

A New Approach to Assess Objectively the Workforce's Performance: the Development of a New Competence Index

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ABSTRACT

Since workers' performance is very important in the continuous quality improvement, this study proposes an objective evaluation of the workforce quality in terms of competence. In the apparel industry this assessment is still subjective and done by individual judgment based on quotations. Our approach aims to express the capability of each worker in each executed operation by an index which contains both work quality and production capacity. So, a Multi-Criteria Decision Making (MCDM) method which is the Weighted Sum Model (WSM) was used. To determine the work quality, correct indicators were required. So, in a first step a Measurement System Analysis (MSA) was essential to analyze the system providing these indicators. The measurement system stabilization strengthened the reliability of the extracted data and guaranteed a fair workers' judgment. Therefore, an objective competency matrix reflecting the level of labor was obtained by calculating the Competence Index. This database was useful to pilot optimally the work group and to develop a dashboard summarizing the strengths and weaknesses of the workforce performing an article. Containing many indicators, the dashboard revealed a general overview of the operators' performance and production process vulnerability in the face of hazards. From this dashboard, the company managers could make correct decisions about training programs and recruitments. The Competence Index was also used to optimize the line balancing. This optimization allowed working with the most performing group, which minimizes defects, increases productivity and so improve the company's earnings.

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Keywords: Quality Index, Competence Index, MCDM, WSM, MSA, line balancing optimization

Introduction

Quality means satisfying the customer's needs in all respects (Roach, 1994). The notion of quality management is a business strategy where continuous improvement is driven by an empowered workforce focused on meeting or exceeding customer requirements (Winchester, 1994). Total Quality Management "TQM" is the

cornerstone of the continuous quality improvement "Kaizen" (Masaaki, 1989). The first and main concern of "TQM" is how to help workers and employees to invest their capabilities in achieving the company's objectives. So, knowing how to measure these capabilities to feed "TQM" with the relevant information is the basis (Ishikawa, 1984). From a normative side, ISO

9001:2008 provides, for human resources management in Chapter 6.2, that the skills performing activities affecting the product conformity should be identified and that companies should implement adequate actions to meet these skills needs (ISO 9001, 2008). Despite the presence of certain workforce-assessing methods, managers have expressed some reservations about these appreciation methods. They expressed their wish to determine objective indicators that would eliminate all subjectivity (Savall & Zardet, 2003). Performance rating, leveling, and the coefficient of performance are examples of the subjective appreciation used in the clothing sector (CETIH, 1994). In our bibliographical research, rare publications have been found in the field of textile quality management. Even though in the past decade, scientific interests in the subject grew considerably, few exposed and introduced aspects of quality assurance for the clothing industry (Brad, 2007). Defects minimization is the key for enhancing product quality. It also reduces production cost by limiting reworks and increasing productivity (Islam & Khan, 2013; Uddin & Rahman, 2014; Jebali et al., 2016). Only in a highly technological and completely automated field, can zero defects be achieved. The human factor, the subjective process, and the lack of automation are the most prevalent causes of non-quality. These causes are frequent in textile industry (Brad, 2007, Souid et al., 2012).

Grouping work tasks to be performed on work stations to realize an expected level of performance is undoubtedly one of the organization problems. The line balancing challenge is to reach equity in the amount of work allocated to each work station. The main line balancing problem is how to satisfy work precedence and optimize performance by allocating tasks to an ordered set of work stations (Ponnambalam et al., 1999; Güner et al., 2012). Optimizing the line balancing is still a big industrial problem: the efficiency difference between an optimal and a sub-optimal assignment can yield economies (or waste) reaching millions of dollars per year. Reducing costs of production leads to lower

prices of manufacturing goods, better company competitiveness and better exploitation of the market potential (Aadarsh, 2015).

In general, the choice of workforce assignment, depending on the firm's specific targets, the availability of means and the individual preferences of the decision makers, is a highly complex problem. The multi-criteria nature of the problem makes Multi-Criteria Decision Making (MCDM) methods a kind of resolution, given that they consider many criteria at the same time, with various weights and thresholds, having the potential to reflect at a very satisfactory degree the vague preferences of the decision makers (Afshari & Mojahed, 2010). Decision making, purely based on past experiences, judgment and intuition has become rather difficult. The human mind is also not capable of perceiving in all details many parameters at a time. Decision making is no more an art where the decision maker can apply mental models to find solutions. It is gradually becoming more and more scientific. In scientific decision making, mathematical models are applied to find solutions to organizational problems (Habiba & Asghar, 2009). The MCDM methods are gaining importance as potential tools for analyzing complex real problems thanks to their inherent ability to judge different alternatives (Choice, strategy, policy and scenario can also be used synonymously) on various criteria (attributes) for possible selection of the suitable alternative. These alternatives may be further explored in-depth for their final implementation (Chung & RTH, 2016). Various MCDM methods have been proposed to solve diverse applications of decision problems (Alam & Ghosh, 2013). One of the MCDM methods is The Weighted Sum Model (WSM). It is the simplest and most often used multi-criteria decision method. This method is based on the weighted average using arithmetic means. An evaluation score can be calculated for each alternative by multiplying the scaled value given to the alternative of that attribute with the weights of relative importance directly assigned by the decision makers followed by

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summing the products for all criteria. The advantage of WSM method is that it is a proportional linear transformation of the raw data. It means that the relative order of magnitude of the standardized scores remains equal (Jaberidoost et al., 2015).

The quality data are crucial in evaluating quality analysis and diagnosis. They are determined by applying a measurement system in measurement procedure. Wrong decisions will certainly be taken if any error occurred on the data. Thus, manipulating and managing “measurement error” called Measurement Systems Analysis (MSA), is of great importance in the improvement process. Most of the quality problems in industries are solved by identifying and correcting inaccurate data and inaccurate measurement processes (Smith et al., 2007; AIAG, 2010; Dhawale and Raut, 2013). MSA assesses the adequacy of a measurement system for a given application. When measuring the output from a process, two sources of variation are considered: Part-to-part variation and measurement system variation. If measurement system variation is large compared to part-to-part variation, the measurements will risk not to provide useful information (Keith and Michelle, 2009). Before collecting the data from a process to check process mastery or capability, it is recommended to analyze the measurement system. This analysis is carried out to confirm that the measurement system discriminates adequately between parts and provides efficient and accurate data (Pan, 2004; Al-Refaie and Bata, 2010).

