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Implementation of Six Sigma Methodologies in Automotive Wiring Harnesses Manufacturing Companies. "ABC" Plant Case Study

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Abstract— The Six Sigma's problem solving methodology DMAIC is one of several techniques used to improve product quality. This paper demonstrates the empirical application of DMAIC methodology to reduce product defects though investigation of root causes of major defects and provide a solution to reduce/eliminate these defects. The analysis from employing Six Sigma indicated that variation in contact crimp height represents 86% of total defects in cable cutting and crimping process. In particular, affinity and cause and effect diagrams have been used to identify potential variation sources. Die applicator capability analysis, press shut height check and assessment of operator self-check have been used to verify the root causes. Process flow chart and PFMEA have been used to assess current control and prevention measures. The vital few causes for wire contact crimp height variation had been identified to include; Worn, loose die applicator, Wrong die applicator setting, improper operator self-check, improper tool maintenance and release procedure and Shut height variation, accordingly the following actions had been decided ; Use Press analyzer to calibrate crimping machine presses and press maintenance, Use Crimp width gauge (SLE) during tool release 2 and after applicator crimper / anvil change , Monitor Contact Crimps by "Crimp Force Monitoring device", Fix new automated micrograph in quality lab. For fast checking contact crimp parameters and tool release. Create and implement process for machine and tools release and Create and implement documented procedure and records for crimping tools check and maintenance before and after finishing production order. As a result defect rate had been decreased from 1066 to 119 PPM and operations failure costs reduced from 18770 € to 1609 € with a saving of 16842 €/Year.

Index Terms— Six Sigma, DMAIC,Wiring Harnesses, Automotive, Internal Failure Costs, Defect Rate,Cable Cutting, Crimping.

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1 Introduction

Automotive companies are operating in an increasingly competitive environment. Regardless of their size and whether they are working in auto assembling or feeding industry, they are forced daily to provide the highest quality products at a lower cost. Companies that fail to improve quality, productivity and customer satisfaction fast enough will face a bleak future where competitors will take their market share that will lead to heavy financial losses.

Intermittent improvements are no longer sufficient to gain or maintain a competitive advantage, to compete effectively in this changing environment. Organizations need to implement fixed methodology like Six Sigma to achieve vast improvements in quality, productivity and customer satisfaction

In general, one of the most vital concerns for the wiring harnesses manufacturers is the elimination of the critical quality defects such as contact crimp height too big or too small. From this point, not only does an organization waste its resources and time to re-manufacture or rework the products, but it also contributes to the loss of customers' satisfaction and trust. As a result, this has driven ABC manufacturing organization to improve the quality of its products in order to create a competitive strategic advantage for its business and introduce itself to become a global organization for further prospects. This paper investigates quality issues and provides a solution to reduce/eliminate the most critical defects. In order to accomplish this, the paper evocates the principles and tools of one of the most effective quality management and improvement methodologies, Six Sigma. In particular, the DMAIC (Define-Measure-Analyze-Improve-Control) problem-solving and improvement model of Six Sigma is followed. Under the umbrella of this model, several statistical and quality improvement tools such as fishbone diagram, Pareto chart, capability analysis, measurement system analysis, PFMEA and control plan have been used. As an initial step, the paper briefly reviews some of the relevant theory of Six Sigma and DMAIC, paying particular attention to the benefits and the positive impact on performance that these approaches bring to organizations, the wiring harnesses manufacturing process supported with a case study.

2 Literature Review

Six Sigma was proposed by Motorola, in the mid-1980s, as an approach to improve production, productivity and quality, as well as reducing operational costs [1]. The Sigma's name originates from the Greek alphabet and in quality control terms, Sigma (σ) has been traditionally used to measure the variation in a process or its output [2]. In the Six Sigma's terminology, the "Sigma level" is denoted as a company's performance [3]. Particularly, a Six Sigma level refers to 3.4 defects per million opportunities (DPMO) [4], or in other words, to have a process which only produces 3.4 defects per every one million products produced.

Besides being ameasure of variability and organization's quality performance, Brue and Howes [5] mention that Six Sigma is also a management philosophy and strategy as well as a problem-solving and improvement methodology that can be applied to every type of process to eliminate the root causes of defects. In particular, some authors argue that the main benefits that an organization can gain from applying Six Sigma are: cost reduction, cycle time improvements, defects elimination, an increase in customer satisfaction and a significant rise in profits [3, 4, 6, and 7]. Markarian [8] suggests that not only can the process improvement generated by Six Sigma be used in manufacturing operations, as it is the case for the project presented in this paper, but it can also be expanded to improve business sectors such as logistics, purchasing, legal and human resources. In addition, Kumar et al. [9] state that although Six Sigma is normally used in defects reduction (industrial applications), it can also be applied in business processes and to develop new business models. Banuelas et al. [10] claim that other benefits such as (1) an increase in process knowledge, (2) participation of employees in Six Sigma projects and (3) problem solving by using the concept of statistical thinking can also be gained from the application of Six Sigma. To illustrate this point, during the utilization of Six Sigma in this research project, several tools and techniques were employed. Therefore, skills in the use of these tools were built up within the staff of the ABC organization. As a consequence, people involved in the project enhanced their knowledge and skills. As a reason, not only does an organization itself gain benefits from implementing Six Sigma in terms of cost savings, productivity enhancement and process improvement, but individuals involved also increase their statistical knowledge and problem-solving skills by conducting a Six Sigma project.

