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STATISTICAL PROCESS CONTROL MODEL IN THE DESIGN AND THE DEVELOPMENT OF FABRICS

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Abstract

In this paper the aim was to create a basic model for total quality management in the organization of the textile production, with an emphasis on Statistical Process Control (SPC) in the design and development process that will completely satisfy the requirements, the needs and the desires of the buyers and all the participants in the business relations. The paper deals with a methodology of the process of fabric's design and development, consisted of two macro stages: 1) development and 2) fabric's production. The monitoring, the analysis and the verification of the process were done using statistical methods, techniques and tools, with which in the most explicit manner data processing, analysis and presentation are done. This is aimed at continuous process improvement. According to this, a few methods were presented: FMEA method, Pareto and Cause and Effect analysis and $\overline{X}$ *- R control chart.*

Key words*: FMEA, Pareto analysis, Cause and Effect analysis,* $\overline{X}$ *- R control chart, design, development, fabrics, project, process.*

1. INTRODUCTION

Fabric's design and development is a creative, technical and empirical process of conceptualizing and designing of the textile, but customer service and communication as well.

The selection of particular combination, configuration, form and shape of appearance is depending on a few different limitations. Finding alternative solutions sometimes outweighs the designer's role as a researcher or an artist. Solving design problems requires a combination of intuition and systematic approach in the understanding of the buyer's requirements [1].

Well designed and innovative fabrics are essential in order to survive and be competitive on the market today. That is why, the process of fabric's design and development very often should be analysed as an integrative and multi-disciplinary process in which the basic activities usually are:

Fabric's development phase

• ***Planning of fabric's design,*** forming an offer of collection of fabrics as a strategic, long term determination of the company. Designing textile fabrics becomes increasingly difficult, because of the increased buyer's requirements for smaller and more fragmented orders of mass-produced fabrics with different designs and quality. In fact, these requirements confront with the economical justification and are far from the present day ideal for construction of higher-speed looms. The designers themselves are in the centre of the conflict of interests between fabric producers, garment makers and the market. In order to fulfil it's goal a trendy collection of designs and fabrics should be fashionably acceptable and saleable, but in it's making to also try to minimize the use of different yarns, colours and different fabric designs, so that it is economically justified. A balance between designer's creativity and commercial constraints has to be achieved [2].

- ***Researching, monitoring, analysing and identifying*** of the buyer's desires, competitor's advancement, benchmarking and the market fluctuation (attending fairs, experts meetings, conferences, seminars and exchange of experience, use of questionnaires, editorials, catalogues, any kind of information sources and multimedia tools). All of these are to be used to determine the fashion need for certain types of fabric. Today, modern buyers express desire and need for less formal clothes, flexible and lighter materials, natural fibres. Also they pay more attention to a 'pleasant feel' of the clothes, to the texture, mildness and comfort, which can be achieved with traditional fibres combined with new technologies [3]. Technological innovations and fashion trends demand constant monitoring and research, because of the product's short lifetime, defined by the unsettled buyer's requirements and ambitions of the most powerful fashion companies for market domination. On the other hand, dictated as well by the increasing technological possibilities for preparation and production of new yarns, machines and auxiliary substances.

- ***Fabric design*** is a complex process which includes:

− Technical conceptualization and modelling of the fabric's construction according to the appropriate possibilities for the choice of the yarn type, which means selection of convenient yarns for the warp and the weft, and combining their structural characteristics: the yarn fineness (*Tt, tex)* in both directions, the warp and weft set (number of threads/cm) and the weave (the pattern of interlacing of warp and weft). Their combination influences the overall colour effect on the fabric's surface [4].

− Creating graphical and aesthetical design solutions – colour selection and warp and weft repeat of the fabric. By skilful interlacing, disposition and grouping of warp and the weft interlacing points and combining colours, an endless number of designs can be created and sometimes the border between the weaving and the art of painting disappears [5].

− Technological definition and projection of the production process's flow: preparation, weaving and finishing.

