TECH 7402 - 8 SEP 94

ADVANCED STATISTICAL QUALITY CONTROL

T, 5:30 - 8:35 P. ET 328

COURSE MAY DEVIATE SOMEWHAT FROM THE CATALOG DESCRIPTION,

ALL ASSIGNMENTS ARE TO BE COMPLETED ON ENGINEERING PAPER, READY TO SUBMIT AT BEGINNING OF CLASS

WILL BE RESPONSIBLE FOR ANY INFORMATION PRESENTED IN CLASS, REGARDLESS OF WHETHER OR NOT IT IS LISTED IN THE SYLLABUS.

TEXT: QUALITY PLANNING AND ANALYSIS, JURAN / GRYNA

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BASIC STATISTICAL METHODS AS THEY ARE APPLIED TO QUALITY CONTROL, AS WELL AS DIFFERENT PHILOSOPHIES OF QUALITY CONTROL.

QUALITY OF SERVICES AS WELL AS PRODUCTS –

W. EDWARDS DEMING –

"THE RIGHT QUALITY AND UNIFORMITY ARE FOUNDATIONS OF COMMERCE, PROSPERITY, AND PEACE."

DEFINITIONS OF QUALITY:

(JURAN) – FITNESS FOR USE, MEANING THAT IT DOES WHAT IT IS DESIGNED TO DO.

(CROSBY) – MEETS THE SPECIFICATIONS WHICH HAVE BEEN ESTABLISHED FOR IT.

(DEMING) – CUSTOMER SATISFACTION.

DR. GENICHI TAGUCHI – ENTIRELY DIFFERENT APPROACH –

TAGUCHI DEFINES QUALITY AS THE CONCEPT OF LOSS TO SOCIETY. LOSS IS MEASURED IN DOLLARS. NO LOSS WOULD MEAN THE ULTIMATE QUALITY. HE EMPHASIZES THE DESIGN STAGE AS THE START OF QUALITY.

<u>TAGUCHI METHODS</u>

DIMENSIONS OF QUALITY:

1. PERFORMANCE – HOW WELL DOES IT DO WHAT IT IS DESIGNED TO DO?
2. FEATURES – ACCESSORIES
3. RELIABILITY – DOES IT DO WHAT IT IS DESIGNED TO DO?
4. CONFORMANCE – TO REQUIREMENTS & SPECIFICATIONS
5. DURABILITY –
6. SERVICEABILITY – CAN IT BE SERVICED IF NECESSARY?
7. AESTHETICS – DOES IT LOOK GOOD/DESIRABLE
8. PERCEIVED QUALITY – THE CONSUMERS CONCEPTION OF A QUALITY PRODUCT.

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RESPONSIBILITY FOR QUALITY - WHO IS RESPONSIBLE? -
SHOULD BE EVERYONE IN THE ORGANIZATION -

1. MARKETING - THE LINK TO THE CONSUMER
2. PRODUCT ENGINEERING - DESIGN THE PRODUCT, SET SPECIFICATIONS, TOLERANCES.
   - AS SPECS GO UP, TOLERANCES DECREASE -
3. PURCHASING - MUST OBTAIN QUALITY RAW MATERIALS AND/OR PARTS ON A CONSISTENT BASIS IN ORDER TO ENCOURAGE QUALITY.
4. MANUFACTURING ENGINEER - ENGINEER THE PROCESSES AND PROCEDURES REQUIRED FOR MANUFACTURE/ASSEMBLY OF THE FINISHED PRODUCT.
5. MANUFACTURING - ACTUALLY ASSEMBLE/PRODUCE THE PRODUCT.
6. INSPECTION & TESTING - INSPECT FOR QUALITY
7. PACKAGING & SHIPPING - MAKE SURE THE PRODUCT GETS WHERE IT'S GOING IN GOOD, USABLE CONDITION.
8. PRODUCT SERVICE - PROVIDE RELIABLE SERVICE IN A TIMELY MANNER. - The best service is never to need service!!

QUALITY SERVICE: RELIABLE & DEPENDABLE, ACHIEVING WHAT THEY SET OUT TO DO. TIMELY, DONE RIGHT THE FIRST TIME. Far greater problems exist with service organizations than do with products and manufacturing concerns.

THE <u>OLD</u> QUALITY PHILOSOPHY:

- PRODUCTION MAKES IT
- Q.C. TESTS IT
- SOME PERCENTAGE WILL ALWAYS FAIL (UNDERSTOOD & ACCEPTED)
- "BURN THE TOAST & SCRAPE IT"
- "STATISTICAL QUALITY CONTROL" (SQC)

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THE NEW QUALITY PHILOSOPHY.

- PEOPLE WHO MAKE IT ALSO TEST IT
- ZERO DEFECTS
- CLOSE COOPERATION WITH CUSTOMERS
- NEW EMPHASIS ON PROCESS - DO IT RIGHT THE FIRST TIME.
- LESS EMPHASIS ON FINAL INSPECTION - IF IT'S DONE RIGHT IN THE FIRST PLACE, IT WON'T NEED IT.
- PROJECT-BY-PROJECT IMPROVEMENT
- REDUCTIONS IN MANUFACTURING COST
- STATISTICAL PROCESS CONTROL."

THE RESPONSIBILITY FOR QUALITY AND OWNERSHIP OF PROBLEMS -

- THE RESPONSIBILITY FOR QUALITY RESTS SOLELY WITH THAT LEVEL OF MANAGEMENT RESPONSIBLE FOR THOSE ACTIVITIES WHICH EITHER CREATE OR DEGRADE QUALITY.
- THERE ARE NO QUALITY CONTROL PROBLEMS - ONLY MARKETING, ENGINEERING, PURCHASING, MANUFACTURING, SALES, & SERVICE PROBLEMS AND THEY BELONG TO THE ACTIVITY WHICH CREATED THEM.
- QUALITY CANNOT BE ACHIEVED UNTIL THAT LEVEL OF MANAGEMENT RESPONSIBLE SETS EXPLICIT STANDARDS FOR QUALITY BEFORE THE WORK IS DONE.
- "THAT'S GOOD ENOUGH" MUST NOT BE A PART OF THE LANGUAGE FOR QUALITY.
- UNDERSTANDING OF AND DEDICATION TO THESE PRECEPTS IS REQUISITE TO CAUSING AND IMPROVING QUALITY.

READ INFORMATION ON PROCESS CAPABILITY & CONTROL

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QUALITY - WAYS OF LOOKING AT IT;

- QUALITY IS NOT THINGS; QUALITY IS PEOPLE - QUALITY IS THE PRODUCT OF PEOPLE.

IF QUALITY IS TO BE ACHIEVED AND MAINTAINED, THE PEOPLE IN THE ORGANIZATION MUST BE QUALITY MINDED. - IF THE PRESIDENT, CEO, ETC.. IS QUALITY MINDED, THE END RESULT WILL USUALLY BE A QUALITY PRODUCT.

THE ONE PERSON WHO MAKES A BIG DIFFERENCE IS THE FRONT LINE SUPERVISOR. - BECAUSE HE IS THE KEY INDIVIDUAL IN DAILY MANAGEMENT RELATIONS.

PAYING SOME ATTENTION TO THE WORKER OFTEN HAS A FAVORABLE EFFECT ON PRODUCTIVITY & QUALITY; IN THE HAWTHORNE STUDY, CHANGES IN THE LIGHTING LEVELS IN WORK AREAS INCREASED PRODUCTIVITY.

QUALITY CONTROL AT THE PLANT LEVEL -

- IS MANAGED COMPLIANCE TO ADEQUATE WORK INSTRUCTIONS DURING ANY PHASE OF WORK IN THE PRODUCT DEVELOPMENT CYCLE.
- IT INCLUDES INSPECTION AND MEASUREMENT OF PRODUCT SERVICE OR CONFORMANCE AT ANY STAGE OF THE DEVELOPMENT CYCLE TO DETERMINE THAT REQUIREMENTS ARE BEING MET.

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QUALITY ASSURANCE -
TAKES PLACE AT THE CORPORATE LEVEL:

CAN HELP TO IMPROVE THE WORKER'S ATTITUDE IN SEVERAL WAYS, SUCH AS THE COMMONLY-SEEN TAGS WHICH SAY 'INSPECTED BY' OR 'PACKED BY', ETC..., GIVING THE WORKER FIRST-HAND INVOLVEMENT IN THE PRODUCTION PROCESS.

- QUALITY IS NEVER AN ACCIDENT.
IT IS ALWAYS THE PRODUCT OF INTELLIGENT EFFORT.
THERE MUST BE THE WILL TO PRODUCE A SUPERIOR THING.

A VIEW OF QUALITY CHARACTERISTICS - VARIABLES & ATTRIBUTES -

VARIABLES - INCLUDE ANYTHING WHICH CAN BE MEASURED, SUCH AS WEIGHT, LENGTH, TIME, TEMPERATURE, COMPRESSION, ETC... - VARIABLES CAN BE DEALT WITH IN TERMS OF NUMBERS.

ATTRIBUTES ARE THOSE QUALITY CHARACTERISTICS WHICH ARE CLASSIFIED AS EITHER CONFORMING OR NOT CONFORMING TO STANDARDS SUCH AS A 'GO/NO GO' GAGE, OR MCDONALD'S SPECIFICATION FOR MAXIMUM FRENCH FRY AGE AS 10 MINUTES. - ANYTHING WHICH WOULD BE A PASS/FAIL SITUATION.

DIFFERENT APPROACHES ARE USED TO EVALUATE DIFFERENT CHARACTERISTICS.

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THE PROCESS CONCEPT -

A METHOD OF DOING SOMETHING; GENERALLY MAY INVOLVE A NUMBER OF STEPS OR OPERATIONS. A PROCESS IS A MAJOR COMPONENT OF THE MANAGEMENT MEASUREMENT SYSTEM. IT IS ANY PHYSICAL FUNCTION WHICH OCCURS OVER TIME AND MUST BE CONTROLLED AND UNDERSTOOD.

MAN-MADE PROCESSES CAN BE GROUPED INTO 4 CATEGORIES -

1. INDIVIDUAL: CONTROLLED BY THE OPERATOR, SUCH AS RUNNING A GENERAL PURPOSE LATHE OR OTHER SHOP MACHINE.
2. FUNCTION CONTROLLED: THE OPERATOR PARTICIPATES BUT DOES NOT TOTALLY CONTROL THE RESULT.
3. AUTOMATIC PROCESSES: THE OPERATOR IS ESSENTIALLY NOTHING MORE THAN A CARETAKER.
4. AUTOMATED - SELF MONITORING, SELF ADJUSTING - ADAPTIVE CONTROL.

THE NATURE OF THE VARIATION WILL BE DIFFERENT FOR THE DIFFERENT TYPES OF PROCESSES.

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MONITORING THE PRODUCT

SCRAP ← DEFECTIVE → REWORK

RAW MATERIAL → PROCESS → COMPLETED PART → GOOD

COMPLETED PART → DEFECTIVE

INSPECT → COMPLETED PART

TRADITIONAL METHOD OF MONITORING THE FINISHED PRODUCT,

MONITORING THE PROCESS

RAW MATERIAL → PROCESS → COMPLETED PART

PROCESS CONTROL → PROCESS

IF SOMETHING IS NOT QUITE RIGHT, TAKE CORRECTIVE ACTION IN THE PROCESSING STAGE.

A PROCESS IS SAID TO BE IN STATISTICAL CONTROL WHEN THE ONLY SOURCE OF VARIATION IS COMMON CAUSES.

"A STATE OF STATISTICAL CONTROL IS NOT A NATURAL STATE FOR A MANUFACTURING PROCESS. IT IS INSTEAD AN ACHIEVEMENT, ARRIVED AT BY ELIMINATING ONE BY ONE, BY DETERMINED EFFORT, THE SPECIAL CAUSES OF EXCESSIVE VARIATION."

— W.E. DEMING

NORMAL DISTRIBUTION

99.73% OF DIST. FALLS BETWEEN $\pm 3\sigma$
95.46% " " " " $\pm 2\sigma$
68.26% " " " " $\pm 1\sigma$

PROCESS CAPABILITY

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THE PROCESS MUST BE BROUGHT TO ITS CONSISTENTLY NORMAL STATE.

PROCESS CAPABILITY IS DETERMINED BY THE TOTAL VARIATION THAT COMES FROM COMMON (OR NATURAL) CAUSES, OR THE MINIMUM VARIATION REMAINING AFTER ALL SPECIAL (OR ASSIGNABLE) CAUSES HAVE BEEN ELIMINATED.

PROCESS CONTROL - STATES THAT ALL PROCESSES ARE MADE UP OF AT LEAST 4 VARIABLE INPUTS:

OPERATOR, MACHINE, METHOD, MATERIAL

OR, ACCORDING TO MAGOWAN;

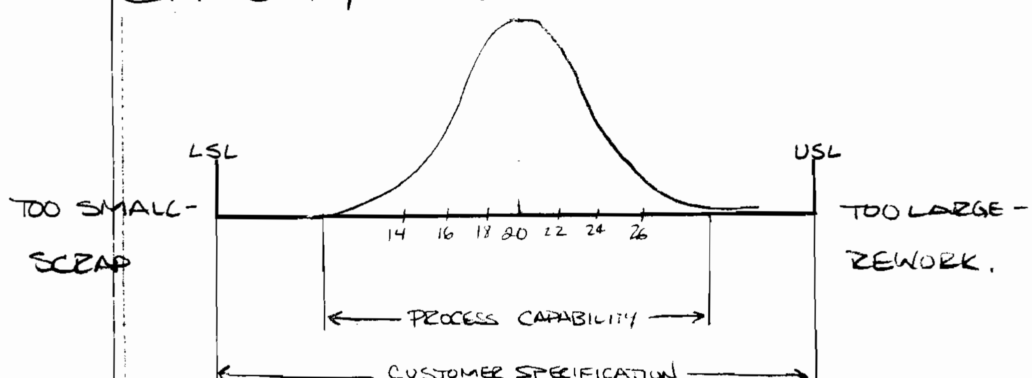
OPERATOR, MACHINE, METHOD, MATERIAL, MISCELLANEOUS.

THE INHERENT VARIATION CAPABILITY OF EACH INPUT MUST BE KNOWN AND OPTIMIZED -

- ELEMENTS OF ANY ATTEMPT TO PERFORM PROCESS CONTROL:

- QUALIFIED OPERATORS - THE HUMAN ATTRIBUTE
- MACHINE CAPABILITY - THE RIGHT TYPE OF MACHINE
- MATERIALS - CONSISTENT, OF GOOD QUALITY.

CAPABILITY INDEX - IF THE PROCESS IS WELL WITHIN USL&LSL.



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ESTABLISHING $\bar{X}$ AND R CHARTS -

A SMALL SAMPLE (e.g. 5 UNITS) IS TAKEN PERIODICALLY FROM THE PROCESS, AND THE AVERAGE ($\bar{X}$) AND RANGE (R) ARE CALCULATED FOR EACH SAMPLE. A TOTAL OF AT LEAST 50 INDIVIDUAL MEASUREMENTS (10 SAMPLES OF 5 EACH) SHOULD BE COLLECTED BEFORE THE CONTROL LIMITS ARE CALCULATED. THE CONTROL LIMITS ARE SET AT $\pm 3\sigma$ FOR SAMPLE AVERAGES AND SAMPLE RANGES. THE $\bar{X}$ AND R VALUES ARE PLOTTED ON SEPARATE CHARTS AGAINST THEIR $\pm 3\sigma$ LIMITS.

CONTROL LIMITS FOR A CHART FOR AVERAGES REPRESENT 3 STANDARD DEVIATIONS OF SAMPLE AVERAGES (NOT INDIVIDUAL VALUES). AS TOLERANCE LIMITS USUALLY APPLY TO INDIVIDUAL VALUES, THE CONTROL LIMITS CANNOT BE COMPARED TO TOLERANCE LIMITS, BECAUSE AVERAGES INHERENTLY VARY LESS THAN THE INDIVIDUAL MEASUREMENTS GOING INTO THE AVERAGES. THEREFORE, TOLERANCE LIMITS SHOULD NOT BE PLACED ON A CHART FOR AVERAGES. THE ONLY VALID COMPARISON THAT CAN BE MADE IS TO CONVERT $\bar{R}$ TO THE STANDARD DEVIATION, CALCULATE THE NATURAL TOLERANCE LIMITS, AND COMPARE TO PRODUCT TOLERANCES.

p296 - GETTING A PROCESS BACK ON TRACK & WHAT TO LOOK FOR. -

Look AT:

PROBLEMS ARISING FROM THE RELATIONSHIP OF MACHINE CAPABILITY TO PRODUCT TOLERANCE.

CHAPTER 13 - MANUFACTURE / PROCESS CONTROL CONCEPTS.

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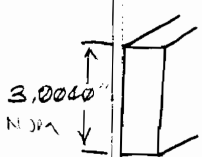
CHAPTER 3 - PROBABILITY DISTRIBUTIONS

THE NORMAL DISTRIBUTION - WHERE 99.73% OF THE DATA POINTS FALL WITHIN $\pm 3\sigma$, 95.46% WITHIN $\pm 2\sigma$, AND 68.26% WITHIN $\pm 1\sigma$. IT IS SYMMETRICAL ABOUT THE MEAN, AND IS CONTINUOUS FROM $-\infty$ TO $+\infty$ - ASYMPTOTIC.

EXAMPLE OF THINGS WHICH FOLLOW A NORMAL DISTRIBUTION INCLUDE STUDENT GRADES AND MANUFACTURED PARTS.

VARIATION IS A FACT OF NATURE AND A FACT OF INDUSTRIAL LIFE.

EXAMPLE:



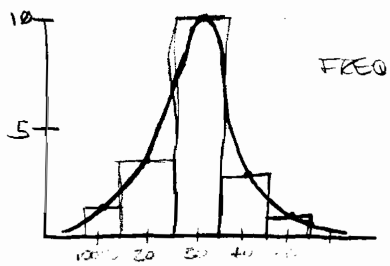
3.0022

3.0063

3.0023

3.0034

3.0051, ETC.



FREQUENCY HISTOGRAM

MEASUREMENT (X)	TALLY	f	fX	fX²
−3.0065				
3.0060 − 3.0055	II	2	6.0120	18.0720
3.0050 − 3.0045	IIII	4	12.0200	36.1201
3.0040 − 3.0035	~~IIII~~ ~~IIII~~	10	30.0400	90.2402
3.0020 − 3.0025	III	3	9.0900	27.054
3.0010 − 3.0015	I	1	3.0020	9.0120
− 3.0005				
		20	60.0830	180.4933

$$\frac{60.0830}{20} = 3.00416 = 3.0042$$

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THE MEAN AND STANDARD DEVIATION CAN WELL DESCRIBE THE NORMAL DISTRIBUTION.

$$\text{MEAN} = \overline{X} = \frac{\Sigma f x}{N}$$

$$\text{STANDARD DEV.} = s = \sqrt{\frac{\Sigma (x-\bar{x})^2}{n-1}}$$

(σ)

{FOR USE WITH RAW DATA, THE n-1 IS USED FOR SMALL (<30) SAMPLES.}

$$\sigma = s = \sqrt{\frac{n(\Sigma f x^2) - (\Sigma f x)^2}{n(n-1)}}$$

{FOR USE WITH GROUPED DATA}

THE VARIANCE, σ^2, IS EQUAL TO THE SQUARE OF THE STANDARD DEVIATION.

FOR A ROUGH ESTIMATE OF σ (or S)

$s = 1/5$ TO $1/6$ of THE RANGE

CALCULATING SOME VALUES MAY YIELD NEGATIVE NUMBER. THE INFORMATION MUST BE CODED IN SOME WAY IN ORDER TO ALLEVIATE THIS PROBLEM. AS IN THE PREVIOUS EXAMPLE,

1. SUBTRACT 3 FROM EACH VALUE
2. MULTIPLY BY 1000 TO GET WHOLE NUMBERS. NOW THE VALUES WOULD BE 6, 5, 4, 3, 2.

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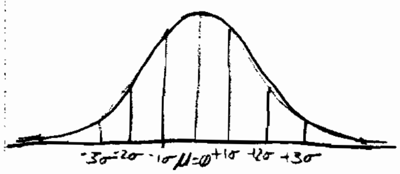
FOR THE NORMAL CURVE, $\mu = 0$ AND $\sigma = 1$ (μ REFERS TO THE UNIVERSE)



THE SIX DIVISION OF THE NORMAL CURVE (-3σ TO $+3\sigma$) IS WHY $\frac{1}{6}R$ OR $\frac{1}{6}R$ YIELDS A ROUGH ESTIMATE OF σ.

OF THE TOTAL DISTRIBUTION;

68.26% FALLS BETWEEN $\mu - 1\sigma$ AND $\mu + 1\sigma$

95.46% FALLS BETWEEN $\mu - 2\sigma$ AND $\mu + 2\sigma$

99.73% FALLS BETWEEN $\mu - 3\sigma$ AND $\mu + 3\sigma$

.135% ABOVE $\mu + 3\sigma$ AND BELOW $\mu - 3\sigma$

DENSITY FUNCTION

ACTUALLY REPRESENTS THE AREA UNDER THE CURVE. IT IS ACCEPTED AS 'THE WAY IT IS', BASED ON THE CURVE ITSELF.

p41 - NORMAL PROBABILITY DISTRIBUTION

$$\frac{100 - 68.26}{2} = 15.87\% \rightarrow \text{THE AREA} < 1\sigma$$

Z SCORES

IF A POINT FALLS AT, PERHAPS, -2.5σ, MUST USE THE TABLES TO OBTAIN THE PERCENTAGE.

$$Z = \frac{x - \mu}{\sigma}$$

$\mu = \bar{x}$ (USING μ IS AN INTRODUCTION OF ERROR

$\sigma = s$ BUT OFTEN CANNOT BE AVOIDED)

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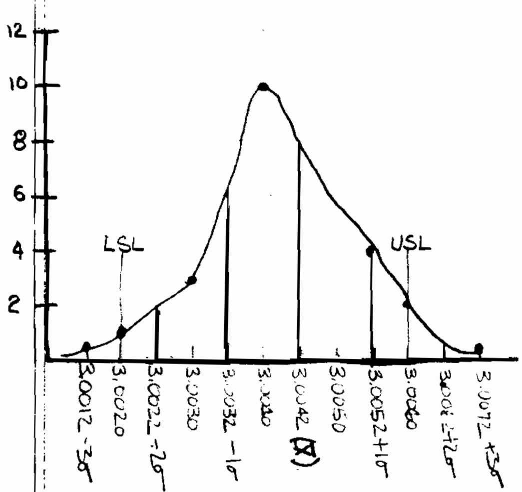
FROM THE PREVIOUS EXAMPLE:

$\bar{X} = 3.0042$ (SAMPLE MEAN)

$S = 0.0010$ (SAMPLE STANDARD DEVIATION)



68.26% BETWEEN 3.0032 AND 3.0052

95.46% BETWEEN 3.0022 AND 3.0062

99.73% BETWEEN 3.0012 AND 3.0072

A LARGER SAMPLE SIZE WOULD MORE ACCURATELY DESCRIBE THE SITUATION.

ASSUME THAT THIS DISTRIBUTION AND THE IDEAL NORMAL CURVE ($\bar{X}=0$ AND $\sigma=1$) ARE ESSENTIALLY ALIKE.

DETERMINING THE PERCENTAGE OF AREA UNDER THE CURVE USING Z SCORES.

$$Z = \frac{X-\mu}{\sigma} \qquad \mu = \bar{X} = 3.0042$$

$$\sigma = S = 0.0010$$

$$Z = \frac{3.0030-3.0042}{0.0010} = \frac{-.0012}{.0010} = -1.2$$ (# of σ ON NORMAL DISTRIBUTION)

TABLE VALUE FOR Z -1.2σ ON THE NORMAL DISTRIBUTION IS .1151 or 11.51%

TOLERANCE = ± .0020

UPPER SPEC LIMIT = 3.0060

LOWER SPEC LIMIT = 3.0020

$$\% \text{ BELOW LSL} = \frac{3.0020-3.0042}{.0010} = -2.2$$

TABLE VALUE for -2.2σ = .0139 or 1.39%

$$\% \text{ ABOVE USL} = \frac{3.0060-3.0042}{.0010} = 1.8$$

TABLE VALUE FOR 1.8σ = .9641

$1.00 - .9641 = .0359$ or 3.59% ABOVE USL

TOTAL OF 4.98% WILL FALL OUTSIDE LIMITS.

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WHAT CAN BE DONE;

FOR THE PREVIOUS EXAMPLE, WHAT WOULD HAPPEN IF THE CURVE WERE MOVED. THOSE BELOW LSL ARE SCRAP, THOSE ABOVE USL ARE REWORK.

1. CAN EVALUATE TOLERANCES AND POSSIBLY ADJUST THEM, BUT THIS IS LEAST LIKELY. "TOLERANCE STACKS" - ONE CHANGE AFFECTS ANOTHER TOLERANCE, AND SO FORTH ON DOWN THE LINE.
2. LIVE WITH THE SITUATION - "SUFFER AND SORT"
3. MAKE IT MORE PRECISE BY DECREASING THE VARIATION. TOUGH TO ACCOMPLISH, BECAUSE WHAT ACTUALLY EXISTS IS USUALLY THE NATURAL VARIATION OF THE MACHINE, PROCESS, MATERIALS, ETC...
4. MOVE THE MEAN (OR AIM) OF THE PROCESS. THE DIRECTION TO MOVE THE MEAN DEPENDS ON WHETHER SCRAP OR REWORK IS DESIRED.

REMEMBER! THE TOTAL OF SCRAP & REWORK <u>WILL</u> <u>NOT</u> BE THE SAME AFTER MOVING THE MEAN - THE NORMAL CURVE IS NOT A LINEAR FUNCTION.

IN SOME CASES IT MAY BE DESIRABLE TO DECIDE UPON AN ACCEPTABLE PERCENTAGE FOR SCRAP OR REWORK, AND THAT INFORMATIONS ALLOWS FOR DETERMINATION OF THE PROCESS CENTER.

eg - ALLOW ONLY 5% SCRAP -

① WHERE SHOULD THE PROCESS CENTER BE LOCATED?

② IF THE PROCESS CENTER IS RELOCATED, HOW MUCH REWORK WOULD RESULT?

NEW PROCESS CENTER

$$Z = \frac{x-\mu}{\sigma} = Z_{.005} = -2.575\sigma$$

$$-2.575 = \frac{3.002-\mu}{.0010''}$$

$$-.002575 = 3.002-\mu$$

$$\underline{3.0046 = \mu = \text{NEW MEAN}}$$

INCREASES REWORK -

NEW REWORK

$$Z = \frac{x-\mu}{\sigma} = \frac{\overset{(USL)}{3.0060} - 3.0046}{.0010} =$$

$$\frac{.0014}{.001} = 1.4$$

TABLE VALUE = .9192

$1.00 - .9192 = .0808$ or $\underline{\underline{8.08\%}}$

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MANY THINGS CAN HAPPEN TO THE PROCESS DISTRIBUTION, SUCH AS TOO MUCH VARIATION WITHIN THE PROCESS ITSELF. WHEN DEALING WITH INDIVIDUAL VALUES - GROUPS DISTRIBUTE DIFFERENTLY; TOO WIDE A DISTRIBUTION - TOO MUCH VARIATION - IS COMMON.

- PROCESS OFF TARGET AND NON-NORMAL SCREWS UP THE Z SCORES; RE-CENTER THE PROCESS TO GET IT BACK ON TARGET,

PROCESS CAPABILITY INDEX;

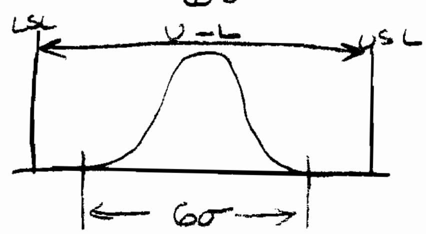
COMPARISON OF ACTUAL TO SPECIFIED VALUES-

THE RELATIONSHIP BETWEEN THE NATURAL SPREAD AND THE CUSTOMER SPECIFICATION CAN BE EXPRESSED IN THE FORM OF AN INDEX NUMBER CALLED THE PROCESS CAPABILITY INDEX - DENOTED BY C_P - THE PROCESS CAPABILITY INDEX DOES NOT TAKE THE PROCESS CENTER INTO ACCOUNT -

$$C_P = \frac{\text{SPECIFICATION WIDTH}}{\text{PROCESS WIDTH}} = \frac{USL - LSL}{6\sigma}$$

VALUE >1 DESIRABLE

VALUE <1 UNDESIRABLE



A VALUE GREATER THAN 1 IS DESIRABLE BECAUSE SOME MOVEMENT IS ALLOWABLE, AND THE PROCESS WILL ALMOST ALWAYS PRODUCE A QUALITY PRODUCT,

IF THE VALUE IS LESS THAN 1, SOME PRODUCTION WILL ALWAYS BE OUTSIDE OF SPECS.

A VALUE EQUAL TO 1 IS NOT DESIRABLE, BECAUSE NO VARIATION CAN BE TOLERATED.

(TAGUCHI) THE LARGER THE NUMBER, THE BETTER - INDICATES A NARROWER DISPERSION.

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PROCESS CAPABILITY - 6σ VARIATION - IS USED IN RELATION TO THE SPREAD OF THE UPPER AND LOWER SPECIFICATIONS.

THE CAPABILITY RATIO IS THE INVERSE OF THE PROCESS CAPABILITY INDEX. HERE, A VALUE LESS THAN 1 IS DESIRABLE, AND A VALUE GREATER THAN 1 IS UNDESIRABLE.

$$\text{CAPABILITY RATIO} = \frac{6\sigma \text{ VARIATION}}{\text{TOTAL TOLERANCE}}$$

BILATERAL AND UNILATERAL TOLERANCES;

	BILATERAL TOL.	UNILATERAL TOL.
EXISTING PROCESS	75%	88%
NEW PROCESS	67%	83% ⇐ NEW PROCESS IS WIDER BECAUSE OF PROBLEMS INCURRED WITH NEW PROCESSES.

CAPABILITY INDEX

$C_p > 1$ - TOTALLY ACCEPTABLE STATE OF CONTROL. MINIMUM ATTENTION OF QUALITY CONTROL DEPT. IS REQUIRED; OPERATOR WATCHES FOR SHIFTS OR SPREADING.

$C_p < 1$ - UNSATISFACTORY STATE OF CONTROL - POSSIBLE ACTIONS;

1. RELAX TOLERANCES
2. CONSIDER THE YIELD. IF O.K., SORT AS A PART OF THE PROCESS WITH QUALITY AUDIT, NO "ACCEPT AS-IS".
3. INVEST TIME, MONEY, AND RESOURCES TO IMPROVE PROCESS CAPABILITY.