One of the Six Sigma's distinctive approaches to process and quality improvement is DMAIC [11]. The DMAIC model refers to five interconnected stages (i.e. define, measure, analyze, improve and control) that systematically help organizations to solve problems and improve their processes. Dale et al. [6] briefly defines the DMAIC phases as follows:

•Define – this stage within the DMAIC process involves defining the team's role; project scope and boundary; customer requirements and expectations and the goals of selected projects [12].

• Measure – this stage includes selecting the measurement factors to be improved [2] and providing a structure to evaluate current performance as well as assessing, comparing and monitoring subsequent improvements and their capability [4].

• Analyze – this stage centers in determining the root cause of problems (defects) [2], understanding why defects have taken place as well as comparing and prioritizing opportunities for advance betterment [13].

• Improve – this step focuses on the use of statistical techniques to generate possible improvements to reduce the amount of quality problems and/or defects [2].

• Control – finally, this last stage within the DMAIC process ensures that the improvements are sustained [2] and that ongoing performance is monitored. Process improvements are also documented and institutionalized [4].

DMAIC resembles the Deming's continuous learning and process improvement model PDCA (plan-do-check-act) [14]. Within the Six Sigma's approach, DMAIC assures the correct and effective execution of the project by providing a structured method for solving business problems [15]. Pyzdek [16] considers DMAIC as a learning model that although focused on "doing" (i.e. executing improvement activities), also emphasizes the collection andanalysis of data, previously to the execution of any improvement initiative. This provides the DMAIC's users with a platform to take decisions and courses of action based on real and scientific facts rather than on experience and knowledge, as it is the case in many organizations, especially small and medium side enterprises (SMEs) [11].

3. Wiring Harnesses Manufacturing Processes.

A wiring harness, also known as a cable harness is an assembly of cables or wires, which transmit signals or electrical power.

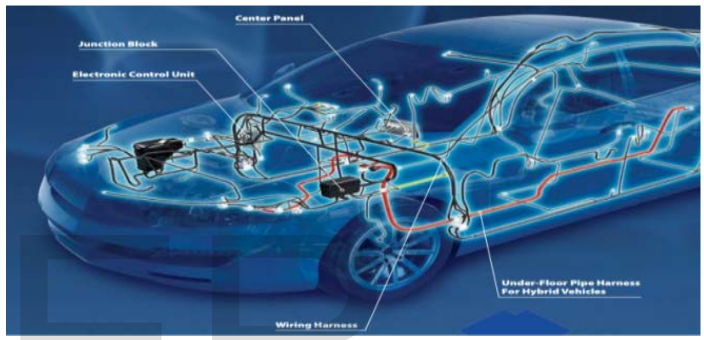

Fig.01 Animation of wiring harnesses fixed in a car [17]

Automotive wiring harnesses running throughout the entire vehicle and relay information and electric power, thereby playing a critical role in "connecting" a variety of components. They make up a circulatory system, comparable to the main arteries and central nerves in the human body.

3.1 Production steps of cable harnesses:

3.1.1 Wire Cutting and Terminal crimping

To produce a wiring harness, the wires are first cut to the desired length, the ends of the wires are stripped to expose the metal (or core) of the wires, which are fitted with the required terminals,

Fig.02 Megomat 3000 Wire cutting Machines.

3.1.2 Subassembly

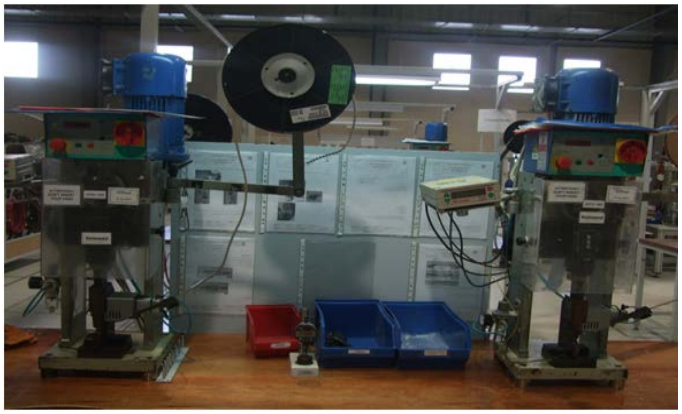

Fig.03 Subassembly work place

In this step, all manual and semiautomatic operations are performed like crimping of more than one wire in the same terminal, twisting, soldering, shrinking, thermal tube cutting, double crimping, splicing and so on.