- ***Testing/reviewing*** of the pilot projects and use of the collected information in the creation of the final project's design solution:

− study, review, analyse and laboratory testing of the prototype,

− communication with the buyers and validation, as well as maintaining continuous service and feedback retrieval and converting it into design solutions,

− marketing presentation of the designed collection of fabrics on the market,

– trend of continuous improvement of the properties of the offered collection of fabrics, establishing consistent development based on the permanent analysis of the current situation. That implies intervention to improve fabric's performances, cost reduction, resource and energy savings, and preservation of the environmental integrity.

– receiving feedback information from the buyers and mediators about the degree of satisfaction with the fabric's performances and potential future expectations, in order to understand their needs and requirements and the potential of the fabric

– monitoring, analysing, circulation and dynamics mapping of the offered collection of fabrics, particularly, but also in the context of competitor's offer on the market,

– using newly-acquired knowledge in the development of the fabric.

Fabric's designers should with great consideration combine aesthetic and functional parameters throughout the development of the design. This implies significant efforts in research, deliberation, modelling and optimization of the prototype until an optimal design solution is created, which will meet all of the specified requests.

Fabric's production phase, which consists of manufacturing, distribution and sale of the fabric [6]. The results from this phase are generator for the fabric's development process.

Use of statistical methods, techniques and tools for quality management in the process of fabric's design and development

The modern quality management systems need continuous process's and product's improvement, which can be achieved by detecting and removing the root causes of defects. This activity should be carried out preventive and should be based on an actual information about the current state of the processes of production. Statistical methods are basic diagnostic tools to detect the causes of defects in the quality management. That is why, it's not a coincidence that their application is recommended in the latest version of ISO 9001/2008. Statistical methods are also basic tools in the Total Management Quality (TQM) system, as well.

Statistics with use of selected methodological methods, techniques and tools, allows describing, summarizing and making conclusions based on the available database. Universality of this science is reflected in the large scale of possibilities for its use: in design experiments and surveys; for describing and summarizing of experimental data; for testing of hypotheses; for determining the quantitative relationships between variables [7]. In the process of fabric's design and development, using processing, analysis and presentation of data related to process's variables or characteristic properties of fabrics, proper conclusions can be reached. Irregularity of raw materials, limited performances of the machines, technology and human factor, as well as variability of conditions in which the processes are performed, cause different values of the observed parameters, and consequently different behaviour of the fabrics. In context of the previous, the designer's role is crucial in preventive reaction and changes of some structural characteristics of the project to solve the deviations, irregularities and unconformities i.e. for correct management of the processes.

The main goal of the statistical methods in the control of the processes is to achieve a level of prevention and systematic improvement of the quality, based on: analysis, monitoring and improvement of the processes.

Statistical methods provide:

- systematic monitoring and perspicuous presentation of the gathered data about the achieved quality level of the fabrics through all phases of the production,
- quick insight into the general level of the quality of the fabrics and the services, especially in the case of important decision making,
- statistical monitoring and verifying of: the current capability of the manufacturing process comparing with past processes, the acceptability of the fabric's quality in shipments, the acceptability of the methods and the procedures, the examination of fabrics and quality control, the acceptability of the achieved level of quality of the final or delivered fabric,
- monitoring, analysis and study of non-conformity, in order to find out the reasons for insufficient quality and
- primarily, elaboration and implementation of projects for improvement of the quality of the fabrics and/or the services and planning of zero defects production.

In this paper some statistical methods, techniques and tools are presented, which can be used by the designer's team in the process of the designing of the fabrics, as well as to improve the performances of the fabrics itself.

2. EXPERIMENTAL

The implementation of the statistical methods and techniques on the process of design and development of fabrics was done using the data from the process of production of fabrics in Teteks Ltd. factory, Tetovo, Republic of Macedonia. The following methods were applied:

FMEA Analysis (Failure mode and effect analysis)

This analysis [8, 9] is systematic, analytical and qualitative analysis of potential failure modes and the consequences (defects), which allow an assessment to be made on the level of severity for each part or subsystem and their impact on the system. The parameters of the analysis are assessed and marked numerically, same as the final assessment of the result of the analysis, which allows comparison of each project's results.