$C_p = 1$ - MARGINALLY ACCEPTABLE STATE OF CONTROL. IMPLEMENT SQC AS A PART OF THE PROCESS. USE $\bar{X}$ AND R CHARTS, PRE-CONTROL, OPERATOR PLOTTED HISTOGRAMS, ETC...
LINE SUPERVISOR MANAGES PROCESS CAPABILITY.

p45 - DISTRIBUTION PATTERNS RELATED TO TOLERANCES. - SECT 3-8, pp 44-46

⇒ A LOT OF VALUABLE INFORMATION CAN BE DETERMINED FROM SIMPLE HISTOGRAMS.

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CONTROL CHARTS:

CONTROL CHARTS ARE A METHOD OF MONITORING (AND DOCUMENTING) PROCESS PERFORMANCE. THEY ARE BASED ON THE FACTS THAT:

* OBSERVATIONS VARY
* VARIATIONS CAN BE MEASURED
* WE CAN DISTINGUISH BETWEEN APPARENT EFFECTS WHICH CAN BE FULLY ACCOUNTED FOR BY BACKGROUND NOISE, AND OTHERS WHICH CANNOT.

PURPOSE: TO ACHIEVE CONSISTENT PRODUCTS

THE FUNDAMENTAL ELEMENTS OF CONTROL CHARTS CONSIST OF:

* TIME-ORDERED PLOTS OF DATA
* LIMITS BASED ON INHERENT PROCESS VARIABILITY (6σ)
* ACTIONS TO TAKE BASED ON PROCESS PERFORMANCE:
  - POINTS OUTSIDE OF LIMITS
  - LONG RUNS ABOVE OR BELOW THE MEDIAN
  - LONG RUNS UP OR DOWN
  - TOO MANY OR TOO FEW RUNS

TIME-ORDERED PLOTS ARE NORMALLY CONNECTED BY LINE SEGMENTS.
LIMITS ARE ESTABLISHED WHILE COLLECTING TRIAL DATA.

PROCESSES IN CONTROL - 29 SEP 87

- A PROCESS IS SAID TO BE "IN CONTROL" IF ITS PERFORMANCE IS NOT AFFECTED BY SPECIAL CAUSES. IF THE VARIATIONS WHICH TAKE PLACE ARE DUE ONLY TO THE INHERENT SOURCES OF VARIATION, THE PROCESS IS IN CONTROL.
- IF SPECIAL SOURCES OF VARIATION ARE PRESENT, THE PROCESS IS SAID TO BE OUT OF CONTROL (ASSIGNABLE CAUSE).
- FOR A PROCESS TO BE IN CONTROL, AS A CONTROL CHART IS EXAMINED, ALL THE PLOTTINGS MUST FALL WITHIN CONTROL LIMITS AND THEY <u>MUST BE RANDOMLY DISPERSED ABOUT THE CENTER LINES</u>.
- A SPECIAL CAUSE <u>DOES</u> <u>NOT</u> <u>ALWAYS</u> INDICATE A DEFECTIVE PRODUCT (SHIFTS AND TRENDS).
- A COMMON CAUSE SYSTEM DOES NOT ALWAYS INDICATE A CONFORMING PRODUCT (CHART OF INDIVIDUALS).
- SPECIAL CAUSES ARE <u>SOMETIMES</u> <u>BENEFICIAL</u> EVENTS - THE REASON THAT INVESTIGATION IS REQUIRED ANY TIME THEY ARE INDICATED.
- NEVER CONFUSE AN "IN CONTROL" PROCESS WITH A "CONFORMING" PROCESS.

⇒ PRE-CONTROL OR NARROW LIMIT GAGING (p 341)

SPC - STATISTICAL PROCESS CONTROL - MANY MANUFACTURERS ARE FORCED BY THEIR CUSTOMERS TO USE SPC.

PRE-CONTROL STARTS A PROCESS CENTERED BETWEEN SPECIFICATION LIMITS AND DETECTS SHIFTS THAT MIGHT RESULT IN MAKING SOME OF THE PARTS OUTSIDE A PRINT LIMIT.

NO PLOTTING IS REQUIRED, AND ONLY A MINIMUM OF 3 PIECES ARE NEEDED FOR CONTROL.

PUT CONTROL IN THE HANDS OF THE OPERATOR (WHERE IT SHOULD BE) AND ELIMINATED 'ROVING INSPECTORS' AND HELPED INDIVIDUALS TO TAKE MORE PRIDE IN THEIR WORK.

PRE-CONTROL (CONT'D) 29 SEP 87

SEVERAL ASSUMPTIONS MUST BE MADE WHEN USING PRE-CONTROL;

1. ASSUME THAT THE PROCESS IS PRODUCING TO A NORMAL DISTRIBUTION.
2. ASSUME THE WORST CONDITION THAT CAN BE ACCEPTED FROM A PROCESS CAPABLE OF QUALITY PRODUCTION.
3. ASSUME THAT THE PROCESS CAN BE CENTERED - (IT MUST BE TO BEGIN WITH).

(p342-343) A SET OF 11 RULES EXISTS - APPLIES WHEN 1 TO 3 PERCENT DEFECTIVE IS PERMISSIBLE AND THE 6σ PROCESS SPREAD IS A MAXIMUM OF 88% OF THE TOLERANCE RANGE.

1. DIVIDE THE SPECIFICATION TOLERANCE BAND WITH PC LINES AT 1/4 AND 3/4 OF THE TOLERANCE
2. START JOB
3. IF PIECE IS OUTSIDE SPECIFICATION LIMITS, RESET. (TO NOMINAL DIMENSIONS)
4. IF ONE PIECE IS INSIDE SPEC. LIMIT BUT OUTSIDE A PC LINE, CHECK NEXT PIECE.
5. IF SECOND PIECE IS ALSO OUTSIDE SAME PC LINE, RESET.
6. IF SECOND PIECE IS INSIDE PC LINE, CONTINUE PROCESS AND RESET ONLY WHEN TWO PIECES IN A ROW ARE OUTSIDE A GIVEN PC LINE.
7. IF TWO SUCCESSIVE PIECES SHOW ONE TO BE OUTSIDE THE HIGH PC LINE AND ONE BELOW THE LOW PC LINE, ACTION MUST BE TAKEN IMMEDIATELY TO REDUCE VARIATION.
8. WHEN 5 SUCCESSIVE PIECES FALL BETWEEN THE PC LINES, FREQUENCY GAGING MAY START. WHILE WAITING FOR FIVE, IF ONE PIECE GOES OVER A PC LINE, START COUNT OVER AGAIN.
9. WHEN FREQUENCY GAGING, LET PROCESS ALONE UNTIL A PIECE EXCEEDS A PC LINE. CHECK THE VERY NEXT PIECE AND PROCEED AS IN 6 ABOVE.
10. WHEN MACHINE IS RESET, FIVE SUCCESSIVE PIECES INSIDE THE PC LINES MUST AGAIN BE MADE BEFORE RETURNING TO FREQUENCY GAGING.
11. IF THE OPERATOR CHECKS MORE THAN 25 TIMES WITHOUT HAVING TO RESET, THE GAGING FREQUENCY MAY BE REDUCED SO THAT MORE PIECES ARE MADE BETWEEN CHECKS. IF, ON THE OTHER HAND, THE OPERATOR MUST RESET BEFORE 25 CHECKS ARE MADE, INCREASE THE GAGING FREQUENCY. AN AVERAGE OF 25 CHECKS TO A RESET IS INDICATION THAT THE GAGING FREQUENCY IS CORRECT.

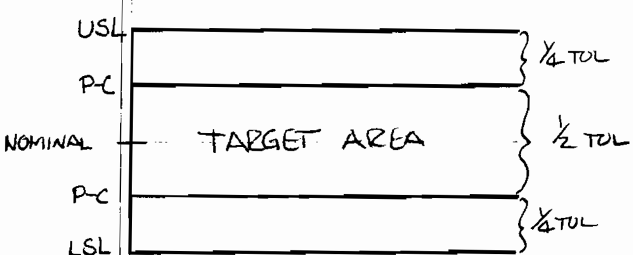
29 SEP 87

TARGET AREA RULES (BROWN):

1. SETUP - JOB IS OK TO RUN WHEN 5 PIECES IN A ROW ARE INSIDE THE TARGET.
2. RUNNING - SAMPLE TWO PIECES -
   - IF 1ST PIECE IS WITHIN TARGET, RUN.
   - IF 1ST PIECE IS NOT WITHIN TARGET, CHECK THE SECOND PIECE.
   - IF BOTH PIECES ARE OUT, GO BACK TO SETUP RULE 1.

PRE-CONTROL IS A HELPFUL TECHNIQUE IN THAT ONLY SINGLE PARTS ARE CHECKED IN EACH CHECK, INSTEAD OF SAMPLE GROUPS.

THE PROBABILITY OF HAVING 2 SUCCESSIVE OUTSIDE TARGET AREA IS ONLY Ø.49%, UNLESS SPECIAL CAUSES ENTER THE PICTURE.



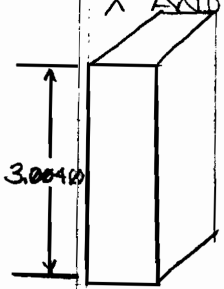
THE MORE THE DISTRIBUTION SPREADS OUT, THE LESS VALUE THE CHART IS. A LARGER SPREAD CAUSES A GREATER POSSIBILITY OF POINTS BEING OUT.

TYPE 2 ERROR - WHEN YOU THINK YOU HAVE A PROBLEM, BUT ACTUALLY YOU DO NOT.

IN PROCESS CONTROL CHARTS PROVIDE IMMEDIATE OPERATOR FEEDBACK AND OPERATOR ACCOUNTABILITY.

$\overline{X}$ AND R CHARTS – CONTROL CHARTS FOR VARIABLES

06 OCT 87



CONSIDER THE PART AT LEFT HAVING A NOMINAL DIMENSION OF 3.0040 INCHES, SIX HYPOTHETICAL SAMPLES OF 5 PIECES EACH.

SAMPLE #	1	2	3	4	5	6
	3.0041	3.0038	3.0045	3.0050	3.0040	3.0035
	3.0048	3.0037	3.0044	3.0047	3.0039	3.0040
	3.0044	3.0038	3.0043	3.0046	3.0040	3.0045
	3.0040	3.0036	3.0042	3.0045	3.0041	3.0035
	3.0047	3.0036	3.0046	3.0042	3.0045	3.0035
ΣX	15.0220	15.0185	15.0625	15.0230	15.0205	15.0190
$\overline{X}$	3.0044	3.0037	3.0044	3.0046	3.0041	3.0038
R	0.0008	0.0002	0.0004	0.0008	0.0006	0.0010

IN A REAL SITUATION UP TO APPROXIMATELY 25 SAMPLE GROUPS WOULD BE USED.

$\overline{\overline{X}} = \frac{\Sigma \overline{X}}{g}$ = GRAND MEAN, WHERE $\overline{X}$ IS THE MEAN FOR EACH SAMPLE GROUP, g IS THE NUMBER OF SAMPLE GROUPS.

$\frac{18.0250}{6} = 3.00416$

$\overline{R} = \frac{\Sigma R}{g} = .00063$

GENERALLY, A PRE-PRINTED FORM WILL BE USED FOR $\overline{X}$ AND R CHARTING.

TRIAL CONTROL LIMITS ARE THEN CALCULATED

(NEXT PAGE)

$\overline{X}$ AND $\overline{R}$ CHART – CONTROL CHARTS FOR VARIABLES (CONT) Ø6 OCT 87

TRIAL CONTROL LIMITS:

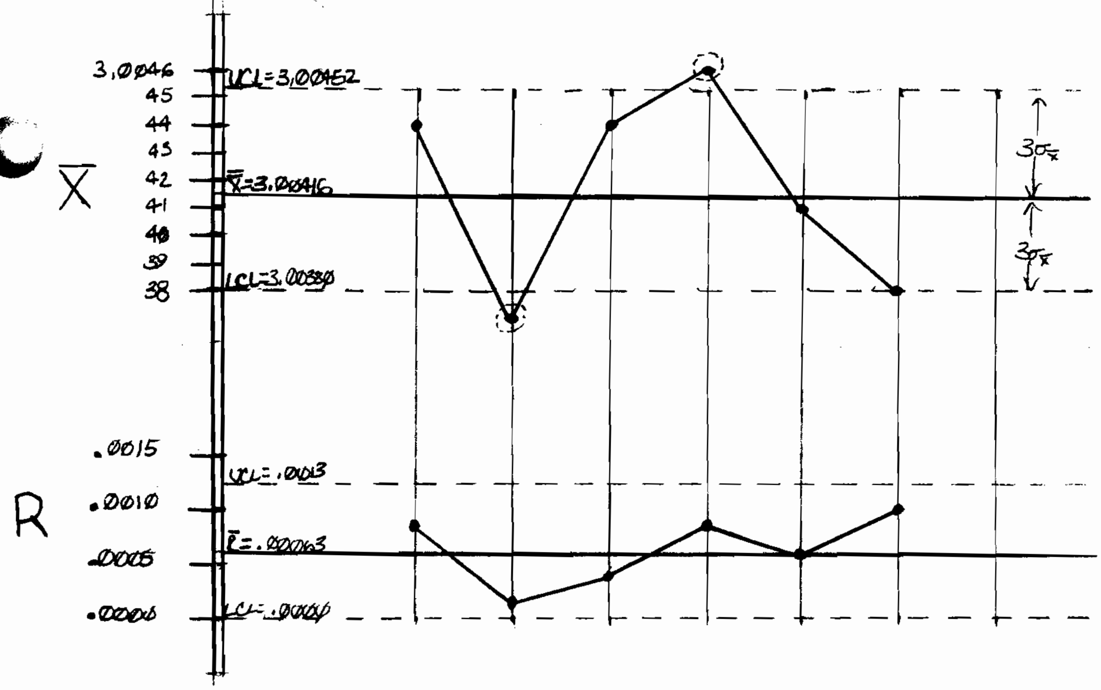
$$UCL_{\overline{x}} = \overline{\overline{X}} + A_2\overline{R} = 3.\emptyset\emptyset416 + .577(.\emptyset\emptyset\emptyset63) = 3.\emptyset\emptyset452$$

TRIAL CONTROL LIMITS

$$LCL_{\overline{x}} = \overline{\overline{X}} - A_2\overline{R} = 3.\emptyset\emptyset416 - .577(.\emptyset\emptyset\emptyset63) = 3.\emptyset\emptyset38\emptyset$$

$$UCL_{\overline{R}} = D_4\overline{R} = (2.14)(\emptyset.\emptyset\emptyset\emptyset63) = \emptyset.\emptyset\emptyset13$$

$$LCL_{\overline{R}} = D_3\overline{R} = (\emptyset)(\emptyset.\emptyset\emptyset\emptyset63) = \emptyset$$



THE PROBABILITY OF POINTS BEING OUT DUE TO CHANCE CAUSE IS APPROX. 0.27%

ELIMINATE THE 'OUT' POINTS AND CONSTRUCT NEW LIMITS.
LEAVE IN THE $\overline{R}$ VALUES, SINCE THEY ARE 'IN'.

TO KNOW WHEN THE SYSTEM IS FUNCTIONING UNDER A CHANCE-CAUSE EFFECT INSTEAD OF ASSIGNABLE CAUSE.

AS DATA IS COLLECTED AND LIMITS REVISED, THEY WILL APPROACH A STEADY VALUE.

CONTROL CHARTS FOR VARIABLES (CONT'D) — 06 OCT 87

AFTER DISCARDING 'OUT' POINTS, NEW LIMITS MUST BE CALCULATED.

$$\overline{X}_{NEW} = \frac{\sum \overline{X} - \sum \overline{X}_d}{g - g_d} = \frac{18.025 - 3.0037 - 3.0046}{6-1-1} = 3.00417 = 3.0042$$

IN THIS CASE $\overline{R}_{NEW}$ = SAME = .00063, SINCE ALL POINTS ON R CHART WERE WITHIN LIMITS AND NONE WERE DISCARDED.

STANDARD DEVIATION, $s = \frac{\overline{R}}{d_2} = \frac{.0006}{2.326} = .00026$

NOW, PROCESS LIMITS ARE CALCULATED AT $\overline{X} \pm 3\sigma$
NORMALLY CALLED NATURAL PROCESS LIMITS (NPL)

$$UNPL = \overline{X} + 3(s) = 3.0042 + 3(.00026) = 3.0050$$
$$LNPL = \overline{X} - 3(s) = 3.0042 - 3(.00026) = 3.0034$$

LOOKING AT THE $\overline{X}$ CHART ON THE PREVIOUS PAGE, ALL POINTS FALL WITHIN THE NATURAL PROCESS LIMITS.

THE DISTANCE BETWEEN THE NATURAL PROCESS LIMITS IS A DISTRIBUTION OF INDIVIDUAL MEASUREMENTS.
THE DISTANCE BETWEEN CONTROL LIMITS IS A DISTRIBUTION OF THE MEAN VALUES.

STANDARD ERROR OF THE MEAN - $3\sigma_{\overline{X}} = \frac{3\sigma}{\sqrt{n}}$

$\sigma = s = \frac{\overline{R}}{d_2}$ $\therefore$ $3s$ or $3\sigma = \frac{3\overline{R}}{d_2}$

Ø6 OCT 87

STANDARD ERROR OF THE MEAN -

$$3\sigma_{\bar{x}} = \frac{3\sigma}{\sqrt{n}}$$

(CONSTANTS FOR $\bar{X}$ AND R CHARTS FROM BOOK ON PAGE 291)

$$\sigma = s = \frac{\bar{R}}{d_2} \quad \therefore \quad 3s \text{ or } 3\sigma = \frac{3\bar{R}}{d_2}$$

IF $A_2 = \frac{3}{d_2\sqrt{n}}$, THEN $3\sigma_{\bar{x}} = A_2\bar{R}$

USL = 3.ØØ5Ø

NOM = 3.ØØ4Ø ± .ØØ1Ø

LSL = 3.ØØ3Ø

CAPABILITY RATIO = $C_R = \frac{6\sigma}{U-L} = \frac{6(.00026)}{3.0050-3.0030} = \frac{[illegible]}{.0020} = 0.78$

SOME COMPANIES USE AS A RULE OF THUMB FOR ADEQUACY THE FOLLOWING MAXIMA FOR THE CAPABILITY RATIO:

	BILATERAL TOL. %	UNILATERAL TOL %
EXISTING PROCESSES	75	88
NEW PROCESSES	67	83

THUS A DIMENSION WITH A BILATERAL TOLERANCE SHOULD BE ASSIGNED TO AN EXISTING PROCESS HAVING PROCESS VARIATION OF LESS THAN 75% OF THE TOLERANCE LIMITS. FOR A UNILATERAL TOLERANCE, e.g. A MAXIMUM ONLY TOLERANCE, THE VALUE OF $\bar{X} + 3\sigma$ SHOULD BE LESS THAN 88% OF THE TOLERANCE LIMIT.

ALWAYS FIRST FIND OUT IF THE PROCESS IS IN CONTROL.

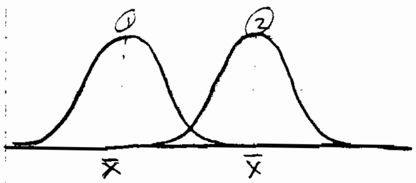
06 OCT 87

(FROM PREVIOUS $\bar{X}$ AND R CHART)

THE OPERATOR MUST BE ASSURED THAT VARIATION IS NATURAL - ONLY WHEN POINTS FALL OUTSIDE THE LIMITS DOES A PROBLEM EXIST.

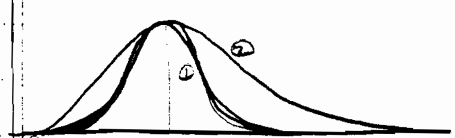
THERE ARE THREE WAYS A DISTRIBUTION MAY VARY -

1. MOVEMENT IN MEAN ONLY -



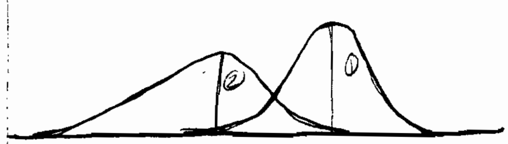
SHOWS UP ON $\bar{X}$ CHART ONLY

2. SHIFTS IN DISPERSION -



R - SHOWS ON R CHART, SOMETIMES ON $\bar{X}$ CHART. ($\bar{R}$ USED IN DETERMINING LIMITS)

3. SHIFTS IN MEAN ($\bar{X}$) AND DISPERSION (R)



SHOWS UP ON BOTH CHARTS, BUT MAYBE NOT AT THE SAME TIME.

ANY TIME A POINT GOES OUT, INVESTIGATE IMMEDIATELY.

13 OCT 87

TEST NEXT WEEK, 20 OCT 87
DESCRIPTIVE STATISTICS, CONTROL CHARTS, AND ANYTHING ELSE THAT HAS BEEN COVERED.

PROCESS CAPABILITY STUDY - CONTROL CHARTS ARE USED BECAUSE THEY SHOW IF THE PROCESS IS IN CONTROL, WHEREAS A SIMPLE LIST OF DATA CANNOT SHOW WHEN A PROCESS IS OUT OF CONTROL. SIMPLE, UNGROUPED DATA CAN ONLY DESCRIBE THE OVERALL CHARACTERISTIC OF THE DATA.

USING THE CONTROL CHART ITSELF TO IMPROVE YOUR SITUATION - *example* - IF IT IS DESIRABLE TO GET A HIGHER YIELD FROM A PROCESS, USE THE CONTROL CHART TO IDENTIFY BREAKTHROUGH OPPORTUNITIES -

POINTS WHICH MAY BE ABNORMALLY HIGH (OR LOW, WHICHEVER IS MORE DESIRABLE) - SHOULD BE EXAMINED TO SEE JUST WHY AT THAT PARTICULAR POINT -
WHEN IT HAS BEEN DETERMINED JUST WHAT CAUSED THE POINT TO BE AT A MORE DESIRABLE LOCATION, ATTEMPT TO MOVE THE MEAN TO THAT POINT, -
ASK: "WHAT WAS BEING DONE WHEN THE RANGE OR MEAN WAS MORE DESIRABLE?" - TRY TO RECREATE THE SITUATION ON A CONTINUING BASIS.

WARNING LIMITS ON CONTROL CHARTS - USU. SET AT 2σ

3 CAUSES FOR 'OUT OF CONTROL'
1. CHANGE IN THE CENTERING OF THE PROCESS.
2. CHANGE IN THE SPREAD OF THE SAMPLE
3. CHANGE IN BOTH.

Increasing the sample size reduces the range of the control limits.

27 OCT 87

$\bar{X}$ CHARTS FOR TRENDED UNIVERSE AVERAGE WITH CONSTANT STANDARD DEVIATION

PAGE 1 of handout - upward trend due to tool wear, or possibly vibration, etc...
May set a machine because of where the trend will go - can calculate info as when to reset machinery, where to set machinery, etc...

USU. BEST TO USE ODD # OF SUBGROUPS

n = 4
g = 7

# SUBGROUP	h	$\bar{X}$ SAMPLE	R SAMPLE	$h\bar{X}$	h^2
1	-3	20	4	-60	9
2	-2	28	4	-56	4
3	-1	31	5	-31	1
→ 4	∅	32	4	∅	∅
5	+1	35	4	35	1
6	+2	41	5	82	4
7	+3	44	5	132	9
		$\Sigma x = 231$	$\Sigma R = 31$	$\Sigma h\bar{x} = 102$	$\Sigma h^2 = 28$

n = 4 NOM. = 32 ± 15
g = 7 USL = 47
LSL = 17

Compute regression line for the data - using least squares method. -

Pick middle point (have the odd # of subgroups) - call it ∅ - h - revised subgroup calc., also $h\bar{x}$ - then h^2 to get rid of neg. sign.

find intercept $a = \bar{\bar{X}}$ - therefore, intercept will be in center instead of @ ∅,∅ in cartesian coord. system.

intercept $a = \bar{\bar{X}} = 33$

$\bar{\bar{X}} = \frac{\Sigma \bar{x}}{g} = \frac{231}{7} = 33$ slope. $b = \frac{\Sigma h\bar{x}}{\Sigma h^2} = \frac{102}{28} = 3.64$

$\bar{R} = \frac{\Sigma R}{g} = \frac{31}{7} = 4.42$ $\bar{X} = a + bh = 33 + 3.64h$

270A.

$\bar{X} = a + bk = 33 + 3.64(k)$ +3, −3

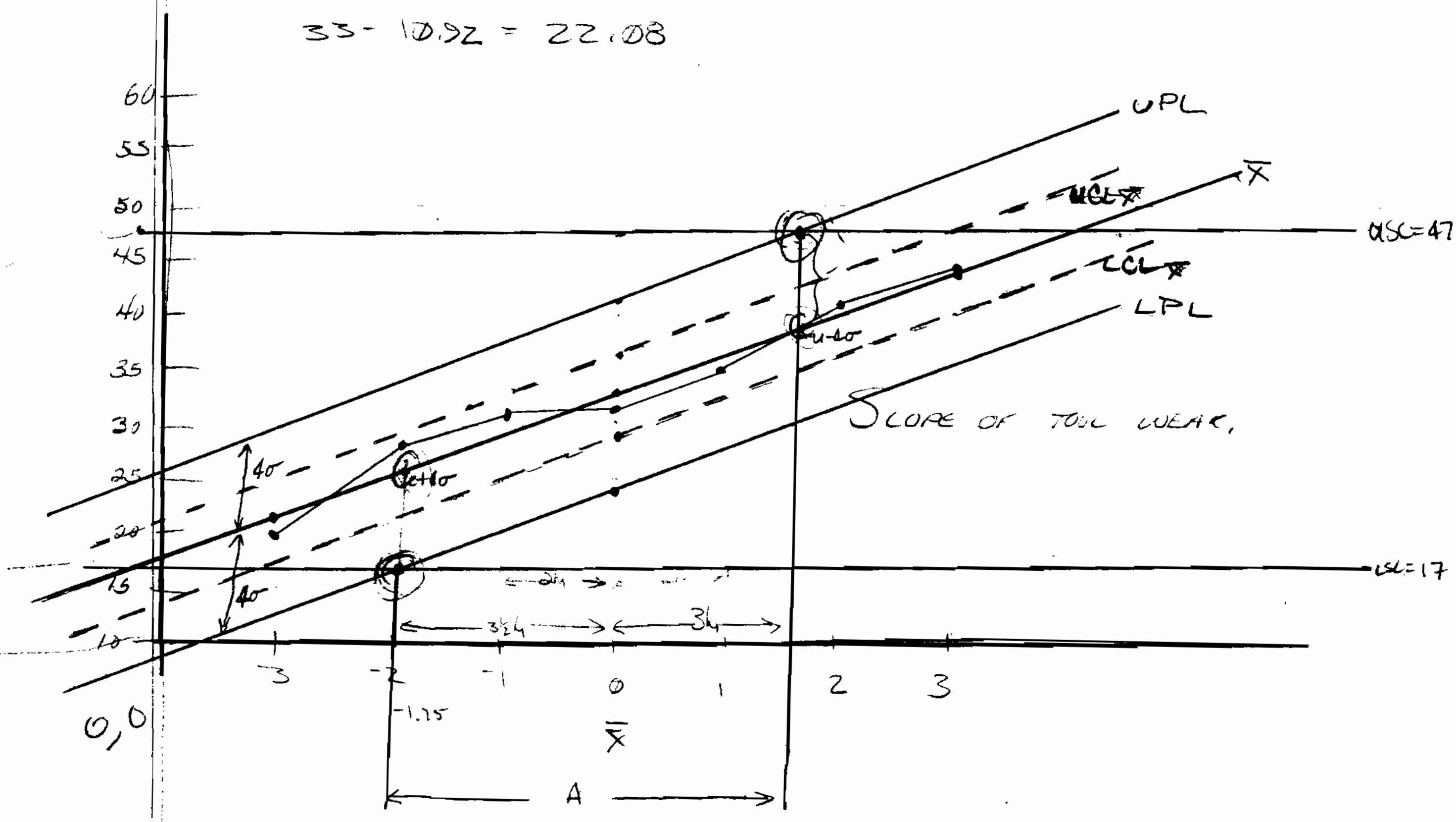
$\bar{X}_{+3} = 33 + 3.64(+3)$

33 + 10.92 = 43.92

Assumes that variation trend is constant

$\bar{X}_{-3} = 33 - 3.64(-3)$

33 − 10.92 = 22.08



intercept in this application is the center point. –

Now, compute control limits & put on chart (for averages)

UCL = $\bar{\bar{X}} + A_2\bar{R}$ = 33 + (.729)(4.42) = 36.22

LCL = $\bar{\bar{X}} - A_2\bar{R}$ = 33 − (.729)(4.42) = 29.78

Now plot points

On a trend-line basis, this chart is for the mult part in control – lines established are O.K.

$$\sigma = \frac{\bar{R}}{d_2} = \frac{4.42}{2.059} = 2.15$$

27 OCT 87

NOW CALCULATE PROCESS LIMITS @ 4σ

$UPL = \bar{\bar{x}} + 4\sigma = 33 + 4(2.15) = 33 + 8.6 = 41.6$

$LPL = \bar{\bar{x}} - 4\sigma = 33 - 4(2.15) = 33 - 8.6 = 24.4$

ON CHART A TELLS HOW LONG CAN GO BEFORE A CHANGE IS MADE, AND WHERE TO START IN THE FIRST PLACE

from the graphical cond, could go 6½ hours before tool change

When reach the point $u - 4\sigma$ - then make a change. — 6½ hour interval — install new sharp tool after each 6½ hour interval. Set AT - $L + 4\sigma$ - (25.6 in this case) center the tool at that point, run for 6½ hours, change tool, reset to $L + 4\sigma$

[illegible] 3σ [illegible].

Regression Analysis—

$y = a + bx$ where y is vertical axis

Sample group [illegible] $\Sigma X = 28$

SC. AVG. [illegible] $\Sigma Y = 231$

$\Sigma x^2 = 140$

$\Sigma xy = 1026$

$\Sigma y = Na + b\Sigma x$

$\Sigma xy = a\Sigma x + b\Sigma x^2$

Working from C-line rather than the [illegible] point.

$\Sigma y = Na + b\Sigma x \rightarrow (231 = 7a + 28b) - 4$

$\Sigma xy = a\Sigma x + b\Sigma x^2 \rightarrow 1026 = 28a + 140b$

$$
\begin{aligned}
-924 &= -28a - 112b \\
1026 &= 28a + 140b \\
\hline
102 &= 28b
\end{aligned}
$$

$b = \frac{102}{28} = 3.64$

$231 = 7a + 28b =$

$231 = 7a + (28)(3.64)$

$231 = 7a + 101.92$

$a = 18.44$

different a — this formula a is always the zero pt (vert. axis)

Page 336-339 within
"Examples of Control Charts" -

Problem 8-2 and 8-6

1. find average fraction defective - $\frac{\Sigma \text{def}}{\Sigma \text{insp}} = \bar{P}$ -

P338

$$UCL_{\bar{p}} = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \qquad UCL_{\bar{p}} = \bar{p} + \frac{3\sqrt{\bar{p}(1-\bar{p})}}{\sqrt{n}}$$

$$LCL_{\bar{p}} = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \qquad LCL_{p} = \bar{p} - \frac{3\sqrt{\bar{p}(1-\bar{p})}}{\sqrt{n}}$$

Plot p for each of the observations —

Variable limits on the chart —

n = # inspected -

p

fraction def = $\frac{\# \text{def}}{\# \text{insp}}$

$\bar{p} = \frac{\Sigma np}{\Sigma n}$

$\frac{\Sigma np}{\Sigma n}$

Not as effective as an $\bar{X}$ or R chart because values are obtained long after the parts have been made & defectives have been produced -
Always an after the fact affair.