3.1.3 Module Assembly

In this step, the cables are assembled and clamped together on a special workbench, pin board (assembly board) or a conveyor, according to the design specification, to form the cable harness.

Fig.04 Harnesses Assembly conveyor.

3.1.4 Electrical Testing

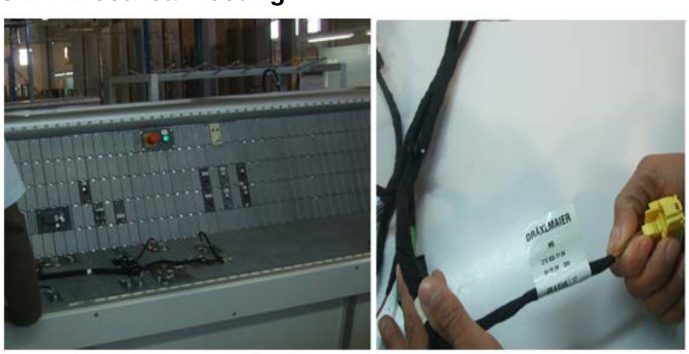

Fig.05 Electrical test station and tested harness

The electrical functionality of a cable harness is tested with the aid of a test board in which the circuit diagram data are preprogrammed into the test board. After passing electrical testing, wiring harnesses are subjected to final inspection for dimensions, passed harnesses fitted in protective sleeves, conduit, or extruded yarn to be ready for shipment.

4. Six Sigma DMAIC Application (Case study).

Phases in the DMAIC framework include the Define, Measure, Analyze, Improve, and Control phases; each phase consists of 3 steps.

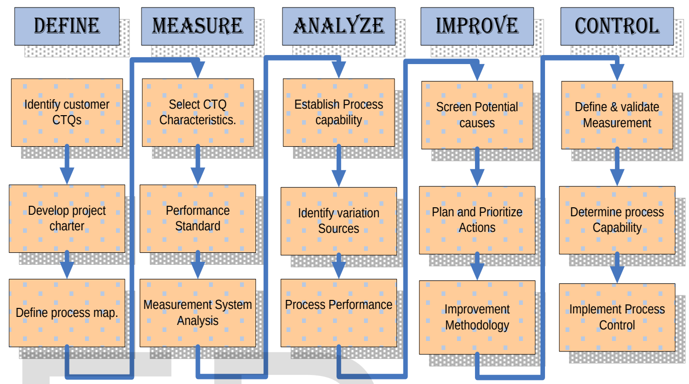

Fig 06-Steps Six sigma DMAIC methodology

4.1 Define

Nonthaleerak and Hendry [18] suggest that a Six Sigma project should be selected based on company issues related to not achieving customers' expectations. The chosen projects should be focused on having a significant and positive impact on customers as well as obtaining monetary savings [18, 19, 20]. The 1st step in this project is to definethe project's scope and boundaries through identifying customer Critical To Quality (CTQs)in which crimping process was selected as a process that requires improvement due to high defect rate (1066 ppm) and high operations failure costs (18770 € /year).

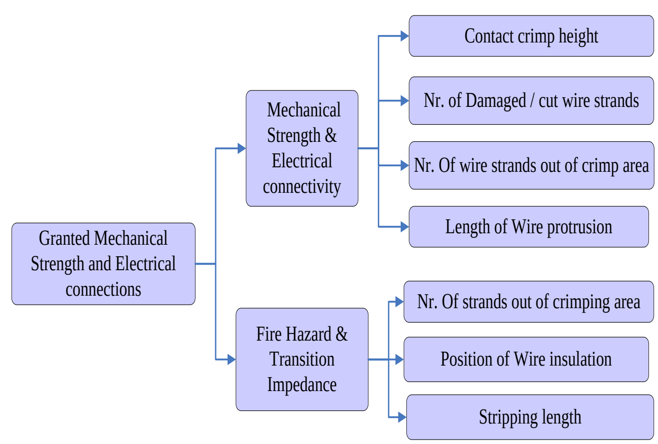

Fig. 07Internal Customer CTQs

The 2nd step in define phase is to document the project's scope, problem statement, goal statement, team roles and responsibilities using the project charter.