The development of relevant indicators helps the industrialists to understand, evaluate, and improve company performance (Souid et al., 2012, Malek et al., 2016). In the apparel sector, the workforce is the center of interest. It must be carefully analyzed because it has a great influence on the manufacturing quality. Thus, the need to objectively assess the workers competence degree and to replace the current subjective methods remains imperative.

Materials and methods

This work was carried out in a company specialized in automotive textile products. This exporting company employs 25 persons with an annual production of 2 000 000 pieces. It makes technical items (security nets, straps, bracelets, gearbox covers...) for the automotive and transport industry to several brands (Mercedes Benz, Volkswagen, DAF...). This type of items requires a high quality level. In fact, its usage attached to human security expects alertness on its manufacturing quality. This work was achieved in a production line making seat belts for the lower bunk of semitrailer truck cabin (Figure 1).

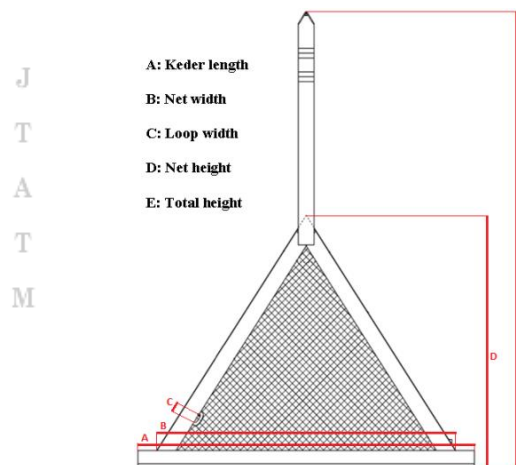


Figure 1: Sketch of seat belt

Constituting 25% of the total production, this is the most produced article with an annual production of about 80000 articles.

The main quality requirements are:

- Control the upside and the down side of the net
- Control sewing regularity of the entire piece
- Check the presence of the loop in the right position
- Check that the net is inserted at the bottom of the keder
- Check the presence of three back stitches on the two ends of the keder and loop

1. Measurement system stabilization

In the apparel sector, the assessment of a product quality and labor competence is based on detected defects. Two types of defects are noted, aspect and measure defects. For the first one, the detection is visual and acquired from the experience. But for the second type, the controller relies on measurement systems that must be reliable to give correct results. Therefore, it is essential to stabilize the measurement systems in order to provide a valid database useful to judge conformity and operator capability.

1.1 Measurement Systems Analysis (Gage R&R study)

The gage repeatability and reproducibility (R&R) study is a critical part of a successful process control system. It estimates how much the total process variation is caused by the measurement system. The measurement system variation consists in:

- Repeatability—variation due to the measuring device, or the variation observed when the same operator measures the same part repeatedly with the same device
- Reproducibility—variation due to the measuring system, or the variation observed when different operators measure the same part using the same device (Duret and Pillet, 2005; ISO 5725, 1994).

If the gage R&R is less than 30%, the system is accepted. Most of the variation is from the parts and not the measurement system. A gage R&R result of greater than 30% shows that the system is not acceptable and must be improved as the appraisers and equipment contribute to more than 30% of the system variation (Juran and Godfrey, 1998; AIAG, 2010; Yeh and Sun, 2013).

According to the Automotive Industry Action Group (AIAG) standards, the testing form required three operators to measure 10 pieces in 3 times (trials) each (AIAG, 2010). The study was conducted so that each operator (one at a time) has chosen one of the pieces (selected randomly from the 10 pieces), and was asked to measure the piece

using the “regular” measurement procedure for that product. The operator repeated this measurement process for the other 9 pieces, and then measured the same 10 pieces (in random order) for the second trial, then again for the third trial. This same study procedure was used for each operator. Calibrated instruments for measurements and software MINITAB for data analysis were used in this study.

1.2 Improvement and reassessment of the unacceptable measurement system

For the unacceptable measurement system, the source of variation was deduced and the process was improved. The new system stabilization was verified by another gage R&R study.

2. Objective evaluation of workforce global performance

The workforce competence is qualified both by work quality and production capacity. Concerning the first criterion, the defect rate produced by each worker is an indicator of the work quality, but this is not enough. In fact, many types of defects can be made at a single operation. Eventually, the impact on product and manufacturing quality changes according to the type of defect. So, it is necessary to identify the weight of each defect to correctly judge the operators. As for the second criterion (production capacity), it can be deduced by the operator’s activity.

2.1 Defect Enhancer Coefficient “DEC”

To characterize every defect, an enhancer coefficient was proposed. In collaboration with the method agent, the defects catalog is made. The items are followed as soon as they reach the assembly line. Indeed, for each model and for each operation of the mounting range, all types of defects are released. To repair a defect there will be a loss in materials and time. The materials quantities needed to repair the defect are calculated and from the unit price of each material the repair material cost is computed. The minutes needed to repair and recheck the defect are measured and multiplied by the minute’s cost to obtain the repair time cost. Finally, by summing the

repair material cost and the repair time cost the defect cost is obtained. So, for every operation, a defects catalog containing the following data was created:

- Defect type
- Defect repair method: explanation of the repair procedure
- Defect repair material: the material needed to repair the defect
- Defect repair time: the time needed to repair and recheck the defect

- Repair material cost: all prices of materials used for repair
- Repair time cost: repair minutes multiplied by the minute's cost
- Defect cost: the sum of repair material and time costs

So to compute the “DEC”, the following formula was used:

$$DEC = 1 + \frac{\text{Defect cost}}{\text{Article cost price}} = 1 + \frac{(\text{repair material cost} + \text{repair time cost})}{\text{Article cost price}} = 1 + \frac{(\sum \text{materials quantities} \times \text{unit prices (€)} + \text{time of repair and recheck (mn)} \times \text{minute's cost (€)})}{\text{Article cost price (€)}} \quad (1)$$

Where: $1 \leq DEC \leq 2$

- DEC = 1: If the defect is minor and without reparation (derogated).
- DEC = 2: If defect cost= article cost price (an irreparable defect (rejected) which is detected in the final product).