Points out of control are due to some assignable cause - there is some reason for a larger fraction defective.

Advantage - there are a lot of things that are not measured because there is not a variable -
ATTRIBUTES - PASS/FAIL

Chart for Attribute —

ASSIGNMENT - 3-8 AND 3-9 ; EXP. DIST.

TEST NOV. 10th

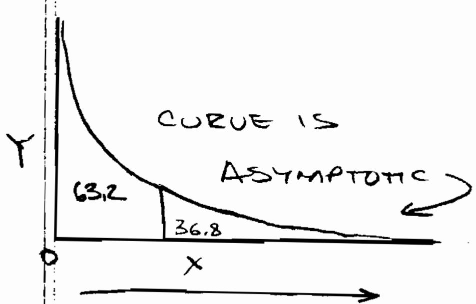
Ø3 NOV 87

p 46 - 47

THE EXPONENTIAL PROBABILITY DISTRIBUTION

SUMMARY OF COMMON PROBABILITY DISTRIBUTIONS - p41

THE EXPONENTIAL DISTRIBUTION IS APPLICABLE WHEN IT IS LIKELY THAT MORE OBSERVATIONS WILL OCCUR BELOW THE AVERAGE THAN ABOVE.



THE EXPONENTIAL DISTRIBUTION IS NOT SYMMETRICAL.

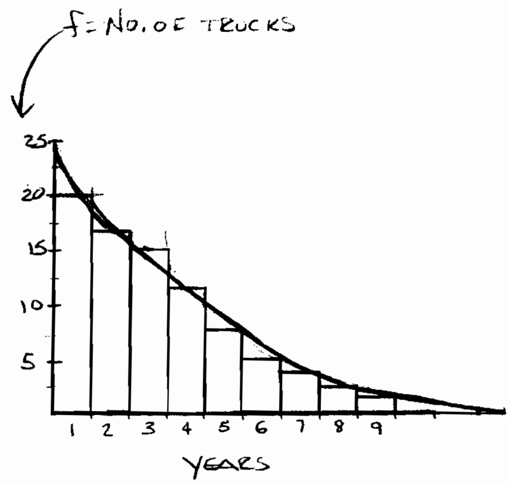
ROUGHLY 63.2% BELOW MEAN

36.8% ABOVE MEAN

MAKING PREDICTIONS BASED ON THE EXPONENTIAL PROBABILITY DIST.

DATA - LIFE OF TRUCKS IN SERVICE

YEARS (x)	# TRUCKS (f)	fx
9	2	18
8	3	24
7	4	28
6	5	3Ø
5	8	4Ø
4	12	48
3	15	45
2	17	34
1	20	2Ø
	$n = \Sigma f = 86$	$\Sigma fx = 287$



$$\bar{X} = \frac{\Sigma fx}{n} = \frac{287}{86} = \left\{ \begin{array}{l} 3.34 \text{ YEARS} \\ \text{AVG. LIFE} \end{array} \right\}$$

Ø3 NOV 87

THE EXPONENTIAL DISTRIBUTION (CONT.)

WHAT IS THE PROBABILITY THAT A TRUCK WOULD LAST AT LEAST 2½ YEARS?

THERE IS A 36.8% CHANCE THAT A TRUCK WILL LAST 3.34 YEARS, THEREFORE, FROM P 47:

$$P = \frac{X}{\mu} = \frac{2.5}{3.34} = \emptyset.75$$

FROM TABLE B, $X/\mu = \emptyset.75$; .4724 (AREA FROM 2.5 TO ∞)

⇒ LASTING AT LEAST 9 YEARS = $\frac{X}{\mu} = \frac{9}{3.34} = 2.7$

FROM TABLE B, $X/\mu = 2.7$; .Ø672, OR APPROX. 7% CHANCE.

— WEIBULL PROBABILITY DISTRIBUTION —

THE WEIBULL DISTRIBUTION IS A FAMILY OF DISTRIBUTIONS HAVING THE GENERAL FUNCTION

$$y = \alpha\beta(x-\gamma)^{\beta-1}e^{-\alpha(x-\gamma)^\beta}$$

WHERE

α = SCALE PARAMETER
β = SHAPE PARAMETER
γ = LOCATION PARAMETER.

THE CURVE VARIES GREATLY DEPENDING ON THE NUMERICAL VALUES OF THE PARAMETERS.

MOST IMPORTANT IS β, WHICH REFLECTS THE SHAPE OF THE CURVE. WHEN $\beta = 1.0$, THE WEIBULL FUNCTION REDUCES TO THE EXPONENTIAL, AND WHEN β IS CLOSE TO 3.5 (AND $\alpha = 1$ AND $\gamma = \emptyset$) THE WEIBULL CLOSELY APPROXIMATES THE NORMAL DISTRIBUTION.

WEIBULL DISTRIBUTION (CONT.) 03 NOV 87

IN PRACTICE, β VARIES FROM ABOUT $\frac{1}{3}$ TO 5. THE SCALE PARAMETER α IS RELATED TO THE PEAKEDNESS OF THE CURVE; AS α CHANGES, THE CURVE BECOMES FLATTER OR MORE PEAKED. THE LOCATION PARAMETER, γ, IS THE SMALLEST POSSIBLE VALUE OF X. OFTEN ASSUMED TO BE Ø, THEREBY SIMPLIFYING THE EQUATION.

MAKING PREDICTIONS USING THE WEIBULL DISTRIBUTION:

PREDICTIONS ARE USUALLY MADE USING WEIBULL PROBABILITY PAPER.

EXAMPLE: THE FATIGUE LIFE OF HEAT TREATED SHAFTS STRESS TESTED IN NUMBER OF CYCLES TO FAILURE WAS

FAILURE NUMBER, i		MEAN RANK
1	11261	.125
2	17786	.250
3	26432	.375
4	28811	.500
5	40122	.625
6	46638	.750
7	52374	.875

PLOT THE DATA ON WEIBULL PAPER, OBSERVE IF THE POINTS FALL APPROXIMATELY IN A STRAIGHT LINE, AND IF SO READ THE PROBABILITY PREDICTIONS (PERCENTAGE FAILURE FROM THE GRAPH.

ORIGINAL DATA USU. PLOTTED AGAINST MEAN RANKS, THUS THE MEAN RANK FOR THE ith VALUE IN A SAMPLE OF n RANKED OBSERVATIONS REFERS TO THE MEAN VALUE OF THE PERCENT OF THE POPULATION THAT WOULD BE LESS THAN THE ith VALUE IN REPEATED EXPERIMENTS OF SIZE n. THE MEAN RANK IS CALCULATED AS $i/n+1$. THE MEAN RANKS FOR THIS EXAMPLE ARE BASED ON A SAMPLE SIZE OF 7 FAILURES. CYCLES TO FAILURE ARE PLOTTED AGAINST VALUES OF THE MEAN RANK. (SEE ATTACHED GRAPH)

WEIBULL ANALYSIS

DATE 03 Nov 87

TEST NO. ______

1% FAILURE ______

NO. OF ITEMS ______

DEVICE ______

5% FAILURE ______

NO. SUSPENDED ______

10% FAILURE ______

SLOPE ______

RELIABILITY AT

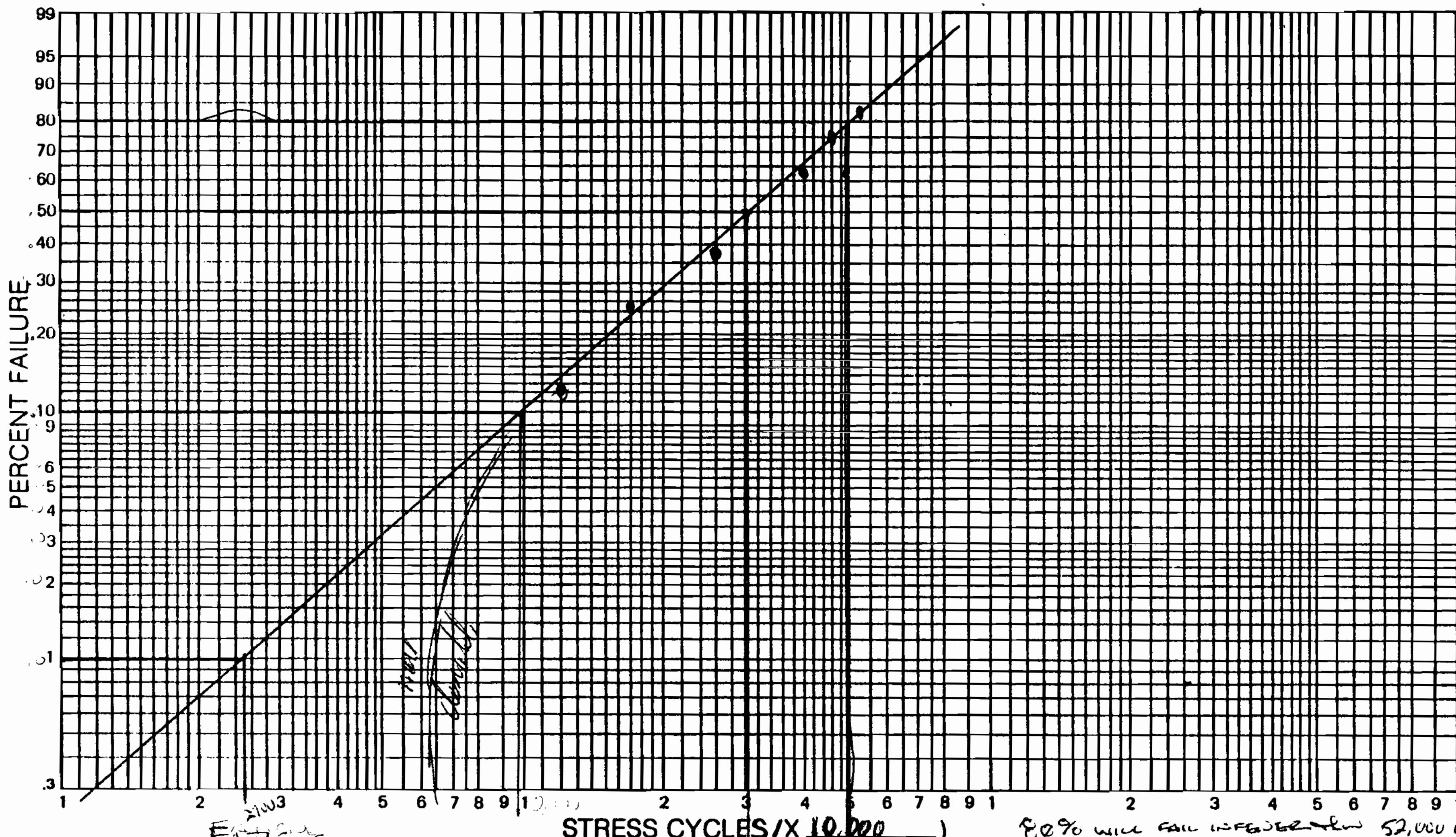
EXP. LIFE ______

______ VOLTS ______ AMPS

______ IS ______ %

CORRELATION ______ %

______ P.F. ______



FATIGUE

50% will fail within 30,000 cycles

← 80%

80% will fail in fewer than 52,000 cycles.

03 NOV 87

WEIBULL DISTRIBUTION (CONT.)

THE POINTS FALL IN APPROX. STRAIGHT LINE SO IT IS ASSUMED THAT THE WEIBULL DISTRIBUTION APPLIES. THE VERTICAL AXIS GIVES THE CUMULATIVE PERCENT OF FAILURES IN THE POPULATION CORRESPONDING TO THE FATIGUE LIFE SHOWN ON THE HORIZONTAL AXIS.

FOR EXAMPLE, ABOUT 50% WILL FAIL IN < 32,000 CYCLES, 80% IN FEWER THAN 52,000. BY APPROPRIATE SUBTRACTIONS, PREDICTIONS CAN BE MADE OF THE PERCENT OF FAILURES BETWEEN ANY TWO FATIGUE LIFE LIMITS.

- THE POISSON AND BINOMIAL DISTRIBUTION -

DEAL WITH DISCRETE OR CONTINUOUS VARIABLES.

BINOMIAL DISTRIBUTION: $(p+q)^n$

p = PROB. OF SUCCESS IN A SINGLE TRIAL

q = PROBABILITY OF FAILURE $(1-p)$

n = SAMPLE SIZE

INFINITE LOT SIZE (>100) (HERE, WITH $p = .5$, THE LOT WOULD BE 50% BAD).

$p(H) = .5$ $\quad (.5+.5)^4$ - TOSS 4 COINS

$p(T) = .5$

$(.5)^4 + (4)(.5^3)(.5)$

$$(.5+.5)^4 = (.5^4) + (4)(.5^3)(.5) + (6)(.5^2)(.5^2) + (4)(.5^1)(.5^3) + (.5^4)$$

$$\underset{p(4H)}{.0625} + \underset{p(3H1T)}{.25} + \underset{p(2H2T)}{.375} + \underset{p(1H2T)}{.250} + \underset{p(4T)}{.0625} = 1.0000$$

APPROACHES THE NORMAL DISTRIBUTION AS n INCREASES

POISSON & BINOMIAL DIST.

Ø3 NOV 87

USUALLY - VERY SMALL P VALUES - P CHART IS A VARIATION OF THE BINOMIAL DISTRIBUTION.

$C_{n,r}\, p^r q^{n-r}$ - FOR 1 TERM ONLY

$p(1\,\text{def}) = (C_{4,1})(.5^1)(.5^3) = (4)(.5)(.125) = .25\emptyset$

$n = 20 \quad p = .01 \quad q = .99$ FINDING 3 DEF. IN SAMPLE OF 20.

$C_{20,3}\,(.01)^3(.99)^{17} = (1140)(.000001)(.8429) = .000961$

POISSON DISTRIBUTION -

AN APPROXIMATION TO THE BINOMIAL DISTRIBUTION

$\dfrac{(np)^r e^{-np}}{r!}$ WHERE n = NUMBER OF TRIALS

p = PROB. OF OCCURENCE

n = NUMBER OF OCCURENCES

TABLE P 602 -

$n = 20 \quad np = (20)(.01) = \emptyset.2$

$p = .01$

$p(3\text{ OR LESS}) = 1.000$

$p(3\text{ EXACTLY}) = 1.000 - .999 = .001$

$p(3) = \dfrac{(.2^3)(2.7182818)^{-.2}}{3 \cdot 2 \cdot 1} \quad .0008 = .0001$

– THE HYPERGEOMETRIC DISTRIBUTION –

Ø3 NOV 87

TAKES THE SAME APPROACH AS THE BINOMIAL, BUT WITH SMALLER NUMBERS,

DEALS WITH A FINITE POPULATION WHERE SAMPLING IS DONE WITHOUT REPLACEMENT,

$C_{n,r} = \frac{n!}{r!(n-r)!}$ – W/O REGARD TO ORDER.