1.Initiator Name:		Kamal Elshawadfy		Date: 01/04/2013	
2.Title		Reduction of defect rate in Cable Cutting Department.			
3.Process		Wire Cutting, Stripping and Crimping Process using fully automatic machines			
4. Project Deliverables:		Reduction of Defect Rate from 1066 ppm to less than 150 ppm. (cumulative ppm)			
5. Problem Statement		Increasing Defect rate in Cable Cutting department in the period between April 2012 to March 2013,causing decreasing of Sigma level to 4.7 leading to loss of revenue, excessive scrap, resort, rework and delaying of delivery of wires to assembly lines			
6. Goal Statement		Metrics		Current	Annual Goal
		Cumulative Defect Rate in Cable Cutting Department.		1066 ppm	< 150 ppm
		Cumulative Internal failure costs in cable cutting department		18770 €	< 6000 €
7. Project Scope		Fully automatic crimping Machines.			
8.Roles and Responsibilities	Sponsors	Schon Juergen BA2-EWS		Project Manager.	
		Szuecs Emil BA2-EWS		Quality Manager.	
	Stakeholders	Quality, Production,, Maintenance and Engineering.			
	Team members	Kamal Elshawadfy, Mohamed Eissa, Taher Kamel, Mohamed Shawkey, Mohamed Mostafa, Mahmoud Maghraby			
9. Resources Required		3 Quality inspectors, ,3 production operators, 3 maintenance Technicians , 1 lab. Specialist.			
10. Project Plan	Phase	Start	End	Responsible	function
	Define	1st April-13	22- April-13	Kamal Elshawadfy	QC Section Head – Cable Cutting
	Measure	16 April-13	30 April-13	Mohamed Shawkey	QA Section Head
	Analyze	01 May -13	30 May -13	Taher Kamel	Prod. Section Head – Cable Cutting
	Improve	1st June-13	30 June -13	Szuecs Emil	Quality Manager
	Control	1st July-13	15 July-13	Schon Juergen	Project Manager.

Fig.08 Project Charter

The 3rd step is mapping the process to assists in understanding where the defects are in the current process,

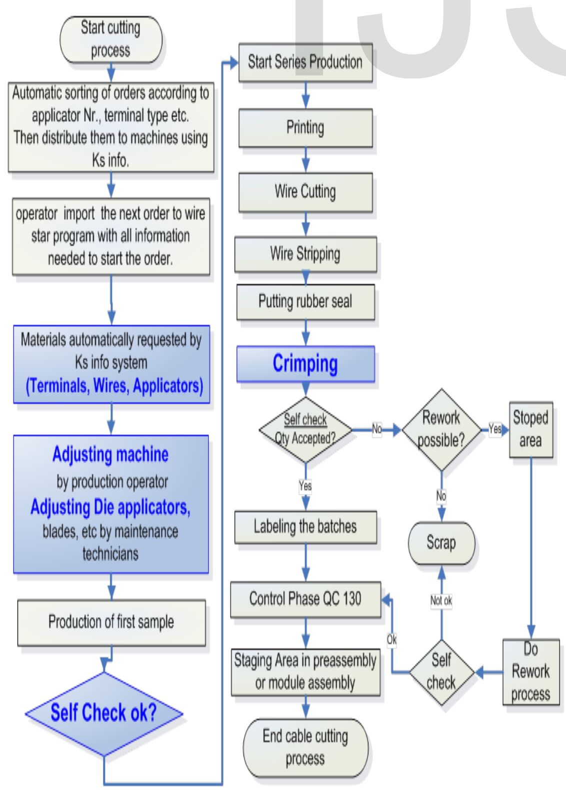

Fig.09 as is Process Flow Chart for cable cutting Process

4.2 Measure

The "measure" phase of the DMAIC problem solving methodology consists of establishing reliable metrics to help monitoring progress towards them. From define phase, it was observed that operations failure costs exceeds the target due to increasing defect rate in the period between April 2012 to March 2013 reaching 1066 PPM .As a next step, a Pareto analysis [21, 22] was carried out to identify the utmost occurring defects and prioritize the most critical problem which was required to be tackled.

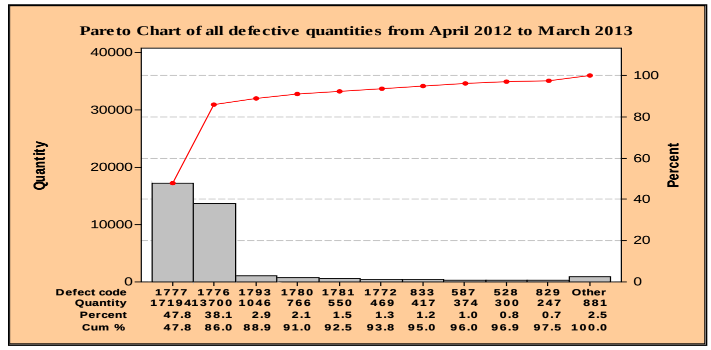

Fig. 10 Pareto chart for defective quantities per defect code.

