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How much tolerance?

ACCURACY is as much needed in business and private life today as it has been since the very beginning in engineering. It is a managerial problem of the greatest importance in industrial production.

Accuracy is a measure of the tolerance allowed between parts of a machine, or in the actions of a man. To be accurate is to conform to a standard, to be correct, to be truthful and precise.

There is nothing degrading in being accurate. Nearly all grand discoveries of science and nearly all great developments in business have been the rewards of accurate measurement and patient labour in the gathering and sifting of numerical results. In our everyday activities it is far better to make some rough measurement than no measurement at all.

The sciences of astronomy, physics and chemistry, and the art of architecture, are built on a foundation of careful measurements made with ingenious instruments and related to known principles. So are the automobile, the factory machine, the cigarette lighter and all big and little mechanical things we use daily. A thousandth of an inch is so small it can hardly be seen, yet it is one of the most important things in modern living.

The early machine builders, like Watt, sought accuracy because they realized that the efficiency of their devices depended upon it. Eli Whitney added another reason: he desired interchangeability of parts. Not to be accurate today is to be a burden on society, because, as Solomon remarked, the man who is slack in his work is brother to him who is a destroyer.

The production of goods for distribution to the world's increasing population has developed amazingly in recent years. The fabric of our society would collapse into a mass of stagnation and pauperism if it were not for the factories and the printing presses; the ships, airplanes and railways; the telegraph, telephone, radio and radar; the electricity and electronics, that form a skeleton on which the flesh and blood of our material civilization are built.

All these demand accuracy. