The MPCpS® Methodology

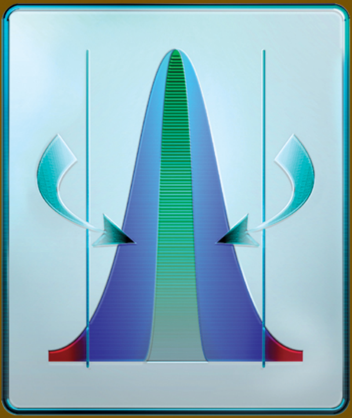
Process Control

A Five-Stage Methodology for Characterizing Processes

Mario Perez-Wilson

Follow this step-by-step approach at your own pace, and teach yourself how to control processes.

You will be improving processes right away!



The MPCpS® Methodology

Process Control

-A Preventive Approach For Total Control During Production -

Mario Perez-Wilson

"The MPCpS Methodology - Process Control"

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THE MPCpS METHODOLOGY - PROCESS CONTROL

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Section 1 - Functional Equilibrium

Introduction

Production machines are usually purchased to perform a particular transformation of raw materials into finished or semi-finished products.

A production system is comprised of machines, gauges, raw materials, sub-assemblies, components, labor, methods and activities. All support producing a quality product at a minimum cost for on-time delivery to the customer.

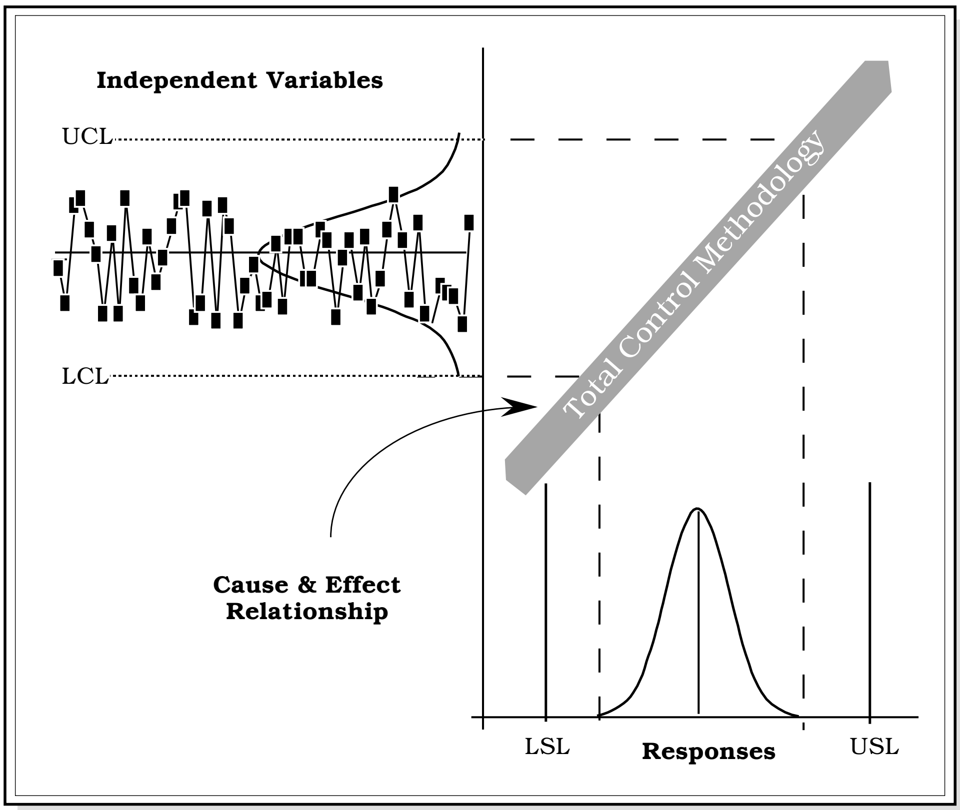
The methods and activities involved in the support of the production system are: the preparation of raw materials or sometimes parts pieced into kits; the selection of tools to be used; the mounting and demounting of fixtures, frames, plates, boats or cassettes; the adjustments to equipment; the use of gauges and inspection of parts; the actual processing of the machines and/or tools; the maintenance of all equipment; the understanding and conformance with production instructions, and the recovery in the event that something goes wrong. And all of these activities must be done without errors while maintaining a good degree of safety.

		Production System		
Quality **Cost** **On time delivery**	Raw Materials	Machines Gauges Labor Materials Methods Procedures Logistics Tools Fixtures Activities Behavior Ergonomics Discipline Human Factors Technology Maintenance Inspection	Finished Product	**Quality** **Cost** **On-time delivery**

Even in the production of the most simple of products, the production system is complex and its uneventful functioning requires a lot of attention to detail. When the products are complex or difficult to produce, the production system will usually carry a quite higher degree of complexity.