Pareto chart shown in Fig.10 indicates that the highest rate of defects was caused contact crimp height too big ((Defect code: 1777) and contact crimp height too small (Defect code: 1776) representing 86% of total defects in cable cutting process. In particular, these types of defectsrepresent the most critical ones, as if it wasn't detected by production operator or quality inspector, it may pass to the customer and can't be detected on time, causing malfunction or safety issue. Therefore, the improvement team and organization decided to initially focus on the elimination of these defects which translated in to operational failure costs and sigma level.

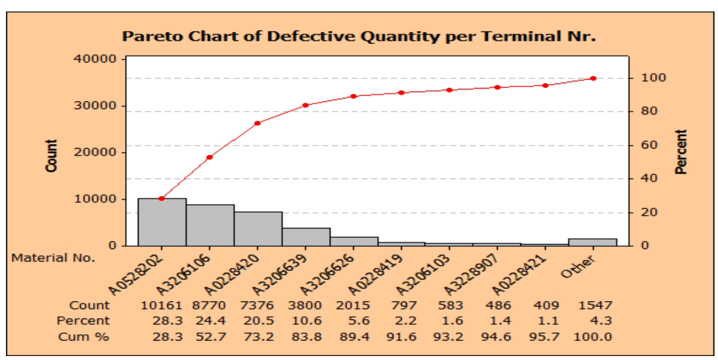

Fig.11 Pareto chart of defective quantities /terminal Nr.

Further analysis (Fig.11) showed that 48.8 % of total defective quantities happens in Terminal Nr. A0528202 and A0228420 (Crimped by Applicator Nr: 5810) and Machine Nr: 321

40.6 % of total defective quantity happens in Terminal Nr. A3206106, A3206626 and A3206639 (Crimped by Die Applicator Nr. 3960) and Machine Nr: 329.

In parallel with monitoring the major defects affecting cable cutting process the measurement systems was assessed and found to be acceptable and capable for distinguishing between parts.

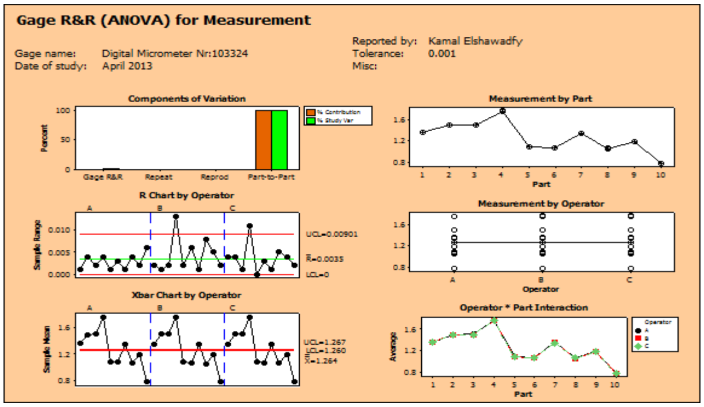

Fig.12 GR&R for digital micrometer

4.3 Analyze

Through analyze phase, affinity diagram performed with ten participants all with knowledge about the problem, working in various functions and positions, Problem Title: What is the cause of "wire crimp height off target?"
Responses were considered as variable Xs

Shut height not adjusted Wrong Machine Setting Wrong Die Applicator setting	Wrong Measurement. Material of Crimper too bad Variation in Wire cross Section
Worn, loose Die applicator. Measurement system not ok. Self-check not done	Variation in Terminal Dimensions. Sampling procedure not adhered. Tool release procedure not adhered.
Tools periodic maintenance plan not followed. Measuring equipment position wrong Measurement Device damaged	Measurement daily verification procedure not adhered. Improper measurement device setting Poor lightening in work place.

Table 01 show potential causes as a result of affinity diagram

In order to illustrate and categorize the possible causes of the problem, a cause-and-effect diagram was constructed. The cause-and-effect diagram is known as a systematic questioning technique for seeking root causes of problems [21].

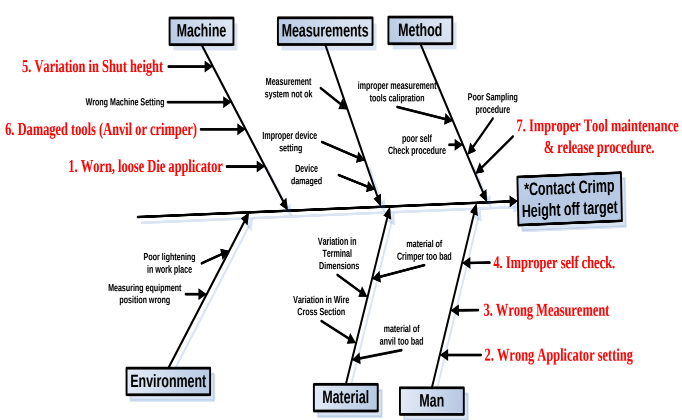

Fig.13 Ishikawa diagram for contact crimp height off target

Identified potential causes had been evaluated by the project team to get below screened list and assessment method.

