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Variation has been studied by statisticians and scientists for decades. Although variation is not a new concept, what is new is the awareness that variation affects everyday activities in the workplace. Modern man is plagued with variation problems ranging from raw materials to finished products and services. No matter how precise our methods of producing products and providing services becomes, there will always be some degree of variation. Today's thrust toward the Total Quality Management (TQM) concept will include the understanding of variation. In fact, the concept of variation may be analyzed in each of Deming's 14 points. Future variation issues will include the understanding and management of people.

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MANAGEMENT OF VARIATION & TQM

A Research Report Written by

Mr. William E. Hughes, Jr.

TABLE OF CONTENTS

INTRODUCTION

Variation has been studied by statisticians and scientists for decades. Although variation is not a new concept, what is new is the awareness that variation affects everyday activities in the workplace. Modern man is plagued with variation problems ranging from raw materials to finished products and services. No matter how precise our methods of producing products and providing services becomes, there will always be some degree of variation. Today's thrust toward the Total Quality Management (TQM) concept will include the understanding of variation. In fact, the concept of variation may be analyzed in each of Deming's 14 points. Future variation issues will include the understanding and management of people.

HISTORY OF VARIATION

Ancient Times

Ancient man necessarily accepted variation as a way of life. A million years ago, tools and weapons were fashioned from stones. Selectively choosing the raw materials to meet his needs was his method of dealing with variation. In around 5000 B.C., the Egyptians derived the "Fitness for Use" concept [Provost and Norman, p. 39], when they implemented the idea of interchangeable bows and arrows. By doing so, craftsmen were made to deal with the variations between raw materials, methods, tools, and craftsmen. If any bow or arrow produced was inspected to be significantly different from the norm, the craftsman simply reworked the item until he deemed it to be fit for use.

Middle Ages

Variation in raw materials and the tools used to work them remained to be a way of life. In order to ensure that variation in the final product was minimized, skilled craftsmen were a necessity [Provost and Norman, p. 39]. To provide for adequately trained and skilled craftsmen, craft guilds were developed. This guild system included the utilization of masters (master craftsmen), journeymen, and apprentices. The master was responsible for overseeing the training of all those under him, and for inspecting their final products. He made sure that the appropriate techniques were used and that the final product would fulfil the requirements for its intended use. Thus, fitness for use remained the prime method for dealing with variation. This concept remained in place until the latter part of the 20th century.

Parts Interchangeability

In the middle 1850's, Honore' LeBlanc, a French gunsmith, developed a system for producing muskets to a standard design [Provost and Norman, p. 40]. This system allowed the interchangeability of parts between muskets. The United States was impressed with this concept and attempted to persuade LeBlanc to implement this system in the U.S. These attempts failed and the U.S. was forced to reconstruct these ideas internally.

Eli Whitney was contracted to supply 10,000 muskets to the U.S. government in two years [Provost and Norman, p. 40]. To provide this service, Whitney trained workers and designed special tools to make parts to a specific design. Each part produced was inspected with respect to a model. After numerous contract overruns, Whitney finally provided this service. The concept was still in its early stages, however, as files were often necessarily utilized by the end-users to perform minor alterations to the parts prior to use.

Specification, Gaging, and Tolerance

Armories of the 19th century implemented an in-process and final inspection procedure using gages [Provost and Norman, p. 40]. The go/no-go gage inspection procedure was developed to replace the subjective inspection methods used prior to their implementation. This method became the system of choice for reducing variation and producing identical parts.

Specifications and tolerances became an integral part of the gage inspection system. Due to increasing demands for part interchangeability, standard dimensioned tolerances were established and utilized by many industries by the end of the 19th century. Thus, workers were no longer necessarily concerned about the fit, form, and function of each piece produced. The worker was now concerned with making the part to a pre-determined print. Inspectors were utilized to cull parts that did not meet print specifications. This type of system is used today to sort out non-conforming parts.

Control Charts

During the 20th century, complex systems (such as computers and telecommunications hardware) were developed and started being produced. These complex systems required a new method for analyzing variation. Walter Shewhart of Bell Telephone Laboratories [Provost and Norman, p. 40] developed the theory and methods to be used during the early 20th century. Shewhart's theory emphasized the importance of the economic balance between looking for assignable causes when they do not exist and overlooking assignable causes that do exist. This method provided an operational definition of the concept of common and special causes that can cause variation. Deming later emphasized that this concept of variation is also applicable to service and administrative processes. Figure 1 reflects a historical timeline of some of the more important developments in variation [Provost and Norman, p. 39].