The state of *functional equilibrium* is not a natural state such as a state of statistical control where the responses are only affected by chance. In a state of *functional equilibrium*, we force the functional state of the system to operate as it was designed, to purposely extend the optimal functionality throughout the life of the product. This is done by means of a controlled feedback-loop operational methodology called the Total Control Methodology, TCM.

The Total Control Methodology attempts to establish a system of rigorous control of the production system by a very precise procedural methodology. Its objectives are to preserve an understood process perpetually in a state of *functional equilibrium*. This means having all elements of the production system working in synergy, maintaining stability, capability and remaining fool-proof of defects as established during its characterization and optimization stages.



TCM establishes monitors, checks and control requirements for the production system and does this specifically, but not limited to responses, variables, materials, resources, maintenance and setup. TCM equally checks that known preestablished cause-and-effect relationships have not been superseded by unknown ones.

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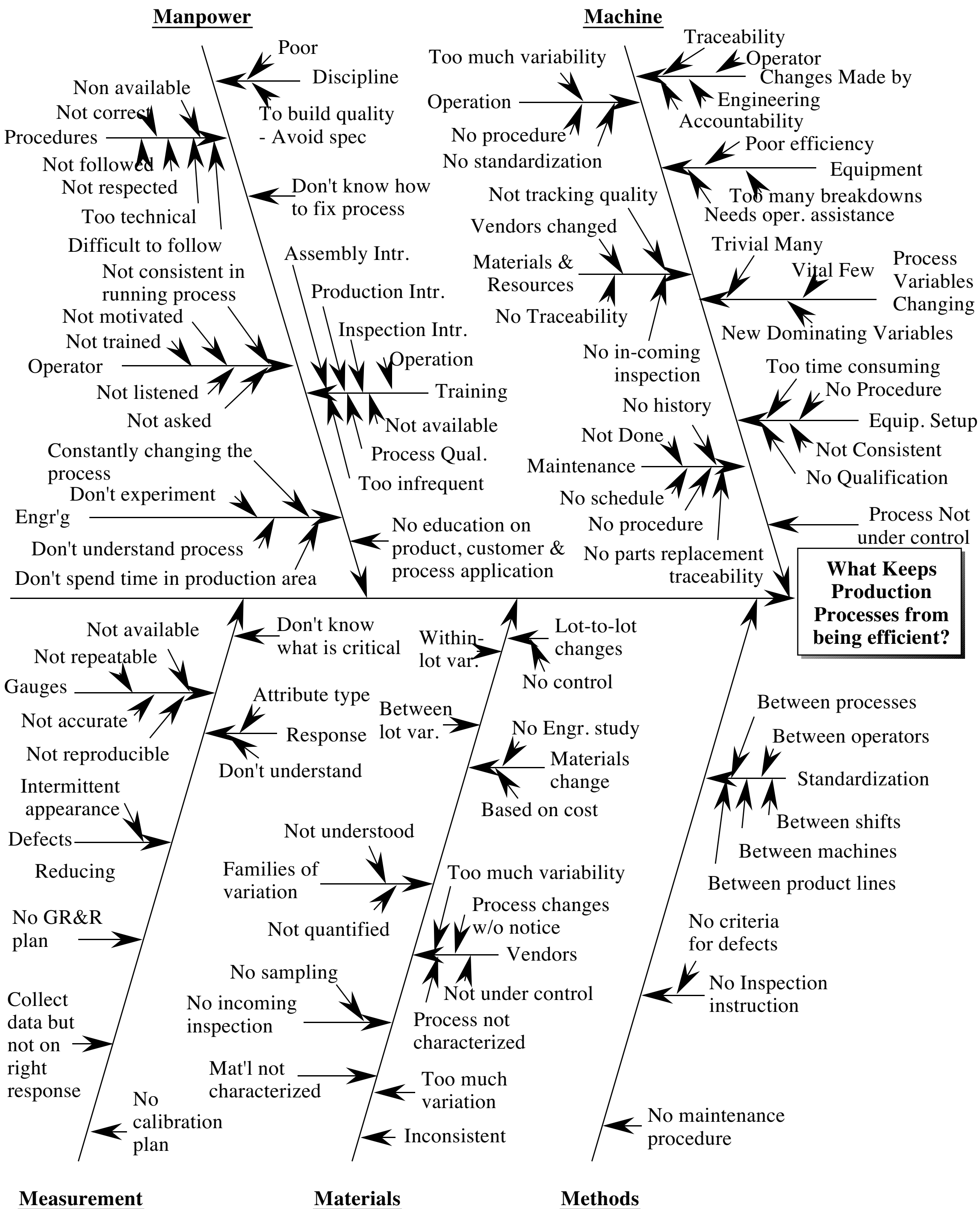

Cause-and-Effect Diagram on issues which affect running a production process efficiently. Environment category purposely not included in brainstorming efforts.