Potential cause	Assessment methodology
Worn, loose Die applicator	Capability Analysis for applicator 5810 &3960.
Wrong Applicator setting	
Improper Self-check procedure	Review Self-Check Procedure
Improper Tool maintenance & release procedure	Review Tool maintenance & release procedure
Variation in Shut height	Check shut height for crimping press of machine 329 and 321.

Table 02 Potential causes for contact crimp height off target

1. Worn, loose die applicator and wrong applicator setting had been assessed and proved as a root cause though binomial capability analysis.

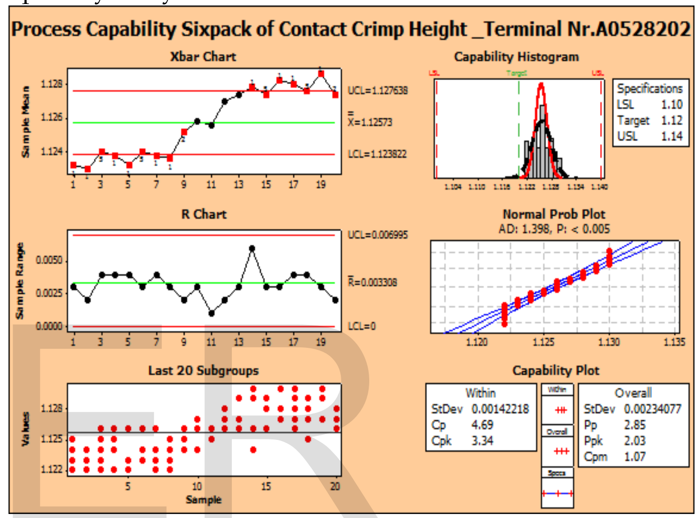

Fig. 14 Process Capability for Terminal A0528202

2. Operator self check found to be the second root cause after assessment of operator performance.

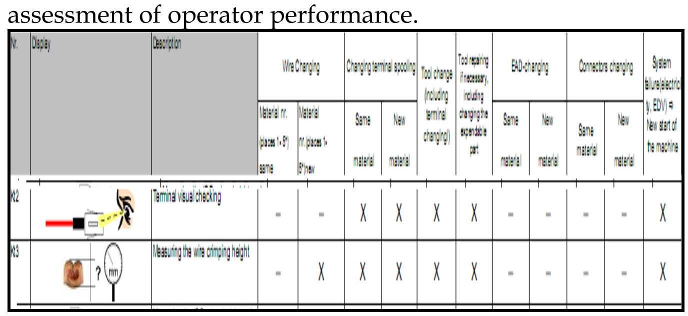

Fig.15 Machine operator check points.

3. Improper tool maintenance & release procedure,
Current process flow chart show that the available control is only by Production operator and maintenance technician at the time of starting production order and no other prevention measures, indicating that process requires many changes to add control and prevention measures to ensure that process output matched with customer requirements.

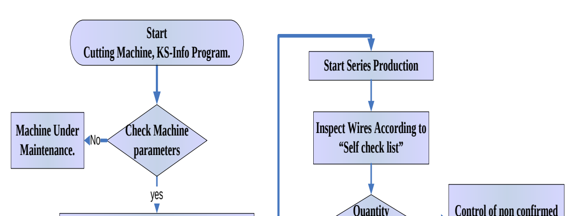

Fig. 16 As is crimping process flow diagram before improvement

Current control detections and preventions still not enough to prevent occurrence of defects indicated by high RPN number despite of implemented actions, meaning that traditional solutions will not be enough to achieve customer targets.

Process Step/ Function	Requirement	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) of Failure	Occurrence	Current Control		Detection	RPN	Recommended Action(s)	Responsibility and Target Completion Date	Action results			
							Detection	Prevention					Severity	Occurrence	Detection	RPN
Crimp Tool Setting	Correct Contact Crimp Height (CCH)	Contact crimp opened, Crimp height variation Scratches on Contact Crimp	Manf.: scrap End user: malfunction	9	Crimper worn or damaged	3	Visual	None	3	81						
		Crimp height variation. Flash formation	Manf.: scrap End user: malfunction	9	Anvil worn (loose or damaged)	4	Visual	None	3	108						
		Crimp height Variation	Manf.: scrap End user: malfunction	9	Die Applicator Worn, loose or damaged	5	Machine Operator Self Check Digital micrometer	None	8	360						
					Press Shut Height Variation	3	Digital caliber	None	6	162						
		Contact Crimp height beyond Tolerence limits	Manf.: scrap End user: malfunction	9	Wrong Die Applicator setting	5	Machine Operator Self Check	None	3	135						
					Wrong measurement device setting	2	Daily verification	None	1	18						
					Wrong Measurement	6	None	None	6	324						

Fig. 17PFMEA Cable cutting Process

4.4 Improve

Through improve phase; thefollowing actions had been implemented to close the gap between customer critical to quality (CTQs) and current process performance.