The higher the defect cost is, the more important the “DEC” is. If the defect is irreparable, the defect cost will be the sum of lost costs of both material and production time. These catalogs are a database that can be exploited for new items. That is to say, if there are similar defects in the database, it is enough to rectify the unit prices and the cost price.

2.2 Quality Index “QI”

To compute the Quality Index, the following steps were adopted:

- Establishment of the competency matrix of workers;
- Quality control execution: The control was carried out in two workstations (intermediate and final control). To get representative results for each operator, we controlled the maximum of pieces in the limits' constraints related to production using two types of control:
- Measurement control: This control targeted the operations that require a measure control. The operations were in the technical specifications sheet with their measurement tables.
- Aspect control: This control concerned the operations that require an aspect

control; their conformity was compared to fixed specifications.

- Data Recording and recount: All operators were tested in each operation which they were judged able to perform according to the competency matrix. The advantage in this company is that it works in large series, so, this test lasted for an entire month in order to assign the operators in different workstations. This allowed widening the database to have a concrete judgment. From the daily report written by the control agent in the intermediate and final control stations, the method agent recorded the data in an excel file. For each worker, the report contained the defects ratio classed by defect type.

The following formula was used to calculate the “QI” of each operator in each executed operation:

$$QI = 1 - \sum DEC \times DR \quad (2)$$

The higher the values of “DR” and/or “DEC” are, the lower the value of “QI” becomes.

Where: $-1 \leq QI \leq 1$

- $QI = 1$: If $DR = 0$ (the worker is considered a skilled one in terms of quality)
- $QI = -1$: If $DR = 100\%$ and $DEC = 2$ (all the controlled pieces contain irreparable defects detected in the final product). This is only a mathematical assumption. In fact, for a given operation, a worker producing a lot of defects even for $DEC=1$ can't be introduced in the competency matrix from the beginning.

Where: "DR" is the Defects Ratio given by the following formula:

$$DR (\%) = \frac{\text{Number of defects}}{\text{Number of controlled pieces}} \times 100 \quad (3)$$

Where: $0\% \leq DR \leq 100\%$

- $DR = 0\%$: all the controlled pieces are compliant.
- $DR = 100\%$: all the controlled pieces are non compliant.

2.3 Competence Index "CI" (The WSM score)

A more generalized indicator called Competence Index "CI" was developed thanks to the WSM method. In fact, this method uses another essential criterion in the workforce judgment which is the Activity "A"

$$A = \frac{\text{Productive time}}{\text{Attendance time} - \text{Time off standard}} \quad (4)$$

Where: $0 \leq A \leq 1$

- $A = 0$: The operator does not produce any piece.
- $A = 1$: As long as the operator is present, the requested quantity is produced.

Every hour, each operator was asked to note the quantity produced in the corresponding operation. This allowed the company to monitor the production by calculating the productivity. The activity is

an indicator reflecting the real production capacity of each worker because it eliminates the time off standard (≥ 10 min) for which the operator is not responsible (machine breakdown, delay in procurement...). From the historical data, the method agent calculated an average activity for each worker in each executed operation, allowing a concrete judgment (Proquez, 2001).

In the MCDM, a complex decision problem was structured as a tree of interrelated decision elements (criteria, decision alternatives). The objective, criteria and alternatives are arranged in a hierarchical structure similar to a family tree. The structure has at least three levels: overall goal of the problem at the top, criteria or attributes that affect the decision in the middle, and competing alternatives (decision options) at the bottom. The process of building this structure not only helps to identify all the elements of the decision more accurately, but also to recognize the interrelationships between them (Albayrak, 2003).

The WSM is probably the most commonly used approach, especially in single dimensional problems. The assumption that governs this model is the additive utility assumption (Adriyendi, 2015; Jorge, Vivares, Ariel, Castro, & Clemencia N.V., 2016). In single-dimensional cases, where all the units are the same, the WSM can be used without difficulty. Difficulty with this method emerges when it is applied to multi dimensional MCDM problems. Then, in combining different dimensions, and consequently different units, the additive utility assumption is violated and the result is equivalent to 'adding apples and oranges' (Jaberidoost et al., 2015).

Our MCDM problem is structured in (Figure 2). As known, an operation can be executed by one or more operators (according to the competency matrix). So, evaluating operators, in order to select the best one when assigning, is the main objective.

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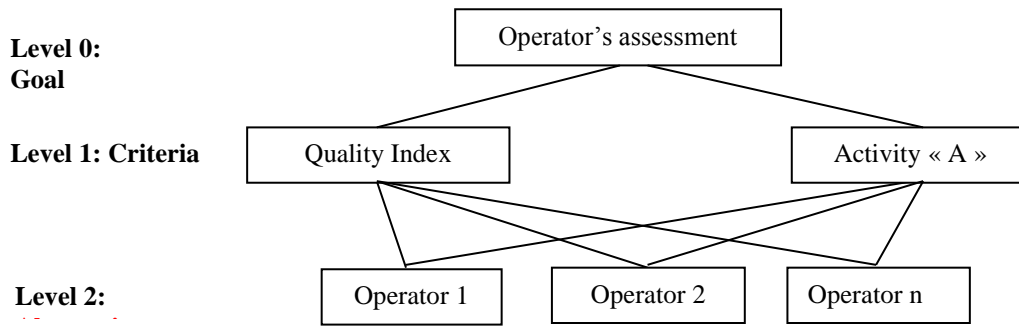


Figure 2: Decomposition of the problem

The basic logic of the WSM method is to obtain a weighted sum of performance ratings of each alternative over all attributes.

The step wise procedure is given below:

Step 1: Construct the decision matrix X

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1p} \\ x_{21} & x_{22} & & x_{2p} \\ \vdots & & \ddots & \vdots \\ x_{n1} & x_{n2} & \dots & x_{np} \end{bmatrix} \quad (5)$$

Where

$$A = \{a_j\}, \quad j=1,2,3,\dots,n \quad (6)$$

$$C = \{c_k\}, \quad k=1,2,3,\dots,p \quad (7)$$

$$W = \{w_k\}, \quad k=1,2,3,\dots,p \quad (8)$$

a_1, a_2, \dots, a_n are feasible alternatives, c_1, c_2, \dots, c_p are attributes (criteria), x_{jk} is the performance rating of j-th alternative with respect to k-th attribute, and w_k is a weight

$$R' = \begin{bmatrix} w_1 * r_{11} & w_2 * r_{12} \dots & w_p * r_{1p} \\ w_1 * r_{21} & w_2 * r_{22} & w_p * r_{2p} \\ \vdots & & \vdots \\ w_1 * r_{n1} & w_2 * r_{n2} \dots & w_p * r_{np} \end{bmatrix}; \sum_{k=1}^p w_k = 1 \quad (12)$$

Step 4: Calculate the score S^{WSM} of each alternative (CI).

$$CI = S^{WSM} = \sum_{k=1}^p w_k r_{jk} \quad ; j=1, 2, 3, \dots, n \quad (13)$$

Where: $-w_{QI} \leq CI \leq 1$

- $CI = -w_{QI}$: If $QI = -1$ and $A = 0$ (it is just a mathematical assumption as explained above for QI (equation 2)).
- $CI = 1$: If $QI = 1$ et $A = 1$.

(significance) of k-th attribute (Adriyendi, 2015).

Step 2: Construct the normalized decision matrix R

$$R = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1p} \\ r_{21} & r_{22} & & r_{2p} \\ \vdots & & \ddots & \vdots \\ r_{n1} & r_{n2} & \dots & r_{np} \end{bmatrix} \quad (9)$$

For beneficial attribute:

$$r_{jk} = \frac{x_{jk}}{x_{jk}^{\max}} \quad (10)$$

For non beneficial attribute:

$$r_{jk} = \frac{x_{jk}^{\min}}{x_{jk}} \quad (11)$$

Step 3: Construct weighted normalized decision matrix R'

3. Practical applications of the Competence Index “CI”

3.1 Objective competency matrix

In an ordinary competency matrix, the workforce classification is made subjectively on the basis of the judgment of experts. The “CI” was calculated for each operator in each executed operation. Thanks to this work, a new competency matrix (m rows, n columns, CI_{ij}) with objective quotations was obtained:

$$\begin{bmatrix} CI_{11} & \dots & CI_{1n} \\ \vdots & \ddots & \vdots \\ CI_{m1} & \dots & CI_{mn} \end{bmatrix} \quad (14)$$

With:

m: Operations number

n: Operators number

CI_{ij} : Competence Index of j-th operator in i-th operation;

$$i = 1,2,3,\dots,m ; j=1,2,3,\dots,n \quad (15)$$

This new matrix expresses exactly the competence degree and the company can manage its workers better.

Therefore, to further exploit the objective competency matrix, other indicators were developed. Based on the “CI” calculation, these indicators shall form a reliable dashboard. So, the company can easily and concretely evaluate its workforce and see how far it is prepared to respond to hazards. Table 1 shows the created indicators.

Table 1: Dashboard indicators

| Indicator | Definition | Formula |
|---------------------------------|---|--|
| Share in competence “SC” | It expresses for each operator its competence proportion compared to the total competence | $SC_j(\%) = \frac{\sum_i^m CI_{i,n}}{\sum_{i,j}^{m,n} CI_{i,j}} \times 100 \quad (16)$ |
| Versatility Index “VI” | It expresses the worker’s ability to execute many operations | $VI_j(\%) = \frac{\text{Number of } CI_{i,n} > 0}{m} \times 100; i=1,\dots,m \quad (17)$ |
| Overall Versatility Index “OVI” | it expresses the whole work group ability to execute numerous operations | $OVI(\%) = \overline{VI_j}(\%) ; j=1,\dots,n \quad (18)$ |
| Mean Competence Index “MCI” | It expresses the operator mean competence of all executed operations | $MCI_j = \overline{CI_{i,n}} ; i=1,\dots,m \quad (19)$ |
| Overall Competence Index “OCI” | It expresses the mean competence index of the whole work group | $OCI(\%) = \overline{CI_{i,j}} \times 100 ; i=1,\dots,m \text{ and } j=1,\dots,n \quad (20)$ |
| Multi-skill Index “MI” | It expresses both versatility and competence of each operator | $MI_j(\%) = \frac{\sum_i^m CI_{i,n}}{m} \times 100 = MCI_j \times VI_j(\%) \quad (21)$ |
| Overall Multi-skill Index “OMI” | It expresses both versatility and | $OMI(\%) = \overline{MI_j}(\%)$ |

| | | |
|------------------------------------|---|--|
| | competence of the whole work group | $= \frac{\sum_{i,j}^{m,n} CI_{i,j}}{m*n} \times 100$ $= OCI (\%) \times OVI (\%) \quad (22)$ |
| Vulnerability Index “VUI” | It expresses the fragility degree of the production process at certain operations in face of hazards, such as absenteeism or a sudden increase in activity volume | $VUI_i(\%) = \left(1 - \frac{\sum_j^n CI_{m,j}}{n}\right) \times 100 \quad (23)$ |
| Overall Vulnerability Index “OVUI” | It expresses the fragility degree of the production process at all the mounting range operations | $OVUI(\%) = \overline{VUI}_i (\%) \quad (24)$ |

3.2 Line balancing optimization

Thanks to the objective judgment obtained from the “CI” calculation, the line balancing is optimized. In fact, the workforce classification facilitates the choice of the most competent operator to the possible extent for each operation in the mounting range.