The analysis is based on practical experience in design of the work process and monitoring of the work, combined with the theory of probability. This method includes analysis of potential occurrence of defects, estimate of the importance of the defects based on the consequences and the possibilities of occurrence, and the probability of detecting the defects with the established control measures. If the system is simple by its structure, consequences can be directly predicted and the necessary changes can be assessed. According to the made assessments, the risk priority number

(RPN) can be calculated and defined by the expression: RPN = O.S.D, where: O is probability of risk's occurrence, S is severity of the defects, and D is ability to detect the defects. Accordingly, effective preventive and corrective actions can be planned.

The successful use of the FMEA method requires a multidisciplinary team of experts, often working in design, technology, procurement, manufacture, quality control and sales.

Pareto analysis

Pareto analysis is a statistical technique that allows the analysed phenomena or the failure's causes to be ordered by the degree of their importance for the quality of the product. It bases on the principle: 80% of problems are the results of 20% of key causes. Although these percentages vary in practice, the general principle is applicable – every reason causes an equivalent problem. Steps to creating a Pareto analysis are: 1) data classification, 2) determining the validity of the characteristic: frequency, time, costs, etc. 3) executors training, 4) data collection using check lists, etc. 5) data reviewing to identify a potential problem, 6) ranking of data categories, 7) calculating of the relative and cumulative frequency of the data, 8) graphic display of the data, 9) identification of the most important causes for the problem [10].

$\overline{X}$ - R Control Chart

Control charts are applied for the rapid and timely detection of process or product variations [11, 12]. They are used for detection of changes in the performance of a product or process, as a function of time and for analysis of the reasons for these changes. For certain period of time, the process flow can be normal, but because of change in the conditions of the process, possibilities can occur for existence of trends. In order to not allow production of defective products, the prime goal is to timely disclose the reasons for these trends and to remove them. The $\overline{X}$ - R Control Chart is a diagram in which the statistic measurements mean and range for quality characteristics of samples taken at different times during the process, are inserted. The process is stable if all the measured sample values are within the process control limits – UCL (upper control limit) and LCL (lower control limit) i.e. to be within 3σ (3 standard errors) above and below of the process's mean $\overline{\overline{X}}$ (the central line). In case that the control limits of normal distribution (UCL and LCL) of the process is narrower or equal to the limits of tolerance – UTL (upper tolerance limit) and LTL (lower tolerance limit) – the process is capable to meet the set requirements.

For $\overline{X}$ -R control chart, control limits are calculated according to the formulas:

$$\overline{X} \text{ control chart: } UCL = \overline{\overline{X}} + A_2\overline{R} \text{ and } LCL = \overline{\overline{X}} - A_2\overline{R}$$

$$\text{R control chart: } UCL = D_4\overline{R}; \ LCL = D_3\overline{R},$$

where: A_2, D_4, D_3 are constants which are taken from the statistic table depending on the sample size (n) and statistical reliability, $\overline{R}$ – average range of sample ranges, $\overline{\overline{X}}$ - average value of the sample means.

Cause and Effect analysis

It is known as an Ishikawa diagram or fishbone diagram – usually used in product designing to identify unwanted factors, which could affect the quality of the product or the process; and also to determine the primary reasons for the problem's emergence. The construction of this diagram is performed in several steps: 1) identification of the problem i.e. effect, 2) possible primary causes for the basic problem are analysed and placed on the main line of the diagram with the effect placed at the end of the line, 3) every primary cause of the problem is discussed and the sub causes are defined, 4) review and discussion about all the possible causes and sub causes for the problem i.e. effect, and identification of those who have caused it [13].