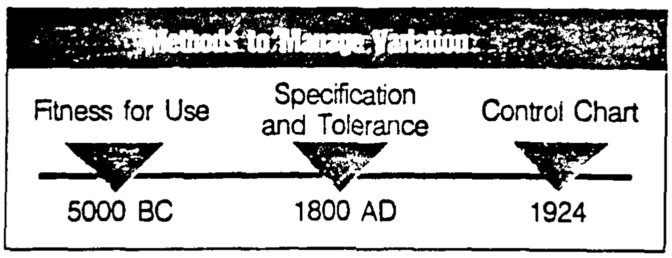

Figure 1.

CONCEPT OF VARIATION

Basics

Joiner and Gaudard [Joiner and Gaudard, p. 29] emphasize that there are seven concepts about variation that everyone should know:

1. All variation is caused. There are concrete reasons why a person's weight fluctuates daily, and why one employee consistently performs better than another.

2. There are four main types of causes to be considered. "Common causes" are those ever present factors that contribute to relatively small (and seemingly random) shifts in day-to-day outcomes. The total of these common causes are often called "system variation", because this collection depicts the expected variation inherent within the system. "Special causes" (also referred to as "assignable causes") represent factors that cause a significant shift in the system. These causes usually represent an outcome whose reason for occurrence is identifiable once analysis is performed to determine its origin. "Tampering" is unnecessary additional variation caused by adjustments made in attempts to compensate for common cause variation. "Structural variation" is expected, systematic changes in

output. Examples of structural variation include trends and seasonal patterns.

3. The managerial action required for each type of cause is different. Thus, the ability to distinguish between these four causes is of the utmost importance. Without this ability to distinguish between the types of causes, management cannot detect real improvement in the process.

4. Receiving timely data can greatly assist in detecting special causes. Investigations should be performed immediately when observances signal that a special cause may be present. Knowledge of the reasons behind these special causes can assist the manager in reducing the number of bad outcomes, and in increasing the number of good outcomes in the future.

5. An in-depth knowledge of the process is required to analyze common cause data.

6. Statistical control of the process is achieved when all variation in the system is due to common causes.

7. The total system variation may be determined by utilizing statistical tests on the process data. This method may be utilized to determine guidelines (control limits) necessary to scientifically and confidently predict statistical control.

Basic Control Chart Theory

Chance variations ordered over time will behave in a random manner [Duncan, p. 375]. They will not show cycles or runs or any other definable pattern. No future variation can be predicted from knowledge of past variations. Variation produced by chance, however, follows statistical laws. Thus, variation produced by such a system can be predicted, even though the effect of any particular cause cannot be predicted. The foundation of control char. theory and analysis is based on this knowledge of the behavior of chance variations.

For a group of studied data found to conform to a statistical pattern and which may reasonably be assumed to have been produced by chance causes, it can be assumed that no special (assignable) causes are present. The underlying conditions which produced this variation are then considered to be under control. If the variations do not conform to this data, however, then the conditions which yield this variation are considered to be out of control. For this case, it may be assumed that one or more special causes are present in the data.

Based on the nature of processes (including services and people), most data deserving management analysis may be assumed to follow a normal distribution. (Note: This may also be proven based on sampling theory and the Central Limit Theorem; topics beyond the scope of this paper). This assumption of the normal distribution is used to develop control limits for the control chart.

The upper and lower control limits (commonly denoted UCL and LCL, respectively) are customarily defined to be some multiple of the standard deviation. For the standard normal distribution (mean=0, variance=1), areas under the curve for different multiples of standard deviations have become commonly used for control limits on a control chart. This relationship is provided in Figure 2 [Salvatore, p. 70] below:

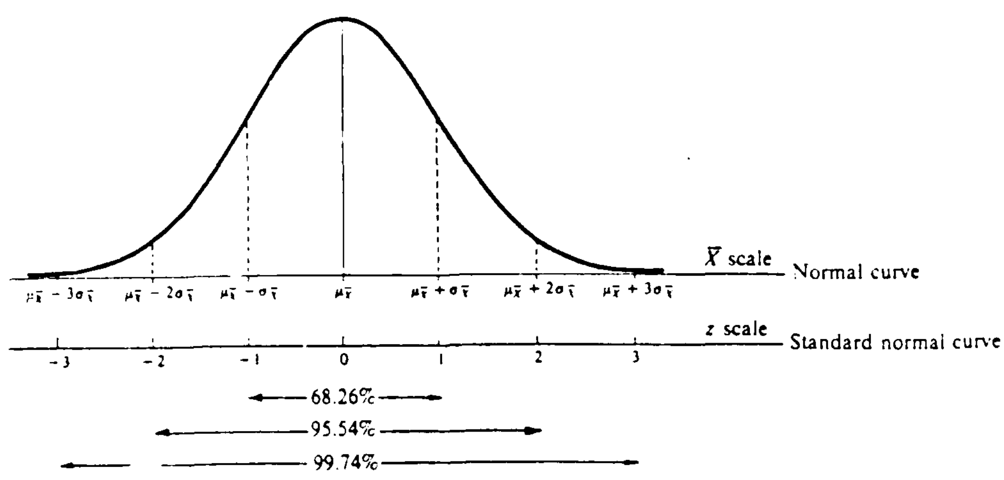

Figure 2. Area under the standard normal curve.