$C_{10,2} = \frac{10!}{2!(8!)} = 45$

THE HYPERGEOMETRIC DIST, DEALS WITH PROBABILITIES BASED ON THESE COMBINATIONS,

$P(d) = \frac{C_{n,r}\, C_{n,r}}{C_{n,r}} =$

\# COMB OF BAD OR DEFECTIVE ITEMS,
\# COMB OF "GOOD" ITEMS
TOTAL # COMB, OF ALL ITEMS,

EX. LOT OF 20 ITEMS, 5 OF WHICH ARE DEFECTIVE, RANDOM SAMPLE OF 3 PARTS. FIND p OF GETTING Ø,1,2, OR 3 DEF IN THAT SAMPLE,

$P_0 = \frac{C_0^5 \cdot C_3^{15}}{C_3^{20}} = \frac{1 \cdot 455}{114\emptyset} = \emptyset.3991 =$ 39.91% CHANCE OF Ø DEF

$P_1 = \frac{C_1^5 \cdot C_2^{15}}{C_3^{20}} = \frac{5 \cdot 105}{114\emptyset} = \emptyset.46\emptyset5 =$ 46.Ø5% CHANCE OF 1 DEF.

$P_2 = \frac{C_2^5 \cdot C_1^{15}}{C_3^{20}} = \frac{10 \cdot 15}{1140} = \emptyset.1316 =$ 13.16% CHANCE OF 2 DEF,

$P_3 = \frac{C_3^5 \cdot C_0^{15}}{C_3^{20}} = \frac{10 \cdot 1}{1140} = \emptyset.\emptyset\emptyset87 =$ Ø.87% CHANCE OF 3 DEF,

IN MOST CASES WILL NOT HAVE A FINITE POP, IMPORTANT FOR SMALL NUMBERS,
PROBABLY NOT MORE THAN SOMEWHERE BETWEEN 50 AND 100 PIECES,
GREATER THAN 100 WILL BE REFERRED TO AS AN INFINITE POPULATION.

10 NOV 87

NEXT WEEK - 11-17-87

POSSIBLY ASQC MEETING
HOLIDAY INN BROOKS RD.

FOR <u>24 NOV 87</u>

WRITE A SHORT REPORT ON SOME ASPECT OF RELIABILITY - NO MORE THAN 3 PAGES, PROPERLY DOCUMENTED.

SOME ASPECTS OF RELIABILITY:

MAINTAINABILITY
RELIABILITY TESTING
RELIABILITY PROGRAMS
QUANTIFYING RELIABILITY
FAILURE RATES

Check
APPLIED SCIENCE & TECHNOLOGY INDEX

ALSO ORAL REPORT TO CLASS -

Read CHAPTER 7 & 8

17 NOV 87

FROM TEST:

ADVANTAGES OF p CHARTS:

1. EASY CALCULATIONS
2. EASY TO UNDERSTAND

- THE p CHART IS AN ATTRIBUTES CHART.

ALSO:

ON $\bar{X}$ CHARTS FOR TRENDED AVERAGE -
⇒ LOOK FOR NEGATIVE SLOPE ⇐

$$\frac{\text{DISTANCE}}{\text{SLOPE}} = \text{TOOLING INTERVAL}$$

$$\frac{(U-4\sigma)-(L-4\sigma)}{b}\begin{pmatrix}\text{SAMPLE}\\\text{TIME}\\\text{INTERVAL}\end{pmatrix} = \text{TIME OF TOOL LIFE}$$

DO NOT USE POISSON DISTRIBUTION IF THE % DEFECTIVE IS GREATER THAN 10%. - ACCORDING TO GOVERNMENT SAMPLING SPECS.

HYPERGEOMETRIC DISTRIBUTION - FINITE LOT SIZE WHERE SAMPLING IS DONE WITHOUT REPLACEMENT.

17 NOV 87

PAPER & PRESENTATION DUE 01 DEC 87
SOME ASPECT OF RELIABILITY.

RELIABILITY IS THE PROBABILITY THAT A PRODUCT OR PART WILL PERFORM ITS INTENDED FUNCTION SATISFACTORILY FOR A PRESCRIBED TIME UNDER SPECIFIED CONDITIONS.

CHAPTER 8 DEALS WITH THE QUANTIFICATION OF RELIABILITY.

REASONS FOR RELIABILITY:
CUSTOMER SATISFACTION
COST
SAFETY

IN A RELIABILITY PROGRAM, THERE IS USUALLY A LOT OF PREVENTATIVE ANALYSIS DURING THE PREDESIGN PHASE AND CONTINUING INTO THE POST DESIGN PHASE.
PREDESIGN AND POSTDESIGN ANALYSIS.

HIGH RELIABILITY:
HIGH MTBF, ETC...

RELIABILITY APPORTIONMENT - THE FINAL RELIABILITY GOAL IS BUDGETED AMONG THE INDIVIDUAL PARTS OF THE SYSTEM.

RELIABILITY PREDICTION

TABLE 7-5 (p176) & 7-6 (p177)
ESTABLISHING RELIABILITY OBJECTIVES AND RELIABILITY APPORTIONMENT.
DESIGN THE QUALITY INTO THE PRODUCT

17 NOV 87

PREDICTION ⇒

RESULTING MEASUREMENTS ARE ONLY GOOD IF YOU COME UP WITH THE RELIABILITY MEASURES SPECIFIED.

MUST UTILIZE PAST RECORDS, CONDUCT TESTING, DESIGN REVIEW (P 181)

FAILURE MODE AND EFFECTS ANALYSIS

FAULT TREE ANALYSIS

PARTS APPLICATION STUDY

APPROVED PARTS LIST

CRITICAL COMPONENTS LIST.

CHAPTER 8 - STATISTICAL AIDS FOR DESIGNING FOR QUALITY.

24 NOV 87

⇒ GET COPY OF DISK WITH LOTUS MACROS & COPY OF DOCUMENTATION.

IF ENOUGH INFORMATION IS NOT AVAILABLE ON RELIABILITY, CAN INVESTIGATE TAGUCHI METHODS,

TAGUCHI EMPHASIZES QUALITY IN THE DESIGN PHASE - WHAT TO DO AS YOU ARE BUILDING THE PRODUCT.

ASI - AMERICAN SUPPLIERS INSTITUTE - A FORD AGCY, NOW INDEPENDENT - USES TAGUCHI

DORIAN SHAININ - DOES NOT LIKE TAGUCHI METHODS -

WAYS TO DETERMINE PROCESS CAPABILITY:

① COLLECT DATA: SUCCESSIVE SAMPLES, ETC...,

$n = 80$ FIND $\bar{X} = \bar{X}'$

FIND $s = \sigma'$

PROCESS CAPABILITY $= 6\sigma$

② COLLECT 20 SAMPLES OF 4 EACH - CONTROL CHART

REVISE CONTROL CHART, FIND $\sigma' = \bar{R}/d_2$

③ PROBABILITY GRAPH PAPER -

- FREQUENCY HISTOGRAM
- CONTROL CHARTS
- PROBABILITY PAPER

CHARACTERISTICS:

GATHER INFORMATION ON PRODUCT AS TO PERFORMANCE - POWER, SERVICEABILITY, SERVICE LIFE, ETC...

THESE FACTORS WILL USUALLY FOLLOW A MORE OR LESS NORMAL DISTRIBUTION.

ENVIRONMENTAL CONDITIONS, REQ'D OPERATING TIME.

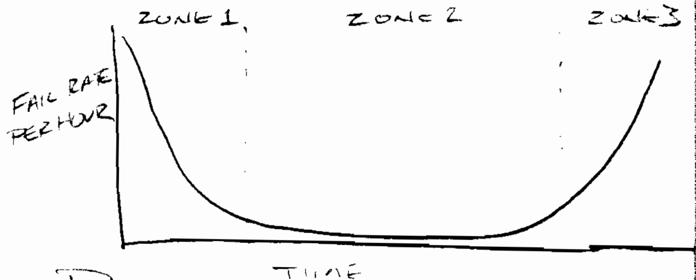
24 NOV 87

CORRECTIVE ACTION SYSTEMS.
MAINTAINABILITY

MTTR - MEAN TIME TO REPAIR - TIME REQUIRED TO SERVICE
A PRODUCT. (p191)

TRADE-OFF PARAMETERS: COST VS. PRODUCT LIFE

CHAPTER 8 - FIG 8-1, p205
BATHTUB CURVE



3 ZONES

① EARLY FAILURE/INFANT MORTALITY PERIOD
② NORMAL OPERATING PERIOD - CONSTANT FAILURE RATE
③ WEAR OUT PERIOD -
(a good example would be automobile tire)

p207 MTBF - MEAN TIME BETWEEN FAILURES
MTTF - MEAN TIME TO FAILURE (NON-REPAIRABLE)
USU. EXPONENTIALLY DISTRIBUTED (p206)

RELIABILITY TESTING DONE AS IN FIG 8-1 & TABLE 8-1
CONSTANT FAILURE RATE ∟ EXPONENTIALLY DISTRIBUTED
(A HIGHER PERCENTAGE FALLS BELOW THE MEAN),
A CURVE CAN BE FITTED TO THE INFANT MORTALITY
AND WEAR OUT PERIODS.

BURN IN / INFANT MORTALITY PERIOD - GAMMA DIST. OR WEIBULL DIST.
WEAR OUT PERIOD - NORMALLY DISTRIBUTED.
(WEIBULL DISTRIBUTION WHERE $\beta = 1.0$ - APPROXIMATE EXPONENTIAL DIST)

24 NOV 87

SOURCES OF PROBLEMS:

ENGINEERING	
ELECTRICAL	30%
MECHANICAL	10%
FIELD OPERATION	30%
MANUFACTURING	20% ← REDUCING THIS WILL NOT IMPROVE RELIABILITY SIGNIFICANTLY UNTIL OTHER AREAS HAVE BEEN REDUCED.
OTHER	10%

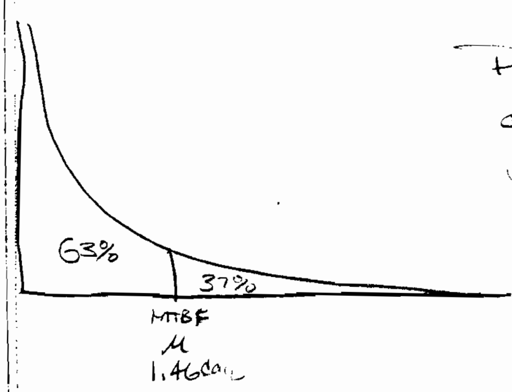
MTBF - MEAN TIME BETWEEN FAILURES

TIMES A PRODUCT FAILED	TIME BETWEEN FAILURES
2.5 DAYS	
	1.3 DAYS
3.8 DAYS	
	1.3 DAYS
5.1 DAYS	
	1.8 DAYS
6.9 DAYS	
	Σ = 4.4 DAYS

μ = MTBF = $\frac{4.4 \text{ DAYS}}{3}$ = 1.46 DAYS MTBF (SHOULD BE A LARGE NO.)

FAILURE RATE - λ (p 207)

$\lambda = \frac{1}{\text{MTBF}} = \frac{1}{1.46} = .685$ (SHOULD BE VERY SMALL)



PRODUCT WOULD HAVE A PROBABILITY OF GOING 1.46 DAYS OR LONGER WITHOUT FAILURE OF ONLY .37 (37%)

(CONTINUED)

24 NOV 87

PROBABILITY : $P_S = R = e^{-t/\mu} = e^{-t\lambda}$

$P(1 \text{ day}) = e^{-1/1.46} = .5041248 \approx 50\%$

(from previous page

50% PROB OF 1 DAY W/O FAILURE

READ INFO ON P 207-208, RE MTBF

PART & SYSTEM RELIABILITY (P208)

SYSTEM RELIABILITY = THE PRODUCT OF THE OVERALL RELIABILITIES OF THE COMPONENTS OF THE SYSTEM

ex. FOR A CAR:

ENGINE	.97	$P_S = (P_E)(P_{ES})(P_{PT})(P_{FS})$
ELECT. SYST.	.94	$= (.97)(.94)(.99)(.95) = .857 = 85.7\%$
POWER TRAIN	.99	
FUEL SYST.	.95	

RELIABILITY (SYS) = 85.7%

REDUNDANCY - PARALLEL

$R = 1 - (1 - P_i)^n$ where

R = RELIABILITY

P_i = RELIABILITY OF INDIV. ELEMENTS

n = # OF IDENTICAL REDUNDANT ELEMENTS

ex. 95% RELIABLE PART, 2 IN PARALLEL -

$1 - (1 - .95)^2 = 1 - (.05)^2 = 1 - .0025 = .9975$

PRODUCTS WITH FAILURE RATES (P214) TABLE 8-3

DO 1ST 7 PROBLEMS ON P 222

Ø1 DEC 87

REPORT WORTH 100 POINTS -

DESIGNING QUALITY INTO THE PRODUCT -

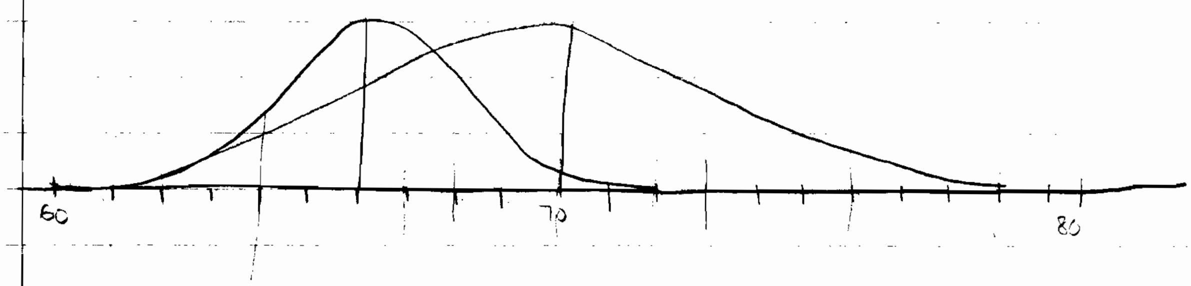
(CH3) P63-79 - STATISTICAL ANALYSES AT THE DESIGN LEVEL.