3. RESULTS AND DISCUSSION

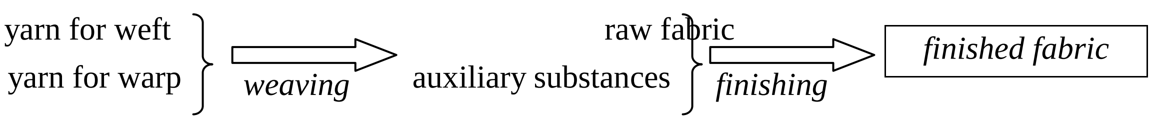
Application of FMEA

In the process of designing, when a new article was introduced, which was to be created with planned participation of the yarn that was already in stock and with already known structural parameters of the fabric, for the first time a FMEA analysis was implemented. This was used to assess the risk of possible defects that could occur as a consequence of a new finishing process of the fabric.

With this new finishing process, the basic fabric underwent an additional process of washing and softening, instead of classic finishing process, which resulted with a new quality of the fabric, same as the one of Shetland tweed. To perform the analysis [14] on a relatively simple system like the fabric is, a project team was set up which included: Manager of Design, as a team leader (coordinator); Designer; Manager of Control; Engineer of Weaving Technology; and Manager of Finishing Process. The team leader informed all the members of the team about the nature and the task of the analysis, and gave individual assignments to each.

1) During the preparation of the analysis, the team leader made all the collected data available to the members, so every one of them could derive their own conclusions for the work at task.
2) The project analysis was performed in several steps, on a classic table meeting, and the following questions were answered:

- *What elements constitute the system (in this case the fabric) and what is its structure?*



In this case, as warp and weft was used carded yarn of 100% wool, with a wool nominally fineness of 24 - 25 μ with parameters shown in table 1.

Table 1. Yarn's parameters of the analysed fabric

Parameter	*Nominal value*	*Average value*	*Coefficient of variation (%)*
Yarn count (tex)	117,65±5 %	123,46	1,45
Twisting (m^{-1})	Z420±5 %	408,4	4,19
Breaking strength (cN)	450,0	448,3	7,6
Breaking elongation (%)	14,5	13,9	6,0
Content of neps (m^{-1})	2-3		
Content of dead fibres	little, but noticeable		

Soaps and softeners in a water bath were used as auxiliary substances.

- *What is the function of the elements of the system?*

In relation to the tolerance of the variations of the yarn's parameters and long-lasting exploitation of the basic project, it is considered that its constructive characteristics (particularly, impact on the warp and weft density, width and fabric's mass/square meter) are tested and proven. Novelty is the finishing's process, because of the effects of the doubled washing cycles.

- *What kind of potential defects can occur on the fabric when in utilization of the buyer, what are the consequences of these defects and what are the causes for their appearance?*

In this context Table 2 was made based on the technical experience of the team members, and then based on it the most possible defects of the fabric were selected and evaluated, as shown in Table 3.

3) By voting, the key risks were selected, and the ratings were agreed for O (probability for *occurrence* of defect), S (the *severity* of the defect for the buyer) and D (probability of defect's *detection* before delivery) (Table 3).

Table 2. Consequences, defects and causes of defects

Defect's consequence	***Defect***	***Cause for defect's occurrence***
Yarn defects		
Bad visual appearance	Occurrence of neps	Yarn neps
Bad visual appearance	Occurrence of thick threads	Yarn fineness unevenness
Bad visual appearance, Problematical for care	Occurrence of dead fibres	Yarn with dead fibres
Bad visual appearance, Possibility for piling effect	Occurrence of threads with different twists	Yarn with twists less than the nominal value
Probability for weaving defects		
Bad visual appearance, Possibility for occurrence of holes	Occurrence of knots due to tying of the broken warps or wefts	Warp or weft breaking
Bad visual appearance, Problematical for care	Grouping of uneven yarn places	Insufficient mixing of the weft threads during weaving
Probability for finishing process defects		
Bad visual appearance, Possibility for piling effect occurrence, Problematical for care, Unpleasant on touch	Too felted surface	Extended time or higher temperature in washing
Reduced width of the fabric	Reduced width of the fabric	Extended time or higher temperature in washing
Bad visual appearance, Problematical for care, Unpleasant on touch	"Broken places" on fabric's surface	Uncontrolled washing process