Applying these limits to the control chart in Figure 3, we can deduce that if only chance causes are present, the probability of a single observation falling above the UCL (using 3 sigma limits) is approximately 0.001 (one tenth of one percent chance), and the probability of an observation falling below the LCL is also 0.001. Figure 3 also points out that the process is out of control based on the single point on the control chart that shown to be out of control [Duncan, p. 380].

An Example of a Fraction-Defective Control Chart (a *p*-Chart)*

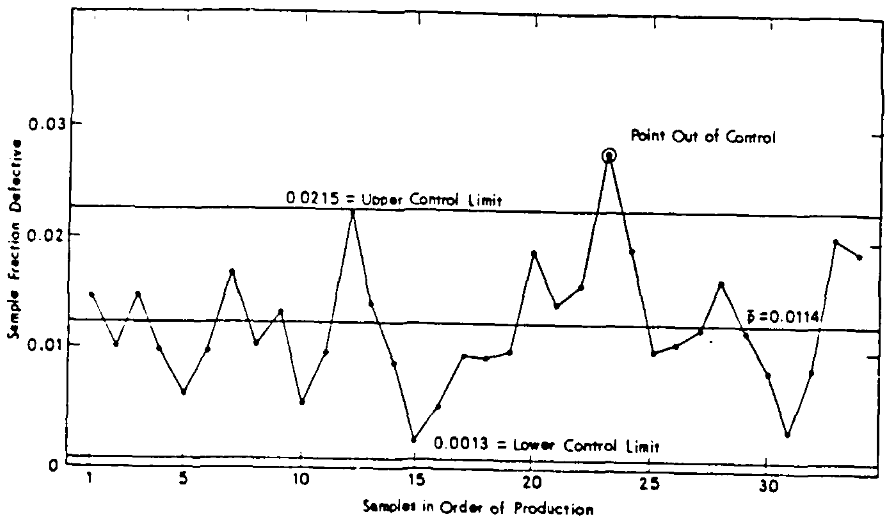

Figure 3. Illustration of a process out of control.

Although 3 sigma limits are most commonly used, the actual limits should be based on the nature of the process and the quality of the analysis desired. In addition, it should be noted that the UCL and LCL must not necessarily be the same distance from the mean, although this is usually the case.

Analysis Of Control Charts

A control chart is not only a device for obtaining a state of statistical control, but also a tool which may be used to determine when the studied process or activity is out of control. Thus, if sample values of X, when ordered in time or on some other basis, all fall within the control limits without varying in a non-random manner within the limits, then the process may be judged to be within control at the level indicated by the chart. "Non-random" is mentioned here, because when trends may be discovered within the control chart data, the data points making up this trend may be analyzed and assigned a cause.

An important theoretical concept concerning the analysis of control charts should be noted. The fact that no points fall outside the UCL and LCL does not necessarily mean that assignable causes are not present. It simply means that the cost of additional analysis to look for special assignable causes is probably not justified.

Based on the limits developed for the control chart in Figure 3, the one point that is out of control implies that the process is out of control. This point is thus worth the time and cost necessary to analyze the reason why it fell beyond the control limits. The cause for this observation may hopefully be discovered. If a cause may be assigned to this point, the process problem causing this variation may (hopefully) be resolved, thus resulting in future process improvement by reducing the likelihood of a similar future occurrence. If the resolution of the problem is independent of all other data, then the control chart now in place may continue to be used. If there is a relationship between this occurrence and other data, then resolving the process to account for this occurrence will provide an even greater improvement to the system. Under these circumstances, it is probably advised that the analyst develop a new control chart in the future which reflects this improved process.

USING CONCEPT OF VARIATION TO MANAGE PEOPLE

Management According To Control Chart Theory

The analysis for conventional production processes should be evident from the explanation on analysis already provided.

There are also many ways managers may use variation theory and control charts which have not widely been discussed in the past. As an example, consider the fictitious (and simplified) ACME Manufacturing Company's April 1991 report in Table 1. For the purpose of this analysis, the report is simplified to include only manufacturing process cost and sales revenue.

April 1991 Variance Summary ($000)			
	Planned	Actual	Fav/(Unfav) Variance
Manufacturing Cost	120.0	102.0	18.0
Sales Revenue	300.0	257.7	(42.3)

Table 1. ACME April 1991 Variance Report.