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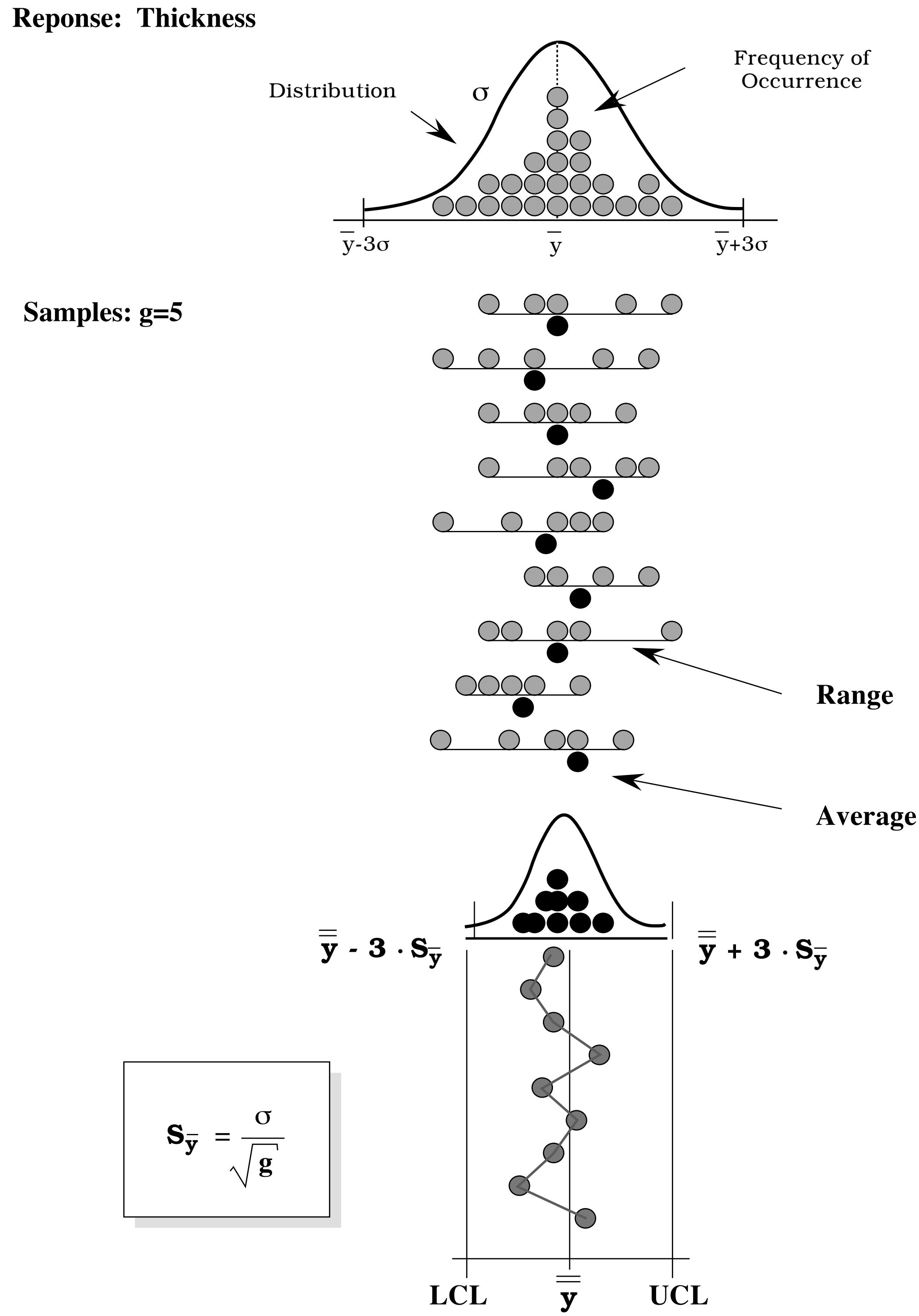

Application of the Central Limit Theorem in statistically calculated control limits

Section 4 - Tolerancing

Introduction

This section covers the topic of tolerance, a very important subject in the attempt to monitor and control processes, parameters, products and characteristics. Several statistical methods are discussed for setting tolerance limits, as well as two alternative methods, based on probabilities. In case when multiple individual dimensions are mating to produce a final overall dimension, the tolerance setting becomes a tolerance stacking problem. Tolerance stacking is discussed and two methods are presented. Finally, regression analysis is covered as a vehicle to establish realistic tolerances.

Tools & Techniques

1. Tolerance
2. Statistical Tolerance Limits
3. Tolerance Stacking
4. Scatter Diagrams
5. Regression Analysis
6. Simple Linear Regression
7. ProSolution Matrix

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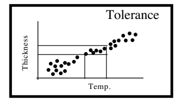


Statistical Tolerance Limits

Statistical tolerance limits specify the practical boundaries of process variability and are valuable input when determining design engineering tolerance limits. Setting up statistical tolerance limits is very similar to setting limits for "process capability".

Two types of methods are used for computing statistical tolerance limits: one that assumes the inherent distribution is normally distributed and the other that does not make the assumption of normality. In other words, it is distribution free.

There are three different methods used when the underlying distribution assumed is normal and one method for non-normal. These methods make use of two probabilities: the confidence level and the population's percentage within the tolerance limits.

Statistical Tolerance Limits Methods

1) **Method:** Average and Standard Deviation

Assumption: Normal Distribution

Procedure: Take a sample of n observations and compute the average ($\overline{X}$) and standard deviation (S).

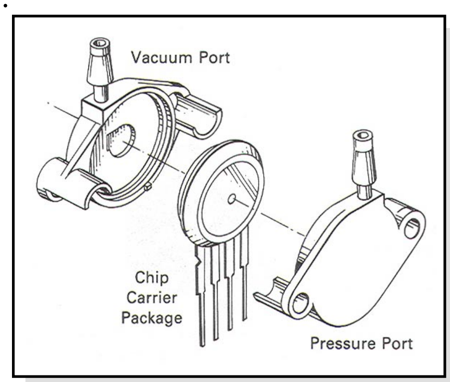
Formula: Single-sided limits, $\overline{X} + K_1 S$ or $\overline{X} - K_1 S$

Double-sided limits, $\overline{X} \pm K_1 S$

Factor K_1: Refer to Tables 5 and 6 in the appendix.

Setting Statistical Tolerance Limits

Silicon piezoresistive pressure sensors (see figure below) provides a linear voltage output (mVdc) directly proportional to applied pressure. Statistical tolerance limits are computed with the four methods using 20 pressure sensor components selected at random. See associated data in Exhibit 16.1.



Pressure Sensor in Chip Carrier Package, Motorola Inc.

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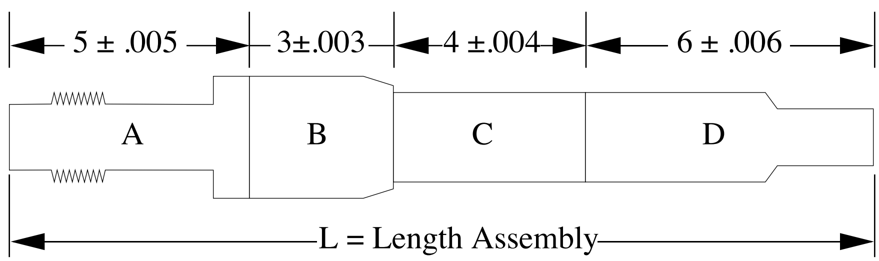
Tolerance Stacking

Tolerance stacking refers to the computation and analysis of tolerances for various individual dimensions and for the final overall dimension produced by the mating and interaction of the various individual dimensions.

Two methods are discussed in this section. The first is the conventional method which uses the Min-Max or additive approach and generates very conservative tolerances. The second is the Root Sum Square (RSS) or Pythagorean method which is a more probabilistic approach to the tolerance stacking problem.

Let's assume we have to produce an assembly comprised of four mating parts with the following dimensional specifications:



We wish to know what the specifications are (nominal and tolerance) for the overall assembly length, L.

$$Spec_{Assy} = N_{Assy} \pm (T_{Assy}/2)$$

Min-Max Method

The min-max is the conventional method used by most designers for determining the overall assembly dimensional specification (nominal, N and tolerance, T), and uses basic arithmetic, i.e., addition, where the sum of the individual parts is equal to the sum of the total assembly. The assembly nominal is then equal to the sum of the individual parts' nominal values.

$$N_{Assy} = N_A + N_B + N_C + N_D$$

$$= 5 + 3 + 4 + 6$$

$$= 18 \text{ inches}$$

$$Spec_A = N_A \pm (T_A/2)$$

$$Spec_A = 5 \pm 0.005$$

$$Spec_B = 3 \pm 0.003$$

$$Spec_C = 4 \pm 0.004$$

$$Spec_D = 6 \pm 0.006$$

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Wave Soldering System

ProSolution Matrix™

Solution [Process Related]

Problem	SOLDER TEMP HIGH	SOLDER TEMP LOW	SOLDER WAVE HEIGHT HIGH	SOLDER WAVE HEIGHT LOW	SOLDER WAVE UNEVEN	SOLDER CONTAMINATED	EXCESSIVE SOLDER DROSS	PREHEAT TEMP HIGH	PREHEAT TEMP LOW	FLUX CONTAMINATED	FLUX SPECIFIC GRAVITY LOW	FLUX SPECIFIC GRAVITY HIGH	FLUX NO LONGER ACTIVE	FLUX NOT MAKING CONTACT	FLUX FOAMHEAD LOW	FLUX UNEVEN	FLUX BLOW-OFF EXCESSIVE	NO FLUX BLOW-OFF	PALLET TOO HOT	CONVEYOR SPEED HIGH	CONVEYOR SPEED LOW	CONVEYOR VIBRATION	CONVEYOR ANGLE HIGH	CONVEYOR ANGLE LOW	EARLY REMOVAL OF BOARD
Insufficient Solder (Flow Thru)	●	●		●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●			●		
Insufficient Solder (Solder Side)	●			●	●	●		●	●	●	●	●	●	●	●	●	●		●	●			●		
De-wetting		●		●		●			●	●	●	●	●	●	●	●	●	●	●	●	●				
Solder Voids or Outgassing	●	●		●	●				●	●	●	●	●	●	●	●		●	●	●	●		●		
Skipped or Ommited Solder				●	●			●		●			●	●	●	●	●		●	●					
Excessive Solder (Comp Side)	●	●	●		●																●				
Excessive Solder (Solder Side)		●			●	●					●	●	●			●		●	●	●	●			●	
Icicles		●		●	●	●		●	●	●	●		●	●	●	●	●		●	●		●		●	●
Bridging		●		●	●	●		●	●	●	●		●	●	●	●	●		●	●	●			●	
Webbing		●				●	●	●		●	●		●	●	●	●	●		●	●	●				
Solder Balls and Splatter	●		●		●				●	●	●							●		●					
Rough or Disturbed Solder		●		●	●	●	●													●		●			●
Grainy Solder		●				●	●		●											●		●			●
Cold Solder Joints	●	●				●			●											●	●	●			●
Discolored Solder Joints	●					●		●	●	●										●	●				
Flux Intrapment									●	●		●						●		●					
Masking Failure	●							●													●				
Blistering	●							●													●				
Measling	●							●													●				
Components Lifted			●		●												●					●	●		●
Warpage	●							●	●												●				
Flooding	●	●	●		●			●	●											●	●				

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Section 5 - Positive Control

Introduction

This section covers the Positrol Plan, a fundamental element of the Total Control Methodology. The Positrol Plan is a single source to provide administration to all the important variables in a process. It also covers the details of setting Positrol Logs, which are the means for traceability during production. Finally, it describes how to use and design Work Standards and ends with a very brief notation of preventive maintenance.

Tools & Techniques

1. Positrol Plans
2. Positrol Logs
3. Work Standards
4. Preventive Maintenance

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Work Standard

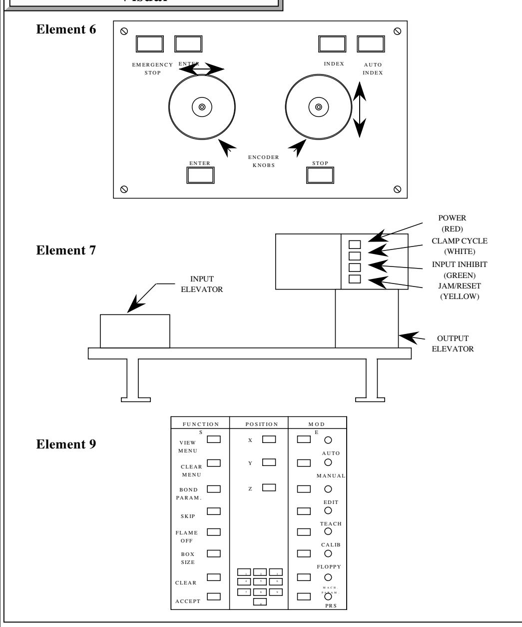
Definition

A Work Standard is a document describes the work to be done in a production station, cell or operation. The work to be done in a production operation can be broken down into a number of simple work elements. These work elements have to be executed in a proper order to produce the desired result in the product being worked on at that particular operation. How exactly and correctly those work elements are done, have a direct impact on the quality and functionality of the product. Skipping a work element may drastically damage the product, and may lead to having to scrap it later. To deter or eliminate the possibility of mistakes of this nature during production, a Work Standard is developed for each production operation.

The Work Standard is a document designed to assist the operator in the setup of the equipment, during the continuous operation of a machine, in following the steps of a process, or in building a complete sub-assembly. The Work Standard does this by describing the work elements in graphical form and detailing it in written form.