Based on the results from the FMEA the following can be concluded: the new process of fabric's finishing could trigger opening of the neps and formation of new ones, as well as occurrence of thick threads on the surface of the fabric, with an average risk 50<RPN<100, which is not insignificant, and some actions of prevention should be considered (removal of the increased nepping, purification of the yarn, and if necessary, removal of the thick threads). However, the risk of occurrence of dead fibres and different felted surface of the fabric is RPN>100, and if feasible, an appropriate preventive action should be undertaken. In this case, it would be advisable to replace the raw materials, i.e. change the yarn that has dead fibres. The occurrence of different felted surface of the fabric could be reduced using a raw material with more fineness of the wool's fibres, and precisely determine the duration and the temperature of fabric's washing process. In the particular case, the risk was eliminated by ordering new yarn, instead of using the ones that were in stock.

Table 3. FMEA analysis

FMEA ANALYSIS FOR RISK PREDICTION OF OCCURENCE OF DEFECTS ON THE FABRIC						Responsible: Design Manager					Date:					
ART. 12345 design 752 ***Shetland tweed***	***O (occurrence)***					***S (severity)***					***D (detection)***					**RPN**
	1	2/3	4/6	7/8	9/10	1	2/3	4/6	7/8	9/10	1	2/5	6/8	9	10	**RPN=O.S.D**
prediction of defect / occurrence of:	insignificant	Low	average	high	very high	insignificant	low	average	high	very high	high	average	small	very small	minor	
A:neps					10			5			1					**50**
B:dead fibres			5						7			5				**175**
C:thick threads					9					9	1					**81**
D:different felted surface				7				5				4				**140**
Preventive/corrective action: For article 12345, design 752 – instead of yarn from stock, an order for new yarn is advised																
LEGEND: RPN<50=low; 50<RPN<100=average; 100<RPN<200=high; 200<RPN<1000=very high; **RESULTS: RPN(A)=50=LOW; RPN(B)=175=HIGH; RPN(C)=81=AVERAGE; RPN(D)=140=HIGH;**																

Application of Pareto analysis

In many cases the designer needs to make a Pareto analysis of defects occurred in the raw fabric, registered just after the weaving process. According to the results of this analysis, a constructive assessment of the fabric's regularity and frequency of the defects can be done. This analysis is especially useful, when certain changes are introduced, such as change of fabric's composition according to the buyer's requirements, or change of the yarn because of irregular yarn count, or change of the type of the loom, etc…

The Pareto analysis was used to analyse the needed operations for sewing of the fabric depending on the type of the occurred defect. The results of the analysed raw fabric, with length of 1000 m, made of 100% wool, with a mass per linear meter of 360 g/m, twill–weave 2/2, and yarn count for the warp and the weft Tt=117,6 tex, are shown in Table 4. With the positioning of the sewing operations on X-axis and the number of defects represented as a length of defects on Y-axis, Pareto diagram is created (Figure 1).

The highest pillars according to the Pareto diagram from Figure 1, and the first for "knocking down", are operation 1 and operation 5 (with cumulative 39.31% from the total number of defects), which represent operations for sewing of broken weft threads (22,07%) and removal of doubled warp threads (17,24%). This suggests problematic quality of yarn for weft, which is characterized by low break strength (machine regularity was previously determined), and doubled warp threads, which are often result of irregular weaving cards.

Table 4. Sewing operations depending on the type of defect on 1000 m raw fabric

No	Operation	Length of defect [m]	Percentage (%) of defects in relation to the total number of defects	Cumulative % of defects
1	Sewing of broken weft threads	32	22,07	22,07
5	Removal of doubled warp threads	25	17,24	39,31
6	Removal of weaving waste	17	11,72	51,03
3	Sewing of irregularly drawn warp threads	16	11,03	62,06
4	Sewing of irregularly interlaced (floated) warp threads	16	11,03	73,09
9	Sewing of threads with irregular count yarn	13	8,97	82,06
7	Removal of thick threads	10	6,90	88,96
2	Sewing of broken warp threads	8	5,52	94,48
8	Sewing of knots	4	2,76	97,24
10	Sewing of irregularly interlaced threads	4	2,76	100,00
	Total	**145**	**100,00**	