Indeed, the mounting range operations are classified according to their influence degree on the end product quality. Thereafter, the workers are assigned to the appropriate operations considering the operations classification and their “CI”. Thus, if there is no problem in saturation ratio, the most

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important operation will have the priority in the operator selection and it will be performed by the most skilled worker. Therefore, this worker is not likely to be affected in another less important operation (in the case of polyvalence).

Results and discussions

1. Gage R&R study

The measurement systems stabilization was done for the 5 measures A, B, C, D and E, but in this study only measures A and B are presented. The statistical results are given in the following tables:

Table 2: Two-Way ANOVA table

| Source | P | | |
|------------------|------------------|------------------|---------------------|
| | Measure | Measure B | |
| | With interaction | With interaction | Without interaction |
| Piece | 0.000 | 0.000 | 0.000 |
| Operator | 0.048 | 0.000 | 0.000 |
| Operator * Piece | 0.001 | 0.438 | - |

Table 3: Statistical results of the gage R&R (ANOVA) study

| Source | Percent study variation (%SV) | |
|------------------|-------------------------------|-----------|
| | Measure A | Measure B |
| Total Gage R&R | 25.16 | 77.12 |
| Repeatability | 18.30 | 32.42 |
| Reproducibility | 17.26 | 69.98 |
| Operator | 9.21 | 69.98 |
| Operator * Piece | 14.60 | - |
| Part-To-Part | 96.78 | 63.66 |
| Total Variation | 100.00 | 100.00 |



Figure 3: Measurement method for measure A

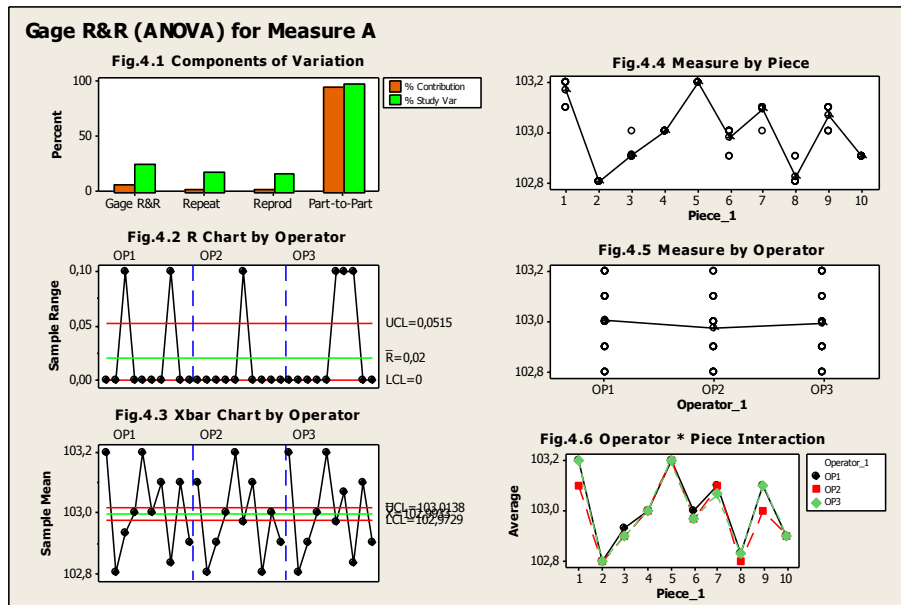


Figure 4: Gage R&R (ANOVA) study for measure A

Measure A (keder length): $103 \pm 0.2\text{cm}$

- Measurement method (Figure 3)
- Place the piece in the template keder

- Note the measure (the tape measure is fixed on the template) results
- Table 3 and Figure 4.1 show from the gage R&R that the measurement system

accounts for less than 30% of the overall variation (25.16%). Therefore, this measurement system is acceptable. The difference in parts accounts for most of the variation (96.78%). Thus, it is a good measurement system.

- Figure 4.2 shows that some points fall above upper control limit (UCL). The operators are not consistently measuring the pieces (example: the repeatability error for pieces 3 and 8 are out of control for operator 1).
- Figure 4.3 illustrates that many points are above or below the control limits. These results indicate that the system can discriminate between parts.
- Figure 4.4 indicates that averages vary enough so that the differences between parts are clear. The operators are measuring consistently and adequately pieces 2, 4, 5 and 10.

- Figure 4.5 shows that the line is not parallel to the x-axis. The operators are measuring the parts differently, on average. Operator 2 seems getting smaller values than operators 1 and 3.
- Table 2 reveals that the P-value for the operator-by-piece interaction is 0.001. According to the AIAG standards, the interaction is significant because $P \leq 0.05$ (AIAG, 2010). This is confirmed by the Figure 4.6, which indicates that the lines cross so that an operator's ability to measure a part depends on which part is being measured.

Consequently, the measurement method is kept. The actual measurement system can give reliable data.

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Measure B (Net width): $91.7 \pm 1\text{cm}$

- Measurement method (Figure 5)
- Place the piece on the table (the apex of triangle is in front of the operator)
- Attach the measure tape on the two ends of the net
- Note the measure results



Figure 5: Measurement method for measure B

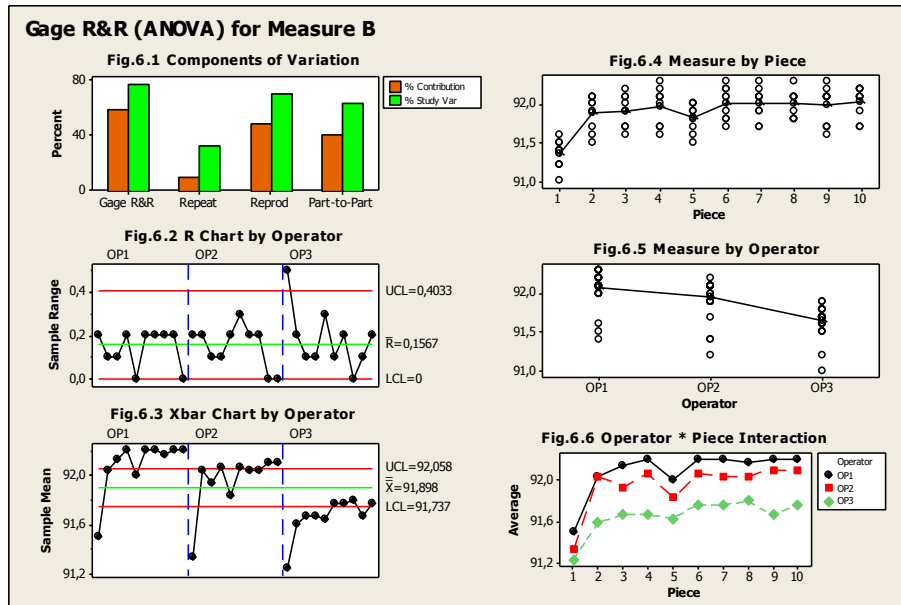


Figure 6: Gage R&R (ANOVA) study for measure B

- Table 3 and Figure 6.1 show that gage R&R is $>30\%$. So, this measurement system is unacceptable. The largest component of variation is the measurement system variation. Hence, it is a bad measurement system. The measurement process is degraded by the reproducibility (69.98%) rather than by the repeatability (32.42%). Indeed, this can be explained by the fact that operators are inadequately trained on this measurement, or it is a bad measurement method.
- Figure 6.2 reveals that for each measured part, operators obtain the same values, except for operator 3 whose measures for piece 1 are varied.
- Figure 6.3 illustrates that many points are above or below the control limits. These results indicate that the system can discriminate between parts.
- Figure 6.4 indicates that averages vary enough so that differences between parts are clear.
- Figure 6.5 shows that the line is not parallel to the x-axis. The operators are measuring the parts differently, on average. Operator 3 seems getting smaller values than the operators 1 and 2.
- Table 2 shows that the P-value for the operator-by-piece interaction is 0.438, which indicates that the interaction is not significant. Therefore, Minitab removes the interaction term from the model and generates a second ANOVA table without interaction.
- Figure 6.6 demonstrates also that operator 1 is measuring parts consistently higher than the other operators.

For these reasons, the measurement method must be changed: the piece should be fixed in the template keder. Therefore, the keder will be stuck. The curve formed due to the keder flexibility will be eliminated. So, with this method the section to measure will be straight.

2. Gage R&R study for instable measurement system

According to the first gage R&R study, the measurement system is stable for measure A and unacceptable for measure B. Thus, a new method is used in order to eliminate the source of variation and to improve the measurement process of measure B. The system is re-evaluated by another gage R&R study. The new statistical results are given in the following tables:

Table 4: Two-Way ANOVA table (after improvement)

| Source | P | |
|------------------|------------------|---------------------|
| | Measure B | |
| | With interaction | Without interaction |
| Piece | 0.000 | 0.000 |
| Operator | 0.301 | 0.168 |
| Operator * Piece | 0.084 | - |

Table 5: Statistical results of the gage R&R (ANOVA) study (after improvement)

| Source | Percent study variation (%SV) |
|------------------|-------------------------------|
| | Measure B |
| Total Gage R&R | 25.85 |
| Repeatability | 25.50 |
| Reproducibility | 4.22 |
| Operator | 4.22 |
| Operator * Piece | - |
| Part-To- | 96.60 |
| Total Variation | 100.00 |

- Improved measurement method (Figure 7)
- Place the piece in the template keder
- Attach the measure tape on the two ends of the net
- Note the measure



Figure 7: Improved measurement method for measure

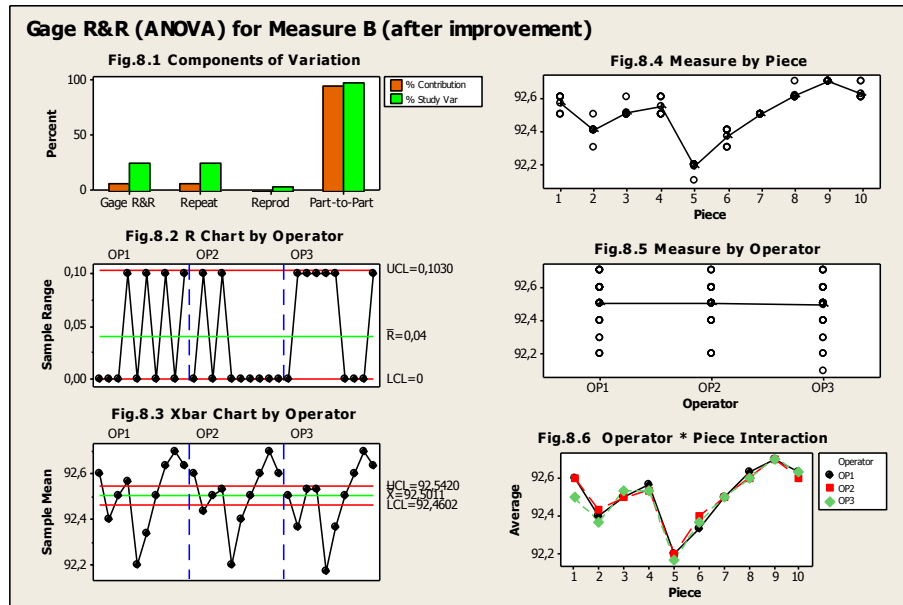


Figure 8: Gage R&R (ANOVA) study for measure B (after improvement)

According to Table 5 and Figure 8, this measurement system is acceptable (25.85%). Previously, the measurement process was degraded by the reproducibility (69.98%). When the measurement method is changed, this indicator decreases (4.22%). This new method allows fixing the piece in the template. So, it reduces the operator intervention in the measurement method, which is in favor of stability. Gage R&R drops from 77.12% to 25.85%, confirming that the curve formed because of the keder

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flexibility is the source of the measurement system variation. Even for the improved method, there is no significant interaction between operator and part for measure B (Table 4).