1. Crimp Press calibration using Press analyzer during machine release and after press maintenance activities.

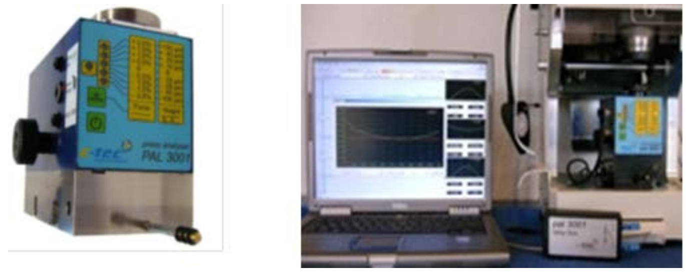

Fig 18-Tec system (pal 3001)

2. Crimp width measurement using Crimp width gauge (SLE) during tool release and after changing applicator spare parts (Crimper & Anvil).

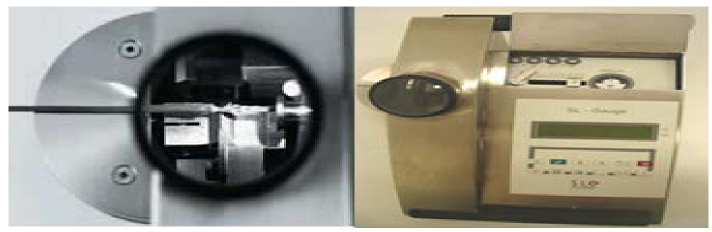

Fig.19 SL gauge crimp width gauge (SLE)

3. Controlling die applicator variation using crimp force monitoring device.

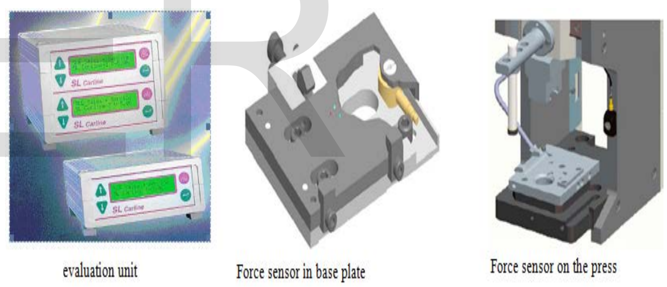

Fig 20-Crimp force monitoring device components

4. Monitoring contact crimp dimensions and crimping spare parts (Anvil and Crimper) through automated micrograph.

Fig 21- Micrograph SBL 3000

5. Create and implement process for machine and tools re-

lease.

6 Create and implement documented procedure and records for crimping tools receiving and inspection after each production order.

4.5 Control phase

Through control phase,the measurements have been defined and validated (operation failure costs and defect rate) in which cumulative operation failure costs decreased to 1066 Euro/year and internal defect rate decreased to be 119 ppm and the process identified to be capable meaning that the expected improvements actually occurred.

The new methods become standardized in practice and lessons learned are documented through:

1. Training of cable-cutting operators on the new used tools and on the new modified processes.
2. Training of maintenance technicians on the new modified processes and tool release process.
3. Update control plan with the revised changes in the process.

BU-BAII	KV_505V02-A_D1 Production leading plan no. PLP_EWSKSVK_013_004 Page 1 of 3	Production Control plan Process 3210 Wire Cutting Door-roof-seat wiring, vehicle 212/218	☐ Prototype ☐ Pre-series ☑ Series	EWS
Project nr.: E10-00057-01		Contact Person / Phone: Mr. Schon DAS-EWS ,	First drawing up date: 08.12.2008	Latest review date: 07.04.2013
Part Description/ Part Name: Door-roof-seat wiring, vehicle 212/218		Main team members: Mr. Mohamed Alaa EWS5- Mr. Eid Mahmoud EWS 4, Kamal Elshwadfy EWS 55, Taher Kamel EWS 410	Client accept according to technical development/ Date: - See harnesses list or accept fax -	
Part nr. / Review level: ---See Module list---		Supplier accept / Plant accept / Date: - Not necessary -	Quality accept from customer / Date: -See Initial sample Documents ; See wires lot from harnesses list-	
Supplier / Plant: Egypt /EWS	Supplier nr.: Plant E5	Other accepts / Date: - Not necessary -	Other accepts from customer / Date: - not necessary -	