CH4 -

RELIABILITY AS A FUNCTION OF APPLIED STRESS & STRENGTH. -

SAMPLE OF 100 MEN & WOMEN

	MEAN HT.	ST DEV.
MEN	7Ø"	3.Ø"
WOMEN	66"	2.Ø"

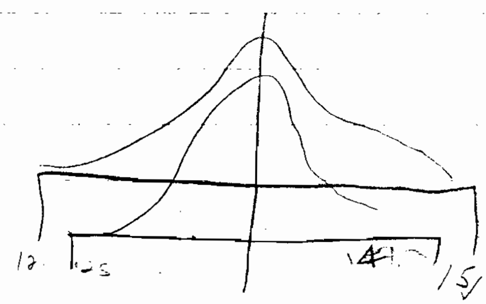


99.73% OF WOMEN 60"-72"

99.73% OF MEN 61 - 79"

Averages; 66 + 70 = 136

[illegible] 61 = 360



Total 72+79 = 151" $\frac{1}{1000}$

$\bar{X}_{TOTAL} = X_1 + X_2 + \ldots$

S_{TOTAL} $\sqrt{S_1 S_2^2 S_2^3 \; S_N}$

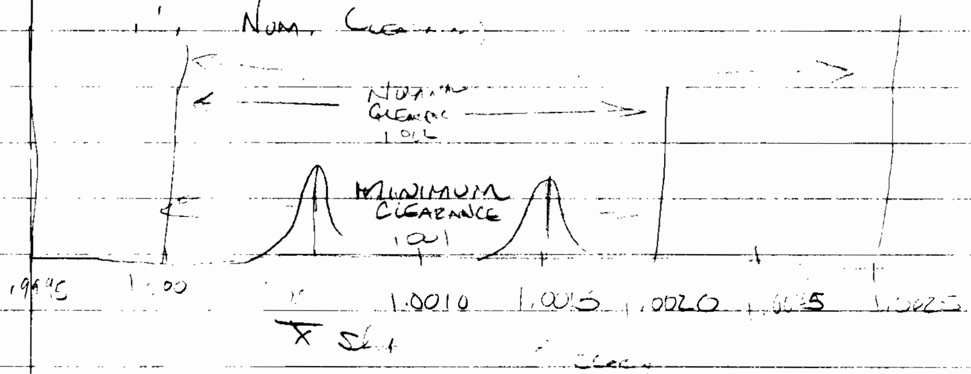
$\sqrt{9+4}$

$\sqrt{13}$

01 DEC 3?

NOM SHAFT DIA. 1.000

Bearing Clearance .001 [illegible]



Shaft 1.000 ± .0025 1.0020 ± .0005

$$S_{clr} = \sqrt{S^2_{shaft} + S^2_{Bearing}} = \frac{.007}{6} \quad 3S_{clr}$$

S_{shaft} .00064

~~$3S_{sh}$ = ...~~ $3S_{clr} = 3(.000236) = .0007$

$6S_{clr} = .002$

S_{clr}: .0033

$$S = \sqrt{.00033^2 + .00333^2}$$
$$= .000236 \times 3 = .0007$$

Tol

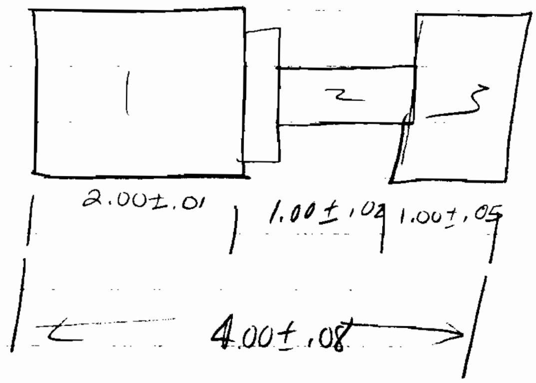
± .0007

Clearance tol - easier to meet -

(1) Must have normal dist

(2) Must [illegible] centering -

Stacking Tolerance 01 DEC 87

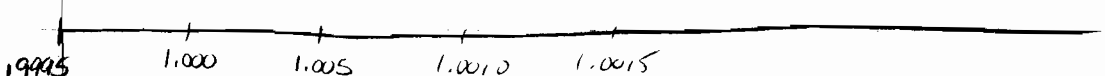


$$T_s = \sqrt{T_1^2 + T_2^2 + T_3^2}$$

$$= \sqrt{.01^2 + .02^2 + .05^2}$$

$$\sqrt{.0001 + .0004 + .0025}$$

.0547723 so 4.00 ± .05



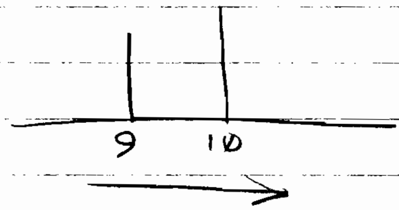
.0001

STRESS & STRENGTH 01 DEC 87

STRENGTH OF PART WORST STRESS

10 9

20 15



$$\text{SAFETY FACTOR} = \frac{\text{AVG STRENGTH}}{\text{WORST STRESS}} = \frac{10}{9} = 1.11 \qquad \frac{20}{15} = 1.33$$

THIS DOES NOT TAKE INTO ACCOUNT VARIATION

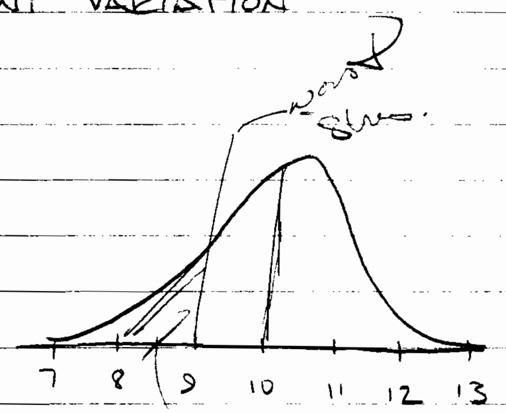
SO:

SAFETY MARGIN

STRENGTH WORST STRESS

$\bar{x} = 10$ 9

$s = 1$

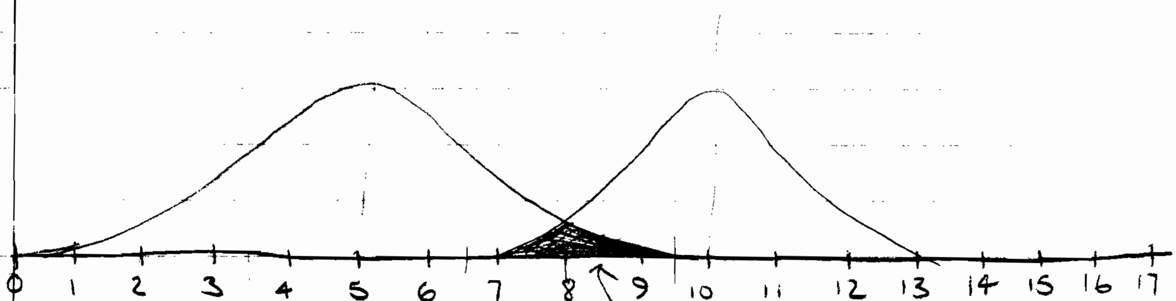


P215-16 $$\text{Safety Margin} = \frac{\text{AVG STR} - \text{WORST STRESS}}{\text{STD. DEV. OF STRESS}}$$

Problem – take into account only the curve associated with strength – maybe some overlap between the two –

01 DEC 87

	STRENGTH OF PART	STRESS
AVG	10	5
S	1	1.5



possibility of overlap between the stress and strain

$$K = \frac{0 - \text{AVG DIFF}}{\text{STDEV DIFF}} = \frac{-5}{1.802} = -2.78$$

TABLE VALUE FOR -2.78 IS $.0027 = 0.27\%$

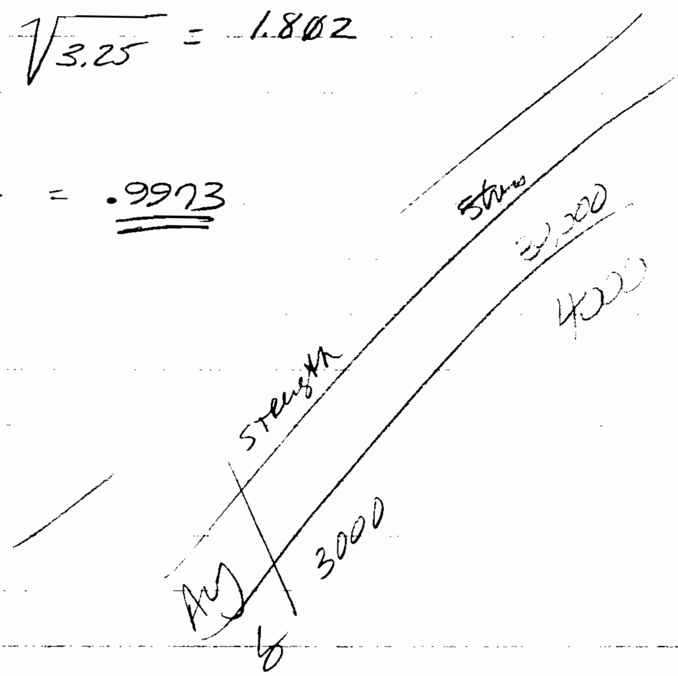
$$\text{AVG. DIFF} = \bar{X}_{\text{strength}} - \bar{X}_{\text{STRESS}} = 10 - 5 = 5$$

$$S_{\text{DIFF}} = \sqrt{S^2_{\text{STRENGTH}} + S^2_{\text{STRESS}}}$$

$$= \sqrt{1^2 + 1.5^2} = \sqrt{3.25} = 1.802$$

RELIABILITY $= 1.0000 - .0027 = .9973$

P 218 RELIABILITY BOUNDARY -



TECH 7402 Ø8 DEC 87

TAGUCHI METHODS

- SEE ARTICLE FOR LISTING OF SOME COMPANIES CURRENTLY USING TAGUCHI.

ANALYSIS OF TAGUCHI -

① AN IMPORTANT DIMENSION OF THE QUALITY OF A MANUFACTURED PRODUCT IS THE TOTAL LOSS GENERATED BY THAT PRODUCT TO SOCIETY.

MAJOR DIFFERENCE FROM THE EIGHT DIMENSIONS OF QUALITY PREVIOUSLY DISCUSSED.

LOSS CAN BE DEFINED IN MANY WAYS - DOLLARS, TIME LOSS, INCONVENIENCE, ETC. - ANYTHING CONSIDERED TO BE 'UN-QUALITY'. LOSSES MUST BE MINIMIZED, BECAUSE THEY CAN LEAD TO FURTHER LOSS (CUSTOMERS)

* LOSS IMPARTED TO SOCIETY. - REACH IDEAL PERFORMANCE IF AT ALL POSSIBLE.

⇒ FEATURES DON'T MEAN BETTER QUALITY - BUT THE AMERICAN PUBLIC LOOKS FOR FEATURES (BELLS & WHISTLES)

② IN A COMPETITIVE ECONOMY, CONTINUOUS QUALITY IMPROVEMENT AND COST REDUCTION ARE NECESSARY TO STAY IN BUSINESS.

* QUALITY IS NEVER GOOD ENOUGH, COST IS NEVER LOW ENOUGH

QUALITY & COST

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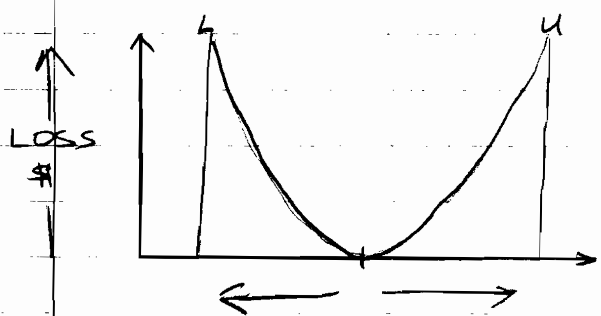
③ A CONTINUOUS QUALITY IMPROVEMENT PROGRAM INCLUDES INCESSANT REDUCTION IN THE VARIATION OF PRODUCT PERFORMANCE CHARACTERISTICS ABOUT THEIR TARGET VALUES.

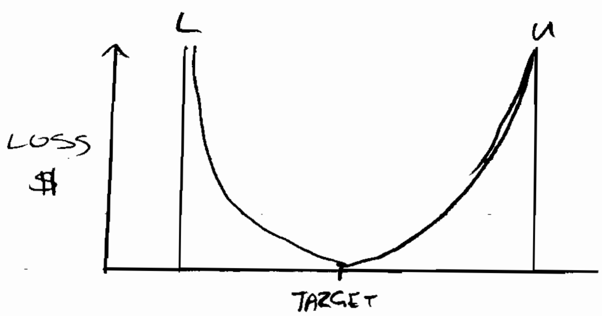
⇒ BRING VARIATION CLOSER TO NOMINAL VALUES
TAGUCHI IS GEARED MORE TOWARD PERFORMANCE.

DECREASE VARIATION & BRING PRODUCTION CLOSER TO MID-RANGE or TARGET VALUE!



THE FARTHER FROM THE TARGET, THE GREATER THE LOSS IMPARTED TO SOCIETY.

④ THE CUSTOMER'S LOSS DUE TO A PRODUCT'S PERFORMANCE VARIATION IS OFTEN APPROXIMATELY PROPORTIONAL TO THE SQUARE OF THE DEVIATION OF THE PERFORMANCE CHARACTERISTIC FROM ITS TARGET VALUE



$$L = K(Y-M)^2$$

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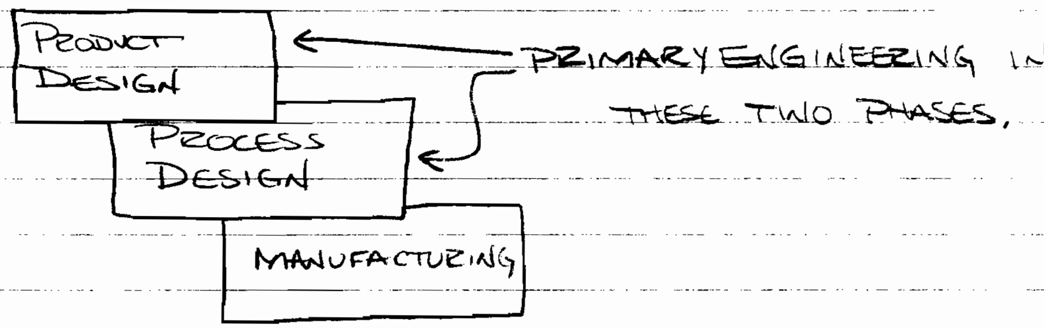
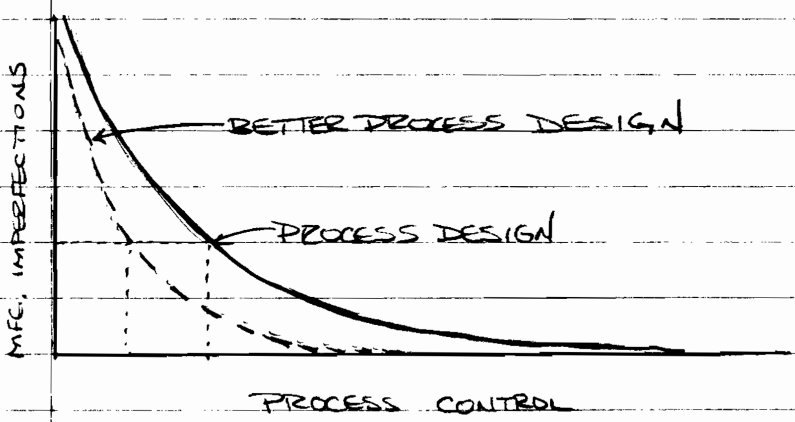
(5) THE FINAL QUALITY AND COST OF A MANUFACTURED PRODUCT ARE DETERMINED TO A LARGE EXTENT BY THE ENGINEERING DESIGNS OF THE PRODUCT AND ITS MANUFACTURING PROCESS.

OVERLAP BETWEEN AREAS:





CONTROL IN MFG. STAGE AND CONTROL IN DESIGN STAGE

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(6) A PRODUCT'S (OR PROCESS') PERFORMANCE VARIATION CAN BE REDUCED BY EXPLOITING THE NONLINEAR EFFECTS OF THE PRODUCT (OR PROCESS) PARAMETERS ON THE PERFORMANCE.

DESIGN QUALITY INTO BOTH THE PRODUCTION PROCESS <u>AND</u> THE PRODUCT.

- ORTHAGONAL ARRAYS

FRONT-END TESTING AND EVALUATION PROGRAM FOR ANY PARTICULAR DESIGN. -

IN ORDER FOR IT ALL TO WORK WITH LITTLE LOSS TO SOCIETY.

MINIMIZATION OF VARIATION ABOUT THE TARGET VALUE - GET IT DOWN TO A REASONABLE LEVEL -

- TRAIN MORE PEOPLE WITHIN THE SYSTEM TO UNDERSTAND STATISTICS.

FINAL EXAM
TUESDAY, 15 DEC 87
5:30 PM

45/45

Scott Southall
10 Nov 87

[illegible]

ADV. QUAL. CONT.