3. Defects catalog

Table 6 shows the defects catalog of the operation «Assemble keder and Net»:

- Aspect defect: «Skipped stitch or Balloon stitch» and «Backstitch missing»
- Measure defect: «Net width»

Table 6: Defects catalog of the operation «Assemble keder and Net»

| Operation | Defect type | Defect repair method | Defect repair material | Repair material cost (€) | Defect repair time (S) | Repair time cost (€) | Defect cost (€) | DEC |
|------------------------|----------------------------------|----------------------|------------------------|--------------------------|------------------------|----------------------|-----------------|-------|
| Assemble keder and Net | Skipped stitch or Balloon stitch | Unthread and redo | Thread | 0.007 | 178.53 | 0.238 | 0.245 | 1.057 |
| | Backstitch missing | Make backstitch | Nothing | 0 | 29.53 | 0.039 | 0.039 | 1.009 |
| | Net width | Irreparable | Band | 0.576 | 260 | 0.347 | 3.477 | 1.805 |
| | | | Net | 1.5 | | | | |
| | | | Loop | 0.01 | | | | |
| | | | keder | 1.006 | | | | |
| | label | 0.006 | | | | | | |
| | Thread | 0.033 | | | | | | |

Based on this catalog, it is clear that the defect «Net width» has the most important “DEC”. This is due to the great loss in terms of time and material compared to other defects.

4. Computing “QI”

Table 7 illustrates the "QI" for three operators who are capable to perform the operation «Assemble keder and Net» according to the competency matrix.

Table 7: “QI” of Operators executing the operation «Assemble keder and Net»

| Operation | Operator | Number of controlled pieces | Number of defects | | | DEC | | | QI |
|------------------------|----------|-----------------------------|----------------------------------|--------------------|-----------|----------------------------------|--------------------|-----------|-------|
| | | | Skipped stitch or Balloon stitch | Backstitch missing | Net width | Skipped stitch or Balloon stitch | Backstitch missing | Net width | |
| Assemble keder and Net | O1 | 140 | 4 | 6 | 0 | 1.057 | 1.009 | 1.805 | 0.927 |
| | O3 | 220 | 0 | 15 | 4 | | | | 0.898 |
| | O4 | 140 | 4 | 2 | 0 | | | | 0.955 |

5. Computing “CI”

The choice of weights depends on each company. According to a questionnaire carried out within the technical staff, the weights are given as follows:

$$w_{QI} = \frac{2}{3}; w_A = \frac{1}{3}$$

This choice reflects the quality level adopted in the company, which judges the workforce

J by promoting twice the quality compared to the activity.

T The decision matrix (Table 8) can be considered also as a normalized decision matrix. Indeed, the performance ratings are percentages calculated from optimum values (in our case, both criteria are beneficial attributes). So, for a given operation, CI can be simply written as follows:

$$CI_j = S_j^{WSM} = \sum_{k=1}^p w_k r_{jk} = w_{QI} \times QI_j + w_A \times A_j \quad (25)$$

Table 8: Decision matrix of operation “Assemble keder and Net”

| Alternatives | Criteria | |
|--------------|----------|-------|
| | QI | A |
| O1 | 0.927 | 0.875 |
| O3 | 0.898 | 0.750 |
| O4 | 0.955 | 0.600 |

Integrating criteria weights in a decision matrix allows the following normalized decision matrix:

Table 9: WSM weighted normalized decision matrix

| Alternatives | QI | A |
|--------------|-------------------------------------|-------------------------------------|
| O1 | $=0.927 \times \frac{2}{3} = 0.618$ | $=0.875 \times \frac{1}{3} = 0.291$ |
| O3 | 0.599 | 0.250 |
| O4 | 0.637 | 0.200 |

Table 10: Score " S^{WSM} " of each Alternative

| | S^{WSM} | Ranking |
|----|-------------------------|---------|
| O1 | = 0.618 + 0.291 = 0.909 | 1 |
| O3 | 0.849 | 2 |
| O4 | 0.837 | 3 |

The operator O4 is the least competent despite having the highest "QI" value. This is explained by the low activity (60%) causing the last rank in the classification. So, we can deduce that even though the "QI" is twice more important than the activity in this company, the operator could not preserve the first rank. To conclude, for operation

«Assemble keder and Net», O1 is the most competent operator followed by O3 then O4.

6. The obtained dashboard

Table 11 shows, for the studied article, the objective competency matrix and the previously defined indicators' values.

Table 11: Dashboard of the studied article

| | | MCI | 0.826 | 0.979 | 0.866 | 0.848 | 0.947 | 0.954 | | | |
|-------|--------------------------|-----------------------------------|-------|-------|-------|-------|-------|-------|--------|--------|---------|
| | | MI (%) | 62% | 12% | 76% | 85% | 24% | 24% | 47% | OMI(%) | |
| | | VI (%) | 75% | 13% | 88% | 100% | 25% | 25% | 54% | OVI(%) | |
| | | Number of executed | 6 | 1 | 7 | 8 | 2 | 2 | Total | | |
| | | SC (%) | 22% | 4% | 27% | 30% | 8% | 8% | | | |
| N° | Operation | Operator Machine | O1 | O2 | O3 | O4 | O5 | O6 | 6 | VUI(%) | |
| 1 | Cut keder | Automatic blade | 0.910 | | 0.783 | 0.777 | | | 2.470 | 59% | |
| 2 | Fixing the strap on 90mm | 1-needle lockstitch machine (301) | 0.753 | | 0.940 | 0.887 | 0.913 | 0.922 | 4.415 | 26% | |
| 3 | Execute cross box | Automate | 0.791 | | | 0.929 | 0.981 | | 2.701 | 55% | |
| 4 | Apply band and net | 1-needle lockstitch machine (301) | 0.733 | 0.979 | 0.960 | 0.880 | | | 3.552 | 41% | |
| 5 | Cut band ends | Hot cutter | 0.860 | | 0.631 | 0.622 | | | 2.113 | 65% | |
| 6 | Assemble keder and net | 2-needles lockstitch machine | 0.909 | | 0.849 | 0.837 | | | 2.595 | 57% | |
| 7 | Execute seams safety | Automate | | | 0.961 | 0.926 | | 0.986 | 2.873 | 52% | |
| 8 | Assemble strap and net | Automate | | | 0.941 | 0.925 | | | 1.866 | 69% | |
| Total | | 8 | 4.956 | 0.979 | 6.065 | 6.783 | 1.894 | 1.908 | 22.585 | 53% | OVUI(%) |
| | | | | | | | | | 87% | OCI(%) | |