Based on this report, the general manager is likely to simultaneously praise the employees responsible for the manufacturing process costs, while reprimanding the sales manager and sales personnel. The problem in this situation is that the manager may not know if these motivational efforts are appropriate. The managers of these departments will probably now expend energy attempting to find out what they did wrong (or right) that these figures were obtained (either by their own motivation or by the direct command from the general manager). This may have been a good management tool for the general manager to apply, but without a proper understanding of variation, the general manager cannot always effectively make this decision. Suppose, however, that control charts for both the manufacturing and sales areas had been established prior to this incident. To provide these charts, past data must be collected and analyzed. Suppose data for the last 12 months (April 1990 - March 1991) is readily available for both manufacturing process costs and sales revenue. Also assume that the planned manufacturing process cost and sales revenue are constant across this period. This assumption is necessary in order to present simple SPC charts (presented in this section of the report) and the derivation of their control limits (in Appendix I). Table 2 presents the summarized variance report for both the manufacturing cost and sales revenue over the last 13 months (includes April 1991).

	Mfg. Costs		Variance	Sales Revenue		Variance
MONTH	PLANNED	ACTUAL	Fav/(Unfav)	PLANNED	ACTUAL	Fav/(Unfav)
April 90	120.0	122.2	(2.2)	300.0	290.3	(9.7)
May	120.0	115.4	4.6	300.0	288.5	(11.5)
June	120.0	110.4	9.6	300.0	310.5	10.5
July	120.0	104.4	15.6	300.0	303.6	3.6
Aug.	120.0	122.2	(2.2)	300.0	319.2	19.2
Sept.	120.0	125.3	(5.3)	300.0	275.5	(24.5)
Oct.	120.0	110.2	9.8	300.0	299.5	(0.5)
Nov.	120.0	111.0	9.0	300.0	304.6	4.6
Dec.	120.0	135.3	(15.3)	300.0	289.6	(10.4)
Jan. 91	120.0	113.0	7.0	300.0	288.5	(11.5)
Feb.	120.0	110.2	9.8	300.0	297.8	(2.2)
Mar.	120.0	133.0	(13.0)	300.0	303.6	3.6
Apr.	120.0	102.0	18.0	300.0	257.7	(42.3)

Table 2. Variance Report for Manufacturing Process Costs and Sales Revenue Over Last 13 Months.

Control charts for manufacturing process cost and sales revenue may now be developed. Figures 4 and 5 present SPC charts for the manufacturing process cost and sales revenue, respectively, using two sigma control limits. Derivation of the control limits for these two charts may be referenced in Appendix I.