TECH 7402

1. If you have a small lot of 20 pieces, 2 of which are defective, and you draw a sample of 3, what are the respective probabilities of getting 0, 1, 2, or 3 defectives? (HYPERGEOMETRIC)

2. You have a very large lot of a particular product that contains 3 1/2% defective. If you draw a random sample of 40 items, what is the probability of getting 3 defective products in the sample? (Solve with binomial and poisson)

3. A random sample of 4 is to be selected from a lot of [illegible] items, [illegible] of which are nonconforming. What is the probability that the sample will contain exactly 1 nonconforming article? (HYPERGEOMETRIC)

4. A random sample of 10 articles is taken from a stream of product 1% nonconforming. What is the probability that the sample will contain no nonconforming articles? (use binomial and poisson)

5. If you have an infinitely large lot of items that contain 5% defective; find all the probabilities when drawing a sample of 4 (i.e. 0 defective, 1 defective, 2 defectives, 3 defectives and 4 defectives in the sample) Use the (a) binomial and (b) poisson to predict the probabilities.

6. Work Problem [illegible] pg [illegible] (NOTE: 1ST VALUE FOR DESIGN III SHOULD BE 900; NOT 9000)
(WEIBULL GRAPH PAPER ATTACHED)

7. WORK PROBLEMS 3-8, 3-9, PG 55-56

I appreciate how easy it is to follow your work - keep it up!

TECH 7402 | 10 NOV 87 | SCOTT SOUTHALL

1) IF YOU HAVE A SMALL LOT OF 20 PARTS, 2 OF WHICH ARE DEFECTIVE, AND YOU DRAW A SAMPLE OF 3, WHAT ARE THE RESPECTIVE PROBABILITIES OF GETTING 0, 1, 2, OR 3 DEFECTIVES?

HYPERGEOMETRIC DISTRIBUTION: $p(\text{DEF}) = \frac{\#\text{COMB. OF BAD} \cdot \#\text{COMB GOOD}}{\text{TOTAL \# COMB OF ALL ITEMS}}$

$$p(0) = \frac{C_0^2 \cdot C_3^{18}}{C_3^{20}} = \frac{1 \cdot 816}{1140} = .7157895 = 71.58\%$$

$$p(1) = \frac{C_1^2 \cdot C_2^{18}}{C_3^{20}} = \frac{2 \cdot 153}{1140} = .2684211 = 26.84\%$$

$$p(2) = \frac{C_2^2 \cdot C_1^{18}}{C_3^{20}} = \frac{1 \cdot 18}{1140} = .0157895 = 1.58\%$$

$$p(3) = \frac{C_3^2 \cdot C_0^{18}}{C_3^{20}} = \frac{0 \cdot 1}{1140} = 0.00 = 0\%$$

TOTAL = 100%

2) YOU HAVE A VERY LARGE LOT OF A PRODUCT WHICH CONTAIN 3½% DEFECTIVE. IF YOU DRAW A RANDOM SAMPLE OF 40 ITEMS, WHAT IS THE PROBABILITY OF GETTING 3 DEFECTIVE PRODUCTS IN THE SAMPLE. (USE BINOMIAL & POISSON TO SOLVE)

$p = .0350$
$q = 1 - p = .9650$
$n = 40$
$r = 3$

BINOMIAL: $p(r) = C_{n,r}\, p^r q^{n-r}$

$$p(3) = C_{40,3}\,(.035)^3(.965)^{37} = (9880)(.0000429)(.2676151) = .1134 = \underline{\underline{11.34\%}}$$

POISSON:

FOR $np = (40)(.0350) = 1.4$, TABLE C VALUE OF .946

FOR EXACTLY 3:

$$p(3) = .946 - .833 = .113 = \underline{\underline{11.3\%}}$$

TECH 7402 — 10 NOV 87 — SCOTT C. SOUTHALL

3) A RANDOM SAMPLE OF 4 IS TO BE SELECTED FROM A LOT OF 12 ITEMS, 3 OF WHICH ARE NONCONFORMING. WHAT IS THE PROBABILITY THAT THE SAMPLE WILL CONTAIN EXACTLY 1 NONCONFORMING ARTICLE? -

USING THE HYPERGEOMETRIC DISTRIBUTION;

$$p(1) = \frac{C_1^3 \cdot C_3^9}{C_4^{12}} = \frac{3 \cdot 84}{495} = .509090\ldots = \underline{\underline{50.90\%}}$$

4) A RANDOM SAMPLE OF 10 ARTICLES IS TAKEN FROM A STREAM OF PRODUCTS THAT HAS 2% NONCONFORMING, WHAT IS THE PROBABILITY THAT THE SAMPLE WILL CONTAIN NO NONCONFORMING ARTICLES? (BINOMIAL & POISSON)

$p = .02$
$q = 1 - p = .98$
$n = 10$
$r = 0$

BINOMIAL: $p(r) = C_{n,r}\, p^r q^{n-r}$

$$p(0) = C_{10,0}\,(.02)^0 (.98)^{10} = 1 \cdot 1 \cdot .8170728 = \underline{\underline{81.70\%}}$$

POISSON:

FOR $np = (10)(.02) = .2$, TABLE VALUE OF $.819 = \underline{\underline{81.9\%}}$

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5.) YOU HAVE AN INFINITELY LARGE LOT OF ITEMS THAT IS 5% DEFECTIVE. FIND ALL THE PROBABILITIES WHEN DRAWING A SAMPLE OF 4, USING a) BINOMIAL AND b) POISSON TO PREDICT THE PROBABILITIES.

$n = 4 \quad p = .05 \quad q = 1 - p = .95$

a) BINOMIAL:

$p(0) = C_{4,0}(.05)^0(.95)^4 = 1 \cdot 1 \cdot .8145063 = 81.45\%$ ✓

$p(1) = C_{4,1}(.05)^1(.95)^3 = 4 \cdot .05 \cdot .857375 = .171475 = 17.15\%$ ✓

$p(2) = C_{4,2}(.05)^2(.95)^2 = 6 \cdot .0025 \cdot .9025 = .0135375 = 1.34\%$ ✓

$p(3) = C_{4,3}(.05)^3(.95)^1 = 4 \cdot .000125 \cdot .95 = .000475 = .05\%$ ✓

$p(4) = C_{4,4}(.05)^4(.95)^0 = 1 \cdot .0000063 \cdot 1 = .0000063 = .00063\%$ ✓

b) POISSON: $np = (4)(.05) = .2$

$p(0) \quad (r=0) = .819 = 81.9\%$ ✓

$p(1) \quad (r=1) = .982 - .819 = .163 = 16.3\%$ ✓

$p(2) \quad (r=2) = .999 - .982 = .017 = 1.7\%$ ✓

$p(3) \quad (r=3) = 1.000 - .999 = .001 = 0.1\%$ ✓

$p(4) \quad (r=4) =$ – NO TABLE VALUES – $= 0\%$ ✓

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(6) 3-10) COMPARE THREE DESIGNS OF A CERTAIN SHAFT-

a.) ARRANGE DATA IN ASCENDING ORDER AND MAKE WEIBULL PLOT FOR EACH DESIGN.

FAILURE # i	DESIGN I	DESIGN II	DESIGN III	MEAN RANK $i/n+1$
1	50	130	340	.1428571
2	100	210	600	.2857143
3	110	330	850	.4285714
4	180	360	900	.5714286
5	220	575	1400	.7142857
6	240	575	1500	.8571429
SUM:	900	2180	5590	

SEE ATTACHED SHEET FOR PLOT OF DISTRIBUTIONS.

b) FOR EACH PLOT, ESTIMATE THE NUMBER OF CYCLES AT WHICH 10% FAIL AND AT WHICH 50% FAIL.

	I	II	III
10%	45	112	300
50%	140	350	900

(IN TERMS OF THOUSANDS OF CYCLES)

c) CALCULATE THE AVERAGE LIFE FOR EACH DESIGN BASED ON TEST RESULTS. ESTIMATE THE PERCENTAGE OF THE POPULATION THAT WILL FAIL WITHIN THIS AVERAGE LIFE.

AVERAGE LIFE I = $900/6 = 150$ | FAILURE % WITHIN AVERAGE 55%

II = $2180/6 = 363.33$ | 52.6%

III = $5590/6 = 931.67$ | 52.6%

d.) COMMENT ON REPLACING THE CURRENT DESIGN I WITH II OR III.

REPLACE DESIGN I WITH DESIGN III. ASIDE FROM COSTING LESS THAN THE CURRENT DESIGN, IT WILL LAST LONGER. SINCE THE AVERAGE LIFE FOR II AND III ARE APPROXIMATELY THE SAME, IT WOULD BE MORE ADVANTAGEOUS TO REPLACE WITH III SINCE THE EQUIPMENT COST WOULD ONLY BE \$500, COMPARED WITH \$125,000 EQUIPMENT COST ~~TO~~ TO PRODUCE A SHAFT THAT IS ONLY \$2 CHEAPER AND IS NOT AS DURABLE.

WEIBULL ANALYSIS

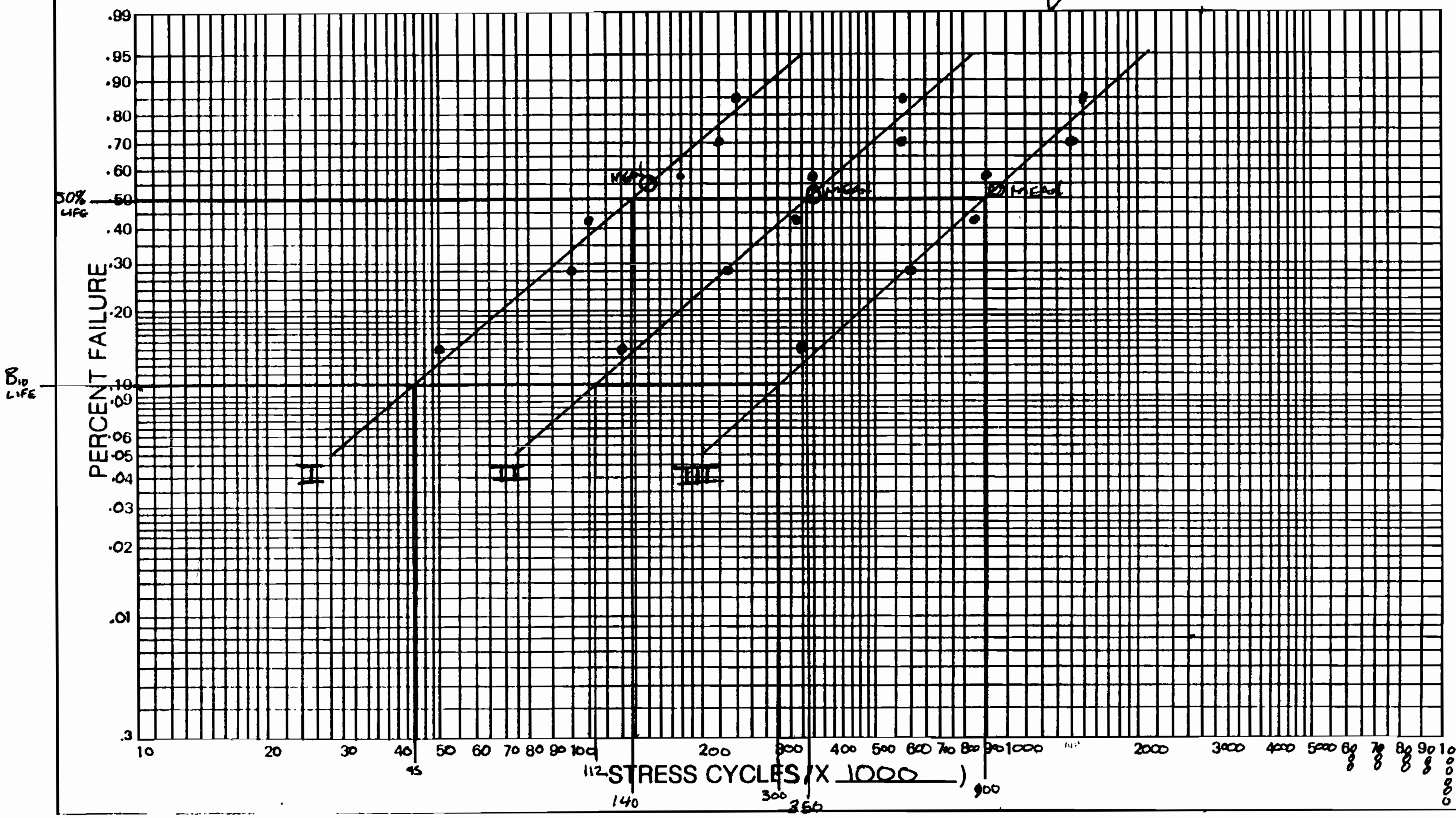
DATE ______________ NO. OF ITEMS ______________ TEST NO. ______________

1% FAILURE ______________ NO. SUSPENDED ______________ DEVICE ______________

5% FAILURE ______________ SLOPE ______________

10% FAILURE ______________ EXP. LIFE ______________ ______ VOLTS ______ AMPS

RELIABILITY AT ______________ IS ______ % CORRELATION ______________ % ______ P.F. ______________



3-8) A POWER COMPANY DEFINES SERVICE CONTINUITY AS PROVIDING ELECTRIC POWER WITHIN SPECIFIED LIMITS TO A CUSTOMER'S SERVICE ENTRANCE. RECORDS INDICATE 416 UNSCHEDULED INTERRUPTIONS IN 1967 AND 503 IN 1966.

a) CALCULATE THE MEAN TIME BETWEEN UNSCHEDULED INTERRUPTIONS ASSUMING POWER IS TO BE SUPPLIED CONTINUOUSLY.

1 YEAR = 8760 HOURS

$$\frac{(8760)(2)}{(503+416)} = 19.0642 \text{ HOURS MTBF}$$

b) WHAT IS THE CHANCE THAT POWER WILL BE SUPPLIED TO ALL USERS WITHOUT INTERRUPTION FOR 24 HOURS? FOR 48 HOURS? ASSUME AN EXPONENTIAL DISTRIBUTION.

24 HOURS $\frac{X}{\mu} = \frac{24}{19.0642} = 1.2589 = 1.3 = 0.2725 = \underline{27.25\%}$ (TABLE B)

48 HOURS $\frac{X}{\mu} = \frac{48}{19.0642} = 2.5178 = 2.50 = 0.0821 = \underline{8.21\%}$ (TABLE B)

3-9) ANALYSIS MADE OF REPAIR TIME OF ELECTROHYDRAULIC SERVOVALVE. DISCUSSION CONCLUDED THAT 90% OF REPAIRS COULD BE MADE WITHIN 6 HOURS.

a) ASSUMING AN EXPONENTIAL DISTRIBUTION OF REPAIR TIME, CALCULATE THE AVERAGE REPAIR TIME.

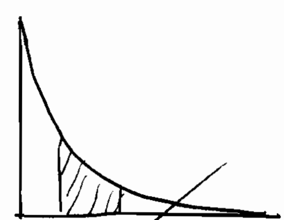
$\frac{X}{\mu} = 2.35$ (TABLE B for 10%) $\frac{6}{\mu} = 2.35$ $6 = 2.35\mu$

$\mu = \underline{2.60 \text{ HRS}}$

b.) WHAT IS THE PROBABILITY THAT A REPAIR WOULD TAKE BETWEEN 3 AND 6 HOURS?

$p(3 \text{ OR MORE HRS}) = \frac{3}{2.60} = 1.2 = .3012$

$p(6 \text{ OR MORE HRS}) = \frac{6}{2.60} = 2.3 = .1003$



$p(\geq 3) - p(\geq 6) = .3012 - .1003 = .2009$ or $\underline{20.09\%}$

(DIFF. FROM BOOK DUE TO FACT THAT AUTHOR INTERPOLATES TO OBTAIN TABLE VALUES).