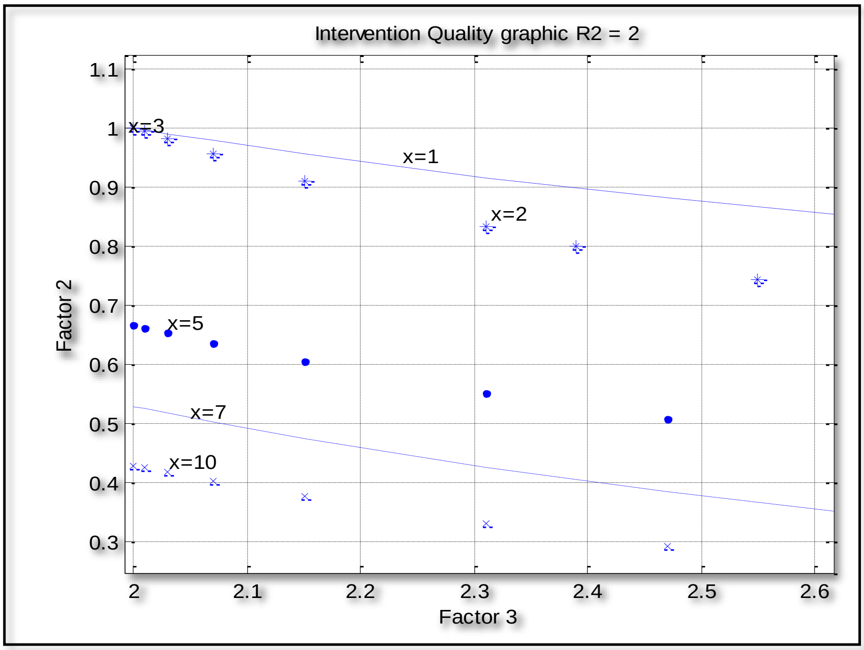

Figure 8. Intervention quality graphic R2 = 2

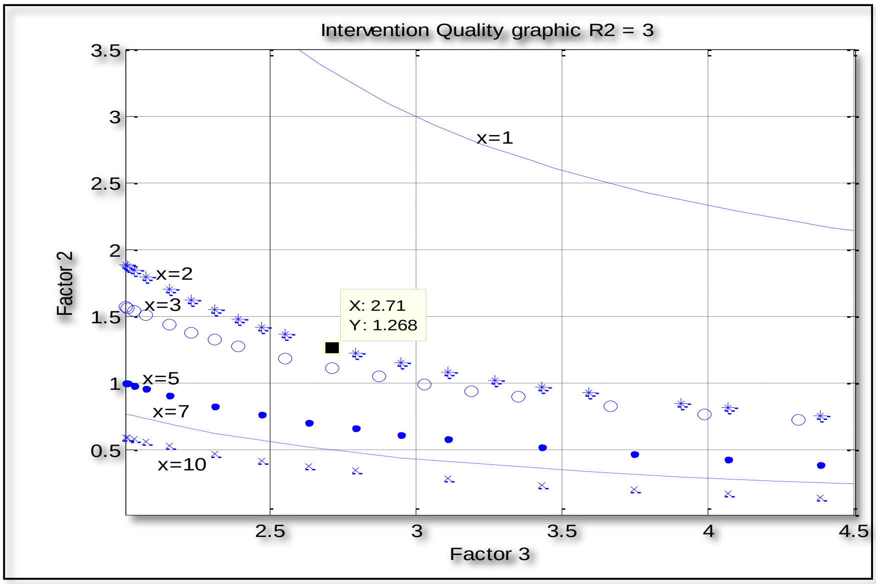

Figure 9. Intervention quality graphic R2 = 3

As a synthesis, it is clear that the established models are operational and can provide a very good help and support to the industrialists to affect its actors to the different daily tasks in an optimal way.

In addition, most of the research work that deals with the improvement of the quality of the maintenance process is concerned with the managerial and organizational aspects. However, the tool proposed in this paper deals with the operational part of the maintenance process.

Moreover, this tool is easily applicable for any manufacturing company because it does not require specific conditions and assumptions. Each company, from its maintenance activities and its human skills, can establish skills identification charts.

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