Process Nr.	Process name/ Description working phase	Machine, installation, device, tool	Features: Nr	Features: Product features	Features: Process parameters	Features: Product specifications/ process (with tolerances)	Special	Checking method: Checking device	Checking method: Sample Size	Checking method: Sample Frequency	Documentation	Reaction plan / Measures plan, correction actions (responsible)
2.	Machine Setting	Crimping Die Applicator 5810 & 3960. Machine Press 329 & 354		Wire length Stripping length Rubber seal position (when is requested)Marking (when is requested) CCH,CCW ICH,ICW (when is requested on the Job card) Pull out force (when is requested on the Job card)	According to FP010958_D5 KS-INFO	AC 013, AC 012, BD 034, EWS016 BD025 AD003		Visual Dial indicator Caliper Pull out force device Measuring tape. Press Analyzer SL-Crimp width gauge Micrograph SBL 3000	BD052 Self-check procedure	BD052 Self-check procedure	KS- Info (Machine Software)	In case of doubts related to production or quality, Stop and readjust machine and inform immediately your supervisor VA EW S107V01
7.	Crimping Process	Production means according to Job card -KS Info		Cabel crimp height (CCH) Insulation Crimp height (ICH) Cable crimp width (CCW) Insulation crimp width (ICW) Pull out force	KS-Info	AC013, AC026, BD034, EWS016		Crimp monitoring system Dial indicator Visual Pull out force device	BD052 Self-check procedure	BD052 Self-check procedure	KS- Info (Machine Software)	In case of doubts related to production or quality, Stop product ,check setting and measuring tools and inform immediately your supervisor VA EW S107V01
9.	Control phase QC 130	Inspection plan		Color Wire length Stripping length Rubber Position Wire Marking CCH ICH CCW ICW	Job Card KS INFO screen	AB010 AC026 AC013 BD025 EWS002 EWS003 EWS010 EWS011		visual Caliber Micrometer Pull out Force Device Measuring Tape	According Inspection Plan	According Inspection Plan	DAS703A01_D4 EW S703A01_D1-D4	In case of doubts related to production or quality, Stop material and inform immediately your supervisor VA EW S107V01

Fig. 22 Updated Control Plan

4. Perform event case process release to ensure that cable-cutting process is controlled and actions are maintained.

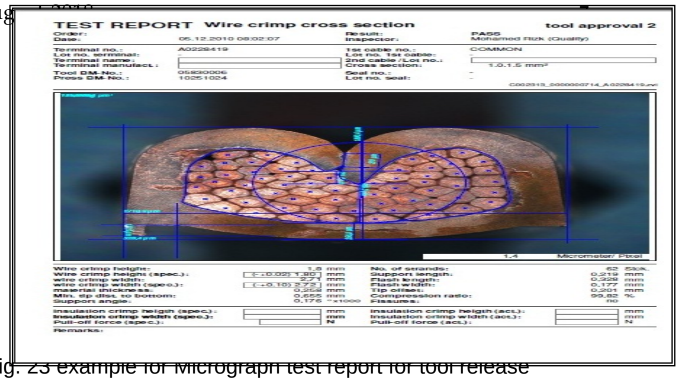

Fig. 23 example for Micrograph test report for tool release

RESULTS, DISCUSSION AND CONCLUSIONS

This paper presented a successful case study of defects reduction in a wiring harnesses manufacturing process by applying Six Sigma methodology. Therefore, the paper can be used as a reference for Manufacturing Industrialists to guide specific process improvement projects, After the analysis carried out in the “analyze” and “improve” phases of DMAIC, the improvement project presented in this paper found that the worn anvil and crimper of dye applicator 5810/33 and 3960/154,press shut height variation and the poor production operator and maintenance technician skills represents the root causes of contact crimp height too big and too small , Actions were to develop all processes related to machines and tool controls including :

- Control and monitor contact crimp dimensions using Micrograph SBL3000.
- Control press shut height using press analyzer.
- Controlling crimp width using SL gauge measuring device.
- Prevent producing defected contact crimps using crimp force monitoring devices.
- Planning and performing machine and tool release to ensure that tools are controlled, capable and reproducible.

By considering this, a reduction in the amount of defects was obtained and defect rate decreased from 1066 to 119 PPM and accordingly operational failure costs decreased from 18770 € to 6000 €. / Year and the crimp height defects were totally eliminated and sigma level increased from 4.6 to 5.2.

In terms of the Six Sigma level, the concept literally refers to reaching a Sigma level of six, or in other words, 3.4 DPMO. In the case of this study, the improvement project presented in this paper has not been able to take the organization studied to achieve a Six Sigma level. However moving from one Sigma level to another does take times [23]. In addition, this study was considered a pilot project that was conducted in order to empirically demonstrate the ABC organization studied that Six Sigma and the DMAIC problem solving methodology are effective approaches capable of improving its manufacturing processes by reducing the amount of defects. This demonstrates that as long as the organization continues embracing Six Sigma within its continuous improvement culture and applies its concepts and principles to systematically solve quality problems, it is believed that benefits such as cost savings, increase in products’ quality and customer satisfactions will be enhanced.

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