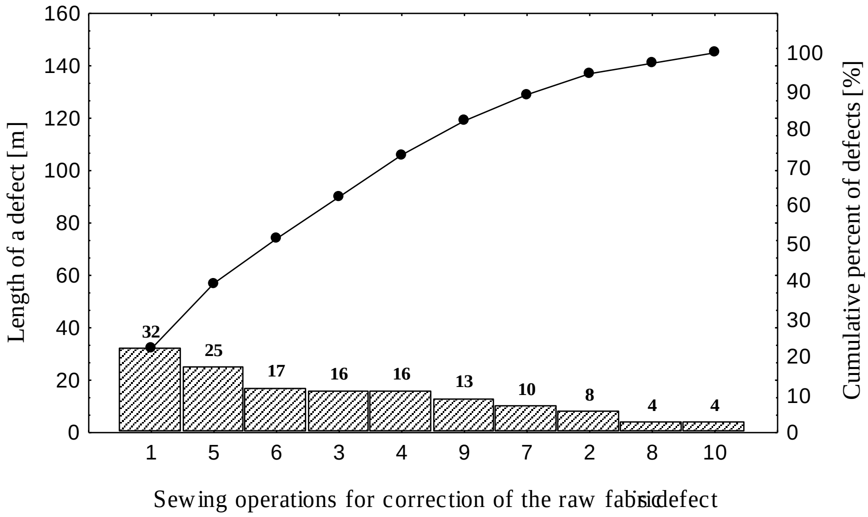


Figure 1. Pareto diagram of the sewing operations depending on the type of defect on 1000 m raw fabric

Application of $\overline{X}$ - R Control Chart

Frequent occurrence in the production of fabrics is the deviations from the fabric's parameters out of the specified bounds of tolerance, which require specific interventions by the design team. The main objective of the changes in the fabric's parameters is to meet the requirements of the customer and in the same time to reduce the costs, caused by the existing non-compliance. Namely, because of problems throughout several production cycles in a single year related with variations in the values of mass/square meter [g/m²] of the fabric, with the use of control chart the count yarn was monitored in the production cycle of the yarn, in relation to the declared count yarn of 117.65 tex used as warp and weft in the fabric. The results of the analysis of the average values of the count yarn Tt [tex] of all yarn lots that were manufactured are shown at $\overline{X}$ - R control chart (Figure 2). It can be seen (Figure 2a) that the mean count yarn from all lots observed is 119.93 tex and is greater than the declared of 117.65 tex, which means that in average a "coarse" yarn was manufactured. The tolerable variation of count yarn for this fineness of the yarn is ± 5%, which means that the tolerance limits are from 111,77 to 123.53 tex. It can be noticed that the upper control limit is above the upper limit of tolerance (UCL=123.80 tex > UTL=123.53 tex), which means that certain lots are characterized with critical, warning values with larger variations of yarn fineness within the lot, as noted by the R-control chart (Figure 2b). Control charts indicate that in the fabrics that were to be produced from the given lots of yarn, an intervention on the project parameters was necessary (especially on the weft, as well as on the warp density [cm^{-1}] in the fabrics construction), with trial testing before the beginning of the serial process of weaving.