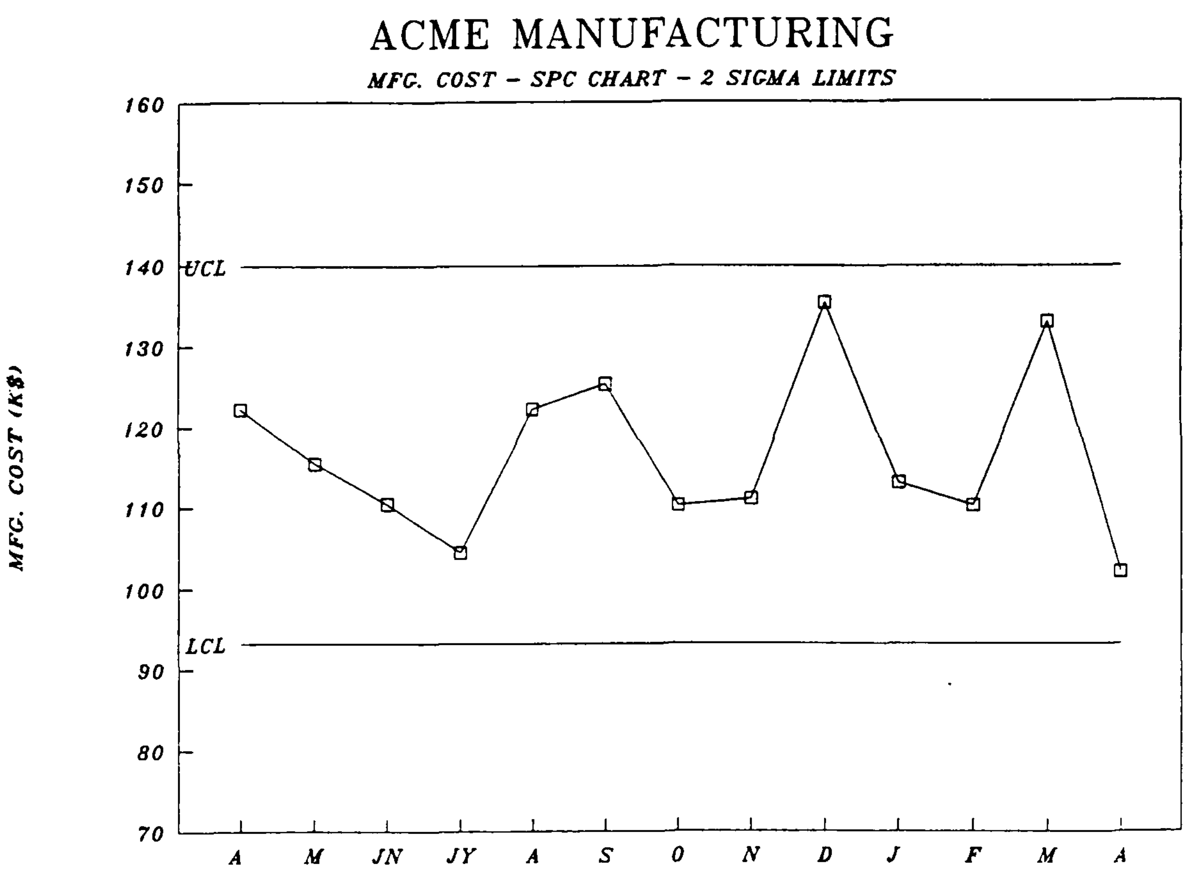

FIGURE 4. MANUFACTURING COST SPC CHART.

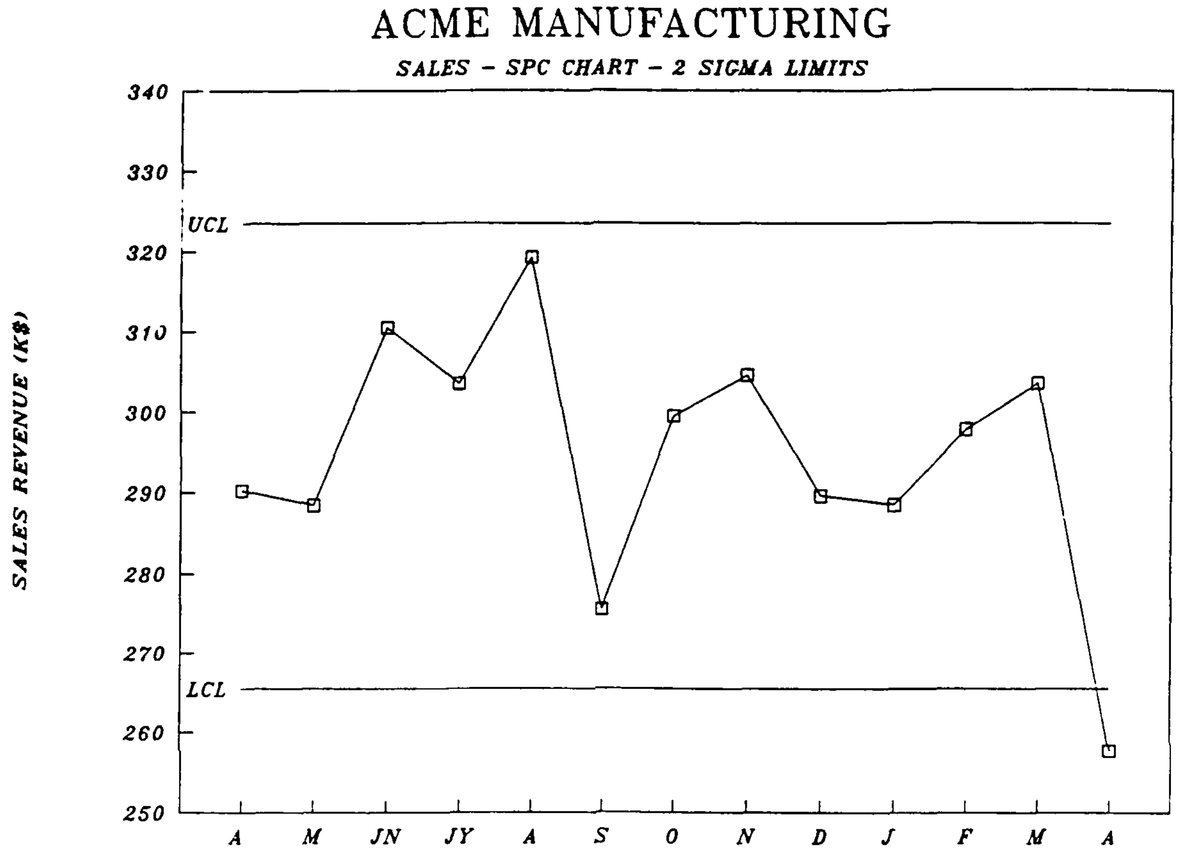

FIGURE 5. SALES REVENUE SPC CHART.