Operation	Automatic Wire Bonding	**Work Standard**	Prod	Eng		**Rev**	B
Machine	K&S 1419 Auto Wire Bonder		QA			**R. Date**	5-12-93

Visual



#	Procedure	Quality Requirements
		NOTE: Dress code of class 1000 clean required.
1	Check amount of Gold wire in spool.	
2	Check condition of the capillary.	x NOTE: Heater and work-holder are very hot. Do not touch any stages.
3	Turn power on the K&L 1419 and all its components. Warm up for 20 minutes minimum.	Machine must not be operated less than 20 minutes after power up.
4	Place & clamp cassette with substrates on Input elevator.	Substrates must be flushed on the cassette.
5	Place & clamp empty cassette on Output elevator	Cassette must be secured on the elevator.
6	Press "**Index**" button on FTCP. Turn AUTO INDEX on.	Work holder clamp opens up.
7	Press "**Jam/Reset**" button on the Handling System Controller box.	First substrate will advance to the work holder.
8	Insert & lock floppy disk into Floppy Disk System drive.	Lock floppy disk drive after inserting floppy.
9	Press "**Floppy Button**" on Dawn Keyboard.	Menu will be displayed on the monitor.
10	Select "1" (Playback) on menu displayed on monitor.	Floppy disk system reads the floppy load the W/B program.
11	Perform "**Eye Calibration**".	No error messages must be displayed.
12	Align first unit.	Must be aligned per APS.
13	Press Mode's Auto and PRS buttons	Machine starts wire bonding.
14	Press 'STOP' on FTCP and inspect first unit bonded.	Inspect wire bond per established criteria.
15	Release 'STOP' on FTCP to continue bonding.	Machine resumes wire bonding operation.
16	Redo steps 5 to 15 for next batch,	

Exhibit 1: A Work Standard for K&S 1419 Auto Wire Bonding Process

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P.M. Plan

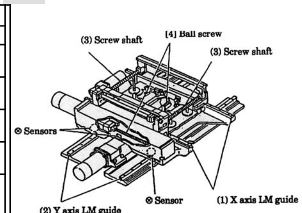
Definition:

The Preventive Maintenance Plan shows the scheduled maintenance of the equipment used in the manufacturing process. To avoid unscheduled downtimes in the equipment, preventive maintenance has to be done on a regular basis.

In the PM Plan, all the parts needing to be serviced or maintained are identified and verified for their proper operation. Traceability is maintained on all the serviced and replaced components. Test, verification, and acceptance procedures are performed prior to placing the equipment back into production.

Area	Component Insertion	**P.M. Plan SMT Chipshooter**	Date Performed:	10-1-92
Operation	SMT Insertion		Next Due Date:	11-1-92
Machine	Chipshooter		Performed By:	J. Carrey
Machine No.:	#2 - XY Table		Visual:	XY Table

No.	Inspection	Period	Action: Check	Action: Clean	Action: Align
0	Make sure XY table movement is smooth.	Daily			
	Make sure dust is not adhering to the screw shaft.	Weekly			
	Make sure dust is not adhering to the XY axis LM guides.	Weekly			
	Make sure dust does not build up in the guide rail slot.	Weekly			
	Make sure the width of the guide rail is 0.5 - 1mm wider than the PCB to be used.	Weekly			
	Make sure dust is removed from the upper surface of XY table.	Weekly			



Part No.	Oiling Point	Lubrication Method	Period	Oil Type	Oil Volume	Action: Check	Action: Clean	Action: Lubricate	Action: Replace	Action: Align
[1]	X axis LM guide	Wipe with cloth dampened with machine oil (Do not apply grease).	Daily	Machine Oil	Moderate Amount					
[2]	Y axis LM guide	Wipe with cloth dampened with machine oil (Do not apply grease).	Daily	Machine Oil	Moderate Amount					
[3]	Screw Shaft	Wipe with cloth dampened with machine oil (Do not apply grease).	Weekly	Machine Oil	Moderate Amount					
[4]	Ball Screw	Remove all dirt adhering to ball screw and apply grease.	Monthly	Grease	Moderate Amount					
[•]	Sensors	Make sure lubrication does not come in contact with sensors.	Daily	Nothing	None					

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Cumulative Count Chart

Definition:

In cases where process performance has improved to very high yields and the defective rate is extremely low, defects are usually reported at low parts-per-million, PPM.

In processes that run at low PPM levels, p-charts cannot effectively be applied because the plot pattern often becomes a straight line centered at zero defects with an occasional point departing from the zero line. Control charts with this kind of pattern yield no conclusions at all, thus preventing the determination of the state of statistical control of the process. A better alternative to p-charts, would be to plot the cumulative count of good units before a defective one is encountered. The cumulative count of number of inspected units before the first defective unit occurs is a variate which follows the Geometric or Pascal distribution.

Instead of monitoring the infrequent number of defective units found in a low PPM process, we monitor the cumulative number of good units. By analyzing the behavior of these runs of good units between defective, we can assess the state of statistical control of the process. The Cumulative Count control chart was first introduced by Thomas W. Calvin in 1983.

p = probability of defective unit

$p = 0.00005$

PPM = Parts-per-million Defective

$= p \times 1{,}000{,}000$

$= 0.00005 \times 1{,}000{,}000$

$= 50$

Cumulative Count Chart

In the Cumulative Count chart, we plot the cumulative number of good units between defective ones. If a sample randomly selected for inspection has no defective units, the count of good units is accumulated, and this cumulative count is plotted.

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Construction of a Cumulative Count Chart

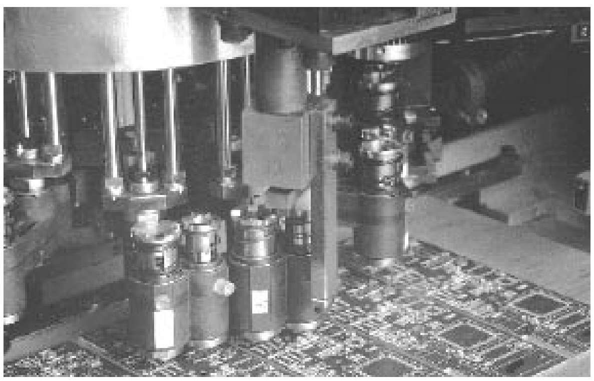
Step 1. Determine the average fraction defective or the PPM level of the process.

Estimate this value across a few weeks or months of production to obtain a good representative value of the process performance.

$$p = 0.00005 \qquad \text{or} \qquad PPM = 50$$

Surface Mount Technology High Speed Chipshooter

Surface Mount components are placed onto a PCB by a high-speed component placement machine called a chipshooter. The chipshooter places components (resistors, capacitors, etc.) at a rate of about 14,400 components per hour, cph, (or 4 components per second). The SM components are verified and accurately placed on the boards assisted by a vision system. The vision system measures the component offset in relationship to the center of the chipshooter's nozzle and it makes a positional correction prior to placing the component on the board. The positional correction prior to placement reduces significantly the number of defective placement to a low PPM level.



The chipshooter has an average performance of about 50 PPM defective level. This defective rate equates to an average fraction defective, p=0.00005 and a yield of 99.995%.

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Mario Perez-Wilson is the founder and CEO of Advanced Systems Consultants and author of nine books: Machine/Process Capability Study - A Five Stage Methodology for Characterizing Manufacturing Processes, Multi-Vari Chart and Analysis, Design of Experiments, The Total Control Methodology - A Preventive Approach for Total Control during Production, Six Sigma - Understanding the Concept, Implications and Challenges, Positrol Plans and Logs, ANOVA - Analysis of Variance for Simple and Complex Experiments, PCB Process Characterization - Applying M/PCpS to the PCB Industry and Gauge R&R Studies - For Destructive and Non-destructive Testing.

Mr. Perez-Wilson has over 23 years of industrial experience in engineering, quality and process improvement and has served at the executive level as Corporate Vice President of Quality for Flextronics International. He holds a B.S. degree in Industrial Engineering from the University of Arizona and Global Leadership from the Thunderbird School of Global Management. He was awarded the "Da N To Tsu" (Japanese for "Best of the Best") award from the Rochester Institute of Technology in the QED 90 Symposium.

One of the original architects of Six Sigma, he served as a Division Statistical Methods Engineering Manager at Motorola. During his tenure, he institutionalized and standardized the application of statistical methods in Motorola's worldwide manufacturing, production and engineering operations. His M/PCpS™ Methodology for characterizing processes has received global recognition and has become the standard in the achievement of Six Sigma.

Mr. Perez-Wilson has conducted seminars for over 18,000 individuals in Brazil, Belgium, People's Republic of China, Germany, Hong Kong, India, Japan, Korea, Malaysia, Mexico, Philippines, Singapore, Sweden, Taiwan, and the United States, and is currently listed in The International Who's Who in Quality.

Some of the companies that have implemented Mr. Perez-Wilson's methodologies are: ADFlex Solutions, AMD, Alphatec U.S.A., Allied Signal Aerospace, Anadigics, Arvin Industries, Arvin North America Automotive, Arvin Ride Controls, Astron, Bausch & Lomb, Burr-Brown, Carsem, Chartered Semiconductor, Connector Service Corp., Conexant, CRC Industries, Crystalline Materials, CTI Cryogenics, Duracell, EG&G, Federal Reserve Bank of New York, Fiberite IBI, Flextronics, General Electric, Guidant, Hewlett-Packard, Indy Electronics, Intel, Korea Electronic Company, Legris, Los Alamos National Laboratory, LSI Logic, Lucas/Nova Sensors, Maremont Exhaust Products, Martin Marietta Astronautics, Mitsubishi Silicon America, Motorola Inc., Multek, Olin Interconnect Technologies, Pacesetter, Peavey Electronics, Philips, Rodel, Ryobi, Sandia National Laboratories, Semi-Alloys, Shimano, Sikorsky Aircraft, Vitelic (Hong Kong), Wavetek and Zimmer.