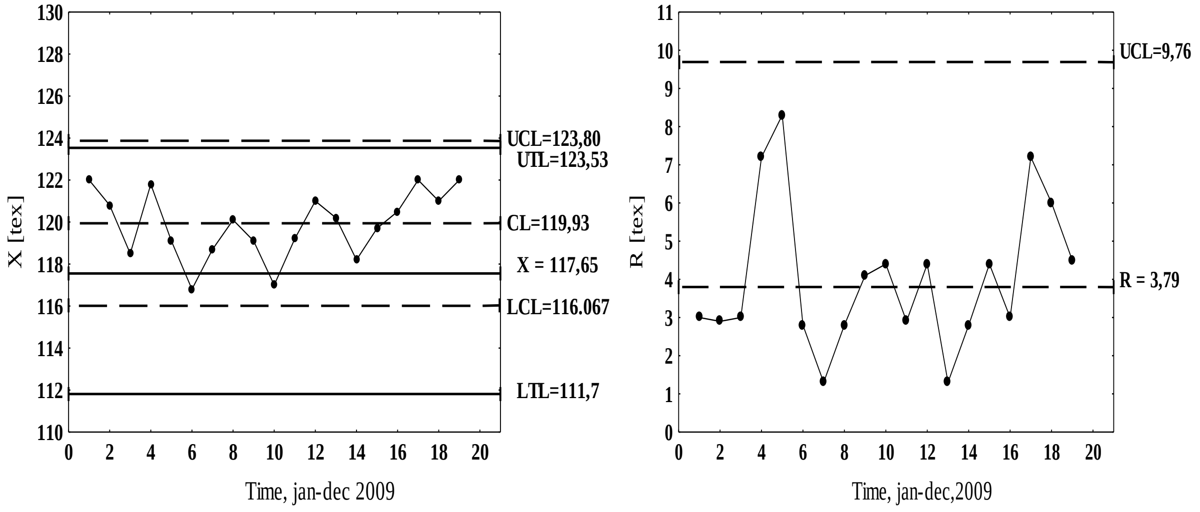


Figure 2. $\overline{X}$ *- R Control chart for average values of count yarn Tt [tex] of lots*

Application of Cause and Effect diagram

Cause and Effect diagram (CE) is used in cases when the reasons for certain deviations of project parameters are not exactly visible and it is necessary to perform their due diligence analysis. These reasons are most often associated with the used material, machine, method, or the man as an operator.

In this case, the CE diagram was used on a manufacturing process of a blanket, 100% acrylic, with dimensions – 150x200 cm and weight of 1350 g. The length of the raw blanket (before finishing process) should range from 210-216 cm, but the procured average lengths were smaller from than the expected for 6%. The blanket is with enclosed report of the pattern, which means that the number of wefts used in the blanket is fixed and defined by jacquard cards, so their change is very undesirable and difficult, and should be done only if utterly necessary. First the reasons for the deviations should be identified, so that appropriate corrective actions could be undertaken.

The analysis of the reasons for the deviation of the blanket's length made with CE diagram (Figure 3), points to the following conclusions:

- **in relation with human factor - weaver:**

− A weaver has a short working experience (is recently employed), and doesn't possess significant experience about understanding the problems;

− Overload, represented by the number of working looms per one employee; negligible self-control that the weaver performed during weaving; and supplemented by longer absence from work, resulted in low quality of the work of the weaver;

− This process is complex (because of the complexity of the models) and the weaver often has to intervene;