Figure 4 shows that the manufacturing process cost is in control over the entire 13 month period (including April 1991). Figure 5, however, shows that the April 1991 sales revenue figure places the SPC chart "out-of-control". Based on Figures 4 and 5 and the theory of control charts, the manager may have responded appropriately to the negative sales figure but inappropriately to the manufacturing process cost figure. Two classifications of mistakes for an inappropriate response of the nature described above include the "misuse of influence" and the "infeasible analysis of common causes".

Misuse Of Influence

Two of the basic processes which can be used to influence behavior through operant conditioning are positive reinforcement and punishment [Hampton, p. 22]. Positive reinforcement is a process which involves providing good, pleasant, or satisfying consequences of behavior in return for a desired response. Examples of positive reinforcement include praise, increased pay, and better working conditions. This management tool is used to establish and maintain a desired behavior.

Punishment is a management tool used to extinguish undesired behavior. Punishment, even when applied appropriately, can have serious drawbacks. There is a limit to the amount of noxious conditions employees will tolerate. In addition, the idea of inflicting unpleasantness on employees is repugnant to managers with wholesome personalities.

According to the definition of common causes, these type of variations are seemingly random and non-feasibly identifiable. Therefore, to praise or punish based on their occurrence will probably motivate those responsible to look for the reason behind the occurrence. Since these reasons cannot be easily (or feasibly) determined, the employee will absorb unnecessary stress over each such incident and may eventually become numb to such punishment, thus removing management's effectiveness to utilize this means of motivation. On the other hand, the receipt of undeserving praise can confuse employees, and make them numb to this type of motivation as well. Other potential negative aspects of misuse of influence include increased absenteeism and turnover, reduced employee creativeness and motivation, and an increased potential of unauthorized data tampering. Data tampering by employees under "punishment" conditions is rather common, since the employee can often hide or manipulate "negative" process results.

Infeasible Analysis Of Common Causes

For the case in which no points fall outside the control chart (assuming no evidence of non-random or trend related variation), the hypothesis that chance alone caused the variation should be assumed. It is thus infeasible and unprofitable to look for assignable (or special) causes. In short, if chance alone can reasonably explain the results, no further analysis is needed or desired.

ANALYSIS OF VARIATION FOR PEOPLE MANAGEMENT

Managers have been conditioned to simply reward employees who perform better within certain groups and punish those whose performance is deemed to be less than average, with little to no analysis performed to determine why certain individuals fall above or below the "norm". People are truly different, and there will always be employees performing above or below average. The concept of variation can assist managers in understanding how to better deal with this fact.

Deming tells us that it is the manager's responsibility to determine which employees perform at a level above or below the "control limits" [Walton, p. 33]. It should be noted, however, that many job situations do not fit the criteria for formally establishing a control chart with upper and lower limits, and in many cases the attempt to establish such a system would be futile or even strongly undesired. For example, the development of control charts for employees who strongly desire (and/or require) autonomy would be inappropriate [Daniel]. These types of employees usually perform uncertain tasks in which absolute goals are seldom established. Examples of these types of employees include professionsals such as research scientists, engineers, lawyers, doctors, and etc. An understanding of the general concept of variation and control charts, however, may be applied in most situations.

Performance Above Control Limits

When an employee is observed to consistently perform significantly better (i.e., above a real or imaginary upper control limit), that employee should be questioned and his or her tools analyzed to determine what it is that assists him or her in achieving superior performance. There are numerous characteristics about this employee which might be discovered that could assist the manager in improving his or her own performance in dealing with all the remaining employees. Some of these characteristics include:

- Better training and/or education
- Improved tools
- Enhanced or more efficient procedures or methods
- Highly appropriate physical match to job
- In touch with more or better communication sources
- Others

Unless these factors are ruled out, the manager should not assume that superior performance is due only to a higher motivation level within the employee.

Once the manager learns the true reason behind the employee's superior performance (i.e., assigns a cause), the manager may then attempt to improve the overall performance of the group by providing other group members (if possible or feasible) with similar means of improvement. If the manager discovers that motivation was, indeed, the key to this superior performance, he may then focus more closely on the motivation aspect of management. The manager may also then analyze the superior employee's motivation level to determine if some revision in the manager's motivational strategy with other employees is desirable.