Comments From Our Customers

"Mario has a real world knowledge of process control, The program is very successful due to the clear, well defined steps and associated forms."

Brad Trent
Program Engineer
Adflex Solutions, Inc.

"Enjoyed the TCM class enormously! This is a powerful knowledge which, when applied properly pays instant dividends."

Chris Lampiris
Sr. Process Engineer
Adflex Solutions, Inc.

"A complete system/methodology to bring up the yield. The book construction is very concise and the approach of teaching during the seminar and exercise is very clear."

Nono R. Reantazo, Jr.
Sr. Quality Engineer
Adflex Solutions, Inc.

"This seminar was outstanding at organizing the tools for improving Process Control. This is the kind of focus that is needed to bring industry to the quality level required and compete in today's marketplace."

John Snide
Manufacturing Engineer
CR Bard USC 1 Div.

"The Methodology and the book are a clear concise explanation of an SPC Program . Many materials are so complex that people feel it will be too difficult to implement. Anyone should be able to implement to this program."

Penny A. Klipfel
SPC Coordinator
LSI Logic Corporation

"Learning SPC through books is like trying to climb a tree with a rope - you can never be sure of reaching the top. But Mario Perez-Wilson's course was like using a ladder to climb it. At every ring we knew where we were and where we were proceeding to. So I would recommend people use this training to achieve a perfect knowledge in SPC."

Chandrakant Rane
Quality Engineer
Motorola (P)P Ltd.

"I've been through so many training sessions. This particular session opened my eyes to the true sense and practical approaches of statistical process control. I'm definitely looking forward to attending Mario's succeeding courses (experimentation and other topics)."

Gabriel A. Remulla
Quality Engineer
LSI Logic Corporation

"A very useful course study for process and test engineers to apply in a manufacturing environment for effective control of their machines and processes."

Arun Subramaniam A.
Task Leader
Motorola (P) Ltd.

"SPC made simple...Mario is just great!"

Patricia Kluka
Quality Control Manager
Columbia Research

"The most comprehensive process control class I have attended. Combines many of today single applications to the total process of quality control."

Corey Jones
Senior Project Engineer
Sikorsky Aircraft

"This course is a must for manufacturing professionals. Mario Perez-Wilson presents his material in an eloquent fashion, displaying his experience, knowledge, and expertise. This was the most concise and comprehensive course I've taken for Process Improvement Methodologies."

Ron Koronkowski
Quality Assurance Engineer
Ventritex, Inc.

This is the best course of actual hands-on use of SPC data for the real world. The instructor is excellent in both the area of presentation and knowledge. His ability to take a sophisticated science and make it applicable as well as comprehendible for the average person places him 'head and shoulders' above the others for real manufacturing use."

Kurt A. Hutchings
Business Unit Manager
Arvin Industries

"This book presents a very methodical and logical approach to not only processing control but also process capabilities. I feel like the points presented and the method will be very beneficial as our processes grow and become more complex"

Eric Farmer
Industrial Engineer
Rodel Inc.

"Use of SPC is the way to keep our leadership in high tech. marketplace and to have a methodology and/or system such as the one developed by Advanced Systems Consultants which has all the elements is a winner."

Siroos Mirzadeh
Section Manager, Assembly Engineering
LSI Logic Corporation

"...very complete program that was very professionally presented. It will be valuable to me because even though I have had SPC training, I don't use it on a day to day basis. This helps me refresh my memory."

Ed Dunivan
Quality Supervisor
Arvin NAA

"The text was easy to understand - examples were clear and to the point...not that much literature which would make reading the text tedious. Mario was excellent in explaining...was open in advising towards solving companies' problems and future discussions on the phone were accepted. Good Job!!!"

John W. Lazar
Process Engineer
Libbey Owens-Ford

"The course gives a straight forward, methodical approach for improving one's processes at a level which was easy to understand. The examples presented showed the power of these techniques when applied. The "hands-on" part of the course was extremely helpful in comprehending how these techniques are applied."

Scott Puller
Process Development Engineer
Bausch & Lomb

"I like your style of data arrangement, and also the Standard Worksheets. That is very useful for every engineer in any industry."

Supawut Maneewan
Quality Assurance Engineer
Adflex Thailand, LTD.

"....a very systematic approach to machine and/or process capability study, which guides the student all the way from the start of the problem to the end--forming positrol plans and control charts, to sustain manufacturing excellence. The book and course are strongly recommended to new engineers and old alike."

A. K. Mah
Senior Process Engineer
Motorola Penang

"I have been taking courses and practicing SPC in a manufacturing environment for 21 years. The realistic approach to implemenation and use, combined with step by step actions and forms will prove extremely beneficial."

John Bleyaert
Manager
Connector Service Corp.