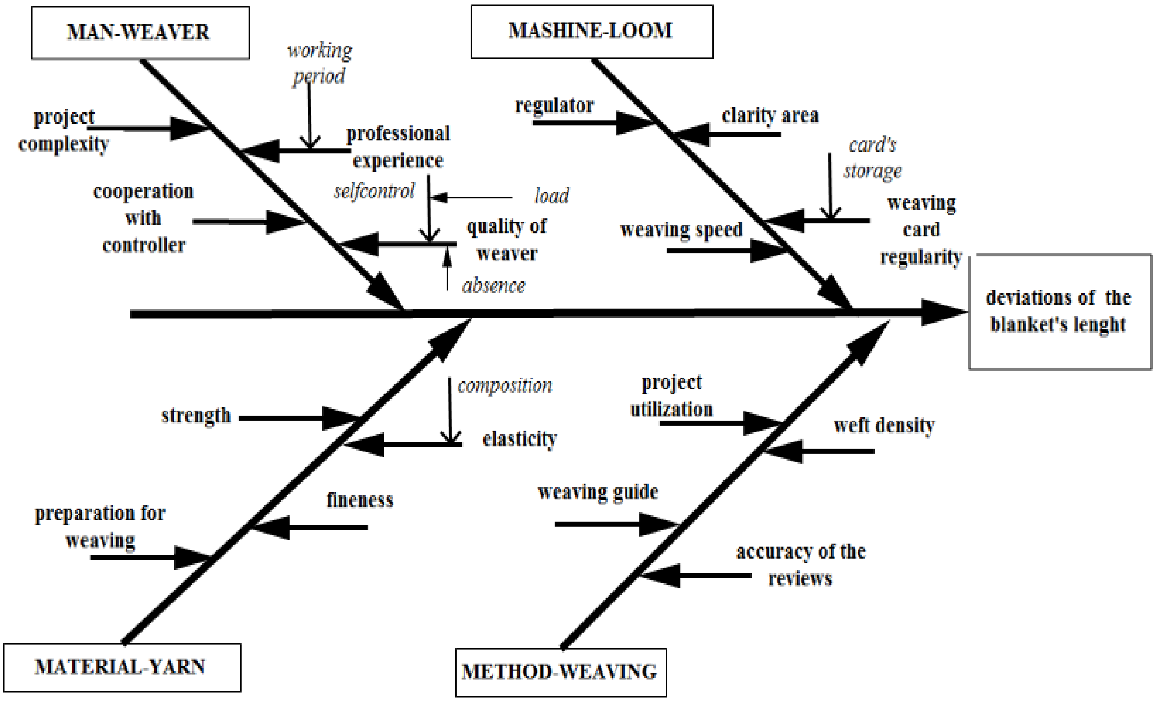


Figure 3. CE diagram for detection of the causes for blanket's length deviations

- **in relation with the factor machine - the loom:**
  - The visibility of the error in the working area of the loom is low;
  - The speed of weaving is high, and the error is even harder to notice;
- **in relation with the factor method - weaving:**
  - The project for the blanket is proven (it has been done and it is verified);
  - The guide for weaving was followed;
  - Accurate inspections were carried out at the weave-beginning;
- **in relation with the factor material - yarn:**
  - The fineness yarn is lower than required;
  - The breaking strength of the yarn is lower;
  - With repeated laboratory tests of the yarn composition, it was concluded that the manipulative composition is inadequate, which leads to increased elasticity of the yarn.

According to the analysis performed with the CE diagram, a conclusion can be reached that the main factor for the deviation of the blanket's length is the irregular yarn composition, which is leading to a significant shrinking of the blanket's warp (length), manifested after the raw fabric is taken down from the loom, during the process of relaxation.

4. CONCLUSION

The use of statistical methods, techniques and tools for quality management of the process of design and development is a real need in order to achieve quality fabrics at lowest cost and minimum (zero) defects.

By applying FMEA a quality platform is created based on which the responsible people can decide whether to apply a set of preventive measures or to disregard certain risk groups as irrelevant for complying with the buyer's requirements, and for the business and it's development, in general.

The Pareto diagram is useful for the designer's indication that the problem of the fabric's quality doesn't come from irregularity or inadequacy of the project, but because of reasons related to the irregularity of the input raw material and the process. Determination of the responsibility for the problems in the production of fabrics, actually, directs the energy needed for quality management towards undertaking corrective and preventive measures, appropriate to the accumulated experience, knowledge and types of defects occurred.

Variations of the values of certain project parameters, previously specified in the project, if not followed by the use of control charts, will result either in frequent and exaggerated interventions in the structural parameters of fabric, which complicate the process of production even more, causing frequent delays (the cost of the process increases, deadlines are prolonged), or no timely interventions at all. If the buyer requires production of the fabric in several different designs, in which such deviations occur, the consequences are predictable.

The most important things when using statistical methods, without any exception, are their proper selection, adequate sample size, and sufficient duration of the analysis, as well as the existence of a reference database based on which in the right time, place and manner, right conclusions can be drawn, about the quality of the process's performance.

The findings of the conducted statistical analysis indicate changes in the project, the process or the operators, done with one single goal: permanent improvement, which in turn causes an increase in the buyer's satisfaction and all the business entities in the process involved.

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