Performance Below Control Limits

As with the superior employee, there may be certain characteristics about an employee who performs significantly below average (below the lower control limit) that may prove to be beneficial once analyzed by the manager. Some of the characteristics the manager may discover upon analysis include:

- o Poor training and/or education
- o Substandard tools, methods, or procedures
- o Poor physical match to task
- o Bad communication skills (receiving or transmitting)
- o Others

Upon detection of the problem and assignment of cause, the manager can hopefully make use of this information to increase the employee's potential performance level. The manager may also discover information that may be used to increase the performance level of other group members as well. If no assignable cause is found from the analysis, the manager might then decide that a revision of his motivational strategies aimed toward this employee (and possibly other employees) may be in order.

W. DEMING'S 14 POINTS AND VARIATION

Brief Background

The work and philosophy of Dr. W. Deming is a cornerstone of today's thrust toward Total Quality Management. Dr. Deming's lifetime mission has been to uncover sources of improvement [Walton, p. 33]. As a statistician, Deming determined that what was necessary was a concept of management that was consistent with statistical methods. Deming's work strongly suggests a management philosophy deeply entrenched in the theory of variation.

Deming spent several years teaching management principles (including control chart theory) to the Japanese following World War II. He continued to refine and enlarge these management principles over the next three decades. He later named his final set of management principles "The 14 Points". The following list depicts Deming's 14 points [Walton, p. 34-36], along with a discussion of how the knowledge of variation is necessary [Joiner and Gaudard, p. 35] if a manager is to appropriately apply the 14 points and TQM theory.

"The 14 Points"

1. Create consistency of purpose for improvement of product and service.

Clear and consistent goals are necessary if employees are to focus on appropriate tasks. Changing the goals to satisfy higher management desires and/or forcing the end to meet the means (tampering) can result in misspent effort, reduction in employee morale, and loss of long term profit. This goal changing philosophy shows a lack of understanding that variation is a "given" in any system.

2. Adapt the new philosophy.

Better quality at reduced costs is possible if managers learn to manage more effectively. Improving management methods includes learning how variation affects the quality of management and the product. It must be realized that tampering and overreaction to common cause variation are poor management practices.

3. Cease dependence on mass inspection.

Inspection only prolongs the symptoms; it does not get rid of the disease. The necessity to live the "quality by inspection" rule results from a lack of understanding of the variation in the process. Dependence on inspection may be eliminated by gaining an in-depth knowledge of the processes and their variability. Once this is accomplished, the manager can then work toward reducing the variability and improving the quality of the product and the profit margin.

4. End the practice of awarding business on price tag alone.

Working with carefully selected, trusted suppliers will almost always reduce the variation of incoming materials or services, thus reducing end-product variation and improving quality. The best deal is not always the best deal!

5. Improve constantly and forever the system of production and service.

Maintaining control over variation and the process, and updating the control methodology as each assignable variation is discovered and accounted for will consistently improve the quality of the output.

6. Institute training.

The lack of consistent training for employees is a major cause of variation. Workers should be trained properly and their work monitored. An efficient and effective monitoring process involves the knowledge of variation. With proper use of variation theory, improperly trained employees may be detected and retrained in the correct procedures.

7. Institute leadership.

Deming teaches us that a leader is a person who helps employees reach higher levels of performance with less effort. The leader, with an appropriate level of knowledge of variation, will attempt to diminish the differences between employes by learning which employees are working within the system (in control) and which employees are working outside of the system. The leader will try to learn the "secrets" behind the knowledge or techniques utilized by the person working above the upper control limits and seek to share this information with those other employees. Conversely, the leader will also learn what keeps some employees working below the lower control level, and will attempt to provide them with the necessary tools and/or motivation to increase their performance.

8. Drive out fear.

Managers often fear situations they have little control over. They often unnecessarily fear fluctuation which is inherent to the system. Knowledge of variation should provide them with knowledge that will eliminate a large portion of this fear, by explaining that certain aspects are either uncontrollable, or that attempts to control are not feasible.

9. Break down barriers between staff areas.

Staff areas and departments often have goals or objectives which differ to the extent that conflict is created. The reduction in variation for these goals and objectives will foster increased cooperation and reduced conflict between these staff areas and departments.

10. Eliminate slogans, exhortations, and targets for the work force.

Wishful thinking seldom works. Increased performance comes mainly from improved processes and techniques. Overemphasis on slogans, goals, and exhortations can lead to worker demoralization and possibly promote tampering, each of which can cause variability and a trend away from effective change.

11. Eliminate numerical quotas.

Quotas do not promote quality of products or services and often lead to inefficiency. An appropriate understanding of variation and the common cause system promotes managers to forecast production that can be realistically met while upholding desired quality standards. The lack of this understanding by the manager can lead to late deliveries, poor quality, and low employee morale.