For this item, we can draw from this dashboard the following conclusions:

- The operator O4 is the most skilled referring to many indicators; possessing 30% of the total competence, executing 100% of the mounting range operations and having the best Multi-skill Index “MI”. However, O2 is the least skilled operator.
- The work group is 54% polyvalent, 87% competent so 47% multi-skilled.
- “Assemble strap and net” is the riskiest operation because it has the highest Vulnerability Index “VUI”. It is the most fragile in the case of absenteeism or if the company considers increasing production.
- The operation “Fixing the strap on 90mm” is the least vulnerable. This can be explained by the proportionally important number of workers executing it.

- With the actual Versatility and competence level, this mounting range is 53% vulnerable.

7. Workers’ assignment

To optimize the line balancing, the assignment was done from the most important to the least important operation. In fact, an operations classification of the mounting range should be conducted. This classification is based on the quality criteria specified in the technical files and the complexity of the operation execution. Referring to the “CI”, the most skilled operator performed the most important operation.

For a comparative study the strategy is reversed. The least competent operator is selected for the most important operation.

Thus, the following assignment is obtained:

Table 12: Worker’s assignment according to their “CI”

| Operation | | Optimal line balancing | | Worst line balancing | |
|-----------|----------------|------------------------|----------------|----------------------|----------------|
| N° | Classification | Operator | CI | Operator | CI |
| 1 | 7 | O1 O3 | 0.910 0.783 | O1 | 0.910 |
| 2 | 8 | O6 | 0.922 | O1 | 0.753 |
| 3 | 4 | O5 | 0.981 | O5 | 0.981 |
| 4 | 3 | O2 | 0.979 | O2 | 0.979 |
| 5 | 5 | O4 | 0.622 | O4 O3 | 0.622 0.631 |
| 6 | 2 | O1 | 0.909 | O3 | 0.864 |
| 7 | 6 | O6 | 0.986 | O6 | 0.986 |
| 8 | 1 | O3 | 0.941 | O4 | 0.925 |

| | | |
|-----|-----|-----|
| OCI | 90% | 88% |
|-----|-----|-----|

The Overall Competence Index “OCI” obtained for the optimal assignment is 90%. This is the best line balancing obtained. For the worst line balancing, the “OCI” is 88%.

Thanks to the overall index, it is easy to compare different possibilities of line balancing and to select the best one based on objective judgment. Taking the example of

the operation n°2, operators O6 and O1 have the same activity (76.7%). The “QI” value is 1 for O6 and 0.746 for O1. Indeed, if the operation is executed by O6, zero defects are expected, but, if O1 is selected, we estimate having 25.4% as defects ratio weighted by the enhancer coefficient, which means a loss of 0.35 € per 100 parts produced. For an

estimated daily production of 2400 pieces for this workstation the loss will be evaluated at 8.41 € per day.

Conclusion

This study has led to a new approach to evaluate and manage the workforce competence. In a first step, a Measurement System Analysis (MSA) was conducted. The indicator "Total Gage R&R" allows knowing if the measurement system is acceptable or not. Thus, for unstable system, it helps to reveal the source of variation and to identify anomalies thanks to the indicators "repeatability" and "reproducibility". An improvement plan was proposed and the system was re-evaluated. Once the system is stabilized, the new measurement procedure is kept. The data collection is authorized only if all the measurement systems are stabilized. In a second step, an objective quotation was proposed. Indeed, the product defect is characterized by an enhancer coefficient "DEC" based on lost costs that reflect severity consequence of non conformity. Then, a Quality Index "QI" was developed. This indicator expresses the work quality since it takes into account the Defects Ratio "DR". To have a correct judgment, this ratio was increased by using the enhancer coefficient because the defects don't have the same weight. Finally, a more generalized indicator called Competence Index "CI" was developed thanks to the WSM. This MCDM method allows including another criterion expressing the production capacity which is the activity level "A". So, an objective evaluation of the workers' competence regarding both the quality and the activity levels was obtained. It is a solution to dispose of the current assessment methods based on subjective quotations given by experts' opinions. Comparing operators is now more reliable, precise and objective.

In a third step, some applications of the created index were presented. An objective competency matrix, on the basis "CI" values, was invented and developed as a dashboard. From the dashboard indicators, the workforce performance can be

visualized as well as the fragility degree of the company at certain operations in the face of hazards. This work helps managers to take decisions about action plans. Indeed, the least multi-skilled operator has a priority in training. Moreover, the more vulnerable operation must be treated either with training or recruitment. This action plan improves the quality, prevents absenteeism and prepares the work team for a production increase. Our assessment approach was applied to all the produced items. The overall indices allowed comparing the situation between the different items in order to set goals. The "CI" was also used to choose the optimal line balancing. In fact, once an objective workforce judgment is obtained and an operations classification is done, an efficient assignment by priorities is guaranteed. Working with the optimal group contributes to minimizing defects, which increases the profit margin and improves competition in the international market. In future work, we should model the workers' global performance from the individual skills in order to predict and optimize the product manufacturing quality by optimizing the choice of the selected work group. At this level, the deficient workstations can be determined in advance and the improvement solutions can be planned. It can be done by specific control procedure adapted to the nature of each deficiency. Therefore, the obtained database can be useful for the methods department which can work on competency matrix improvement.

In addition to its activity and quality of work, the workforce competence can be characterized by its attendance rate; a very important parameter in the apparel industry and is always implicitly taken into account when assigning tasks.

The defects classification (critical, major, minor ...) is still obtained subjectively. The enhancer coefficient can be a solution to set more precisely this classification. Similarly, the "CI" can objectively classify the workers as competent, medium competent, not competent.

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