12. Remove barriers to pride of workmanship.

In general, workers have the desire to do a good job, and are upset when barriers get in the way. Examples of barriers include the pressure to use sub-quality materials, methods, or equipment in order to satisfy production quotas. Lack of control over the quality of output causes demoralization of the employee, and increased variability of the output.

13. Institute a vigorous program of education and retraining.

Providing knowledge of variation and other attempts to improve the employee leads to increased potential for the employee to decrease process variation and increase product quality. The employee's self-esteem will also be improved, which should also provide the increased confidence and motivation necessary to reduce long term output variability.

14. Take action to accomplish the transformation.

Neither workers nor managers can make this transformation alone. Coordinating this effort with everyone involved will contribute to reduced variability and optimization of the overall system.

Deming wrote "It was Dr. Lloyd Nelson who years ago remarked that the most important figures for management are unknown and unknowable. We could add that the most important losses and gains are not even under suspicion" [Joiner and Gaudard, p. 37]. The best weapons against these losses, and the most assistance available to maximize these gains may be found in Deming's 14 points. By fully understanding variation and reducing its effect, management will be able to deal effectively with future challenges.

CONCLUSION

The 20th century brought about complexity in manufacturing and employee management, and created the need for the understanding of variation. Statistical process control was developed to assist management in understanding variation and in the application of certain technological and management control techniques which will reduce variation. Statistical process control and control chart theory can be applied in the management of people as well as the management of processes. The TQM concept relies heavily on the management and reduction of variation in its quest for continuous quality improvement.

The future will bring about an ever-increasing complexity in products, services, manufacturing techniques, employees, and in the management and leadership techniques required for an organization to be effective and profitable. Although many of today's managers get by without an appropriate understanding of variation, "these ideas will be seen in the future as minimum expectations for leadership" [Provost and Norman, p. 44].

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APPENDIX I

Derivation of Control Limits for Figures 4 and 5

The SPC charts shown in Figures 4 and 5 are known as "X-Charts". The control limits for X-Charts are derived by the following equation:

Upper Control Limit (UCL) = $\bar{X}$ + (Sigma Multiple) x $\bar{R}$ / d2

and Lower Control Limit (LCL) = $\bar{X}$ - (Sigma-Multiple) x R / $\bar{d}2$

where;

$\bar{R}$ is the average of the "Moving Range of Two" (i.e., 2 data points). The moving range of two for each month is calculated as the reported value for the (n)th month minus the reported value for the (n+1)th month. The average value may then be calculated as the (Sum of the Moving Range of Two for all months) divided by the number of months (in this case, 13 months).

d2 is the value taken from the E. S. Pearson's table "Percentage Points of the Distribution of the Relative Range w=R/ , Normal Universe". The d2 value taken from this table for n equal to 2 is 1.128.

The actual derivation of the UCL and LCL shown in the report is shown below:

Manufacturing Process Cost

MONTH	(A) PLANNED	(B) ACTUAL	(A - B) MOVING RANGE OF TWO
A	120.0	122.2	6.8
M	120.0	115.4	5.0
JN	120.0	110.4	6.0
JY	120.0	104.4	17.8
A	120.0	122.2	3.1
S	120.0	125.3	15.1
O	120.0	110.2	0.8
N	120.0	111.0	24.3
D	120.0	135.3	22.3
J	120.0	113.0	2.8
F	120.0	110.2	22.8
M	120.0	133.0	31.0
A	120.0	102.0	
	Totals:	1514.6	157.8

Thus,

d2 = 1.128 $\bar{X}$ = 1514.6 / 1 $\bar{R}$ = 157.8 / 12
= * = 13.2

APPENDIX I (Continued)

and with the sigma-multiple defined to be two,

LCL =	116.5 - (2 x 13.2) / 1.128	=	93.1
UCL =	116.5 + (2 x 13.2) / 1.128	=	139.8

The UCL and LCL for the Sales Revenue SPC chart is similarly derived:

	Sales Revenue		MOVING RANGE
MONTH	PLANNED	ACTUAL	OF TWO
A	300.0	290.3	1.8
M	300.0	288.5	22.0
JN	300.0	310.5	6.9
JY	300.0	303.6	15.6
A	300.0	319.2	43.7
S	300.0	275.5	24.0
O	300.0	299.5	5.1
N	300.0	304.6	15.0
D	300.0	289.6	1.1
J	300.0	288.5	9.3
F	300.0	297.8	5.8
M	300.0	303.6	45.9
A	300.0	257.7	
	Totals:	3828.9	196.2

Thus,

d2 = 1.128 $\bar{X}$ = 294.5 $\bar{R}$ = 16.4

and

LCL =	294.5 - (2 x 16.4) / 1.128	=	265.4
UCL =	294.5 + (2 x 16.4) / 1.128	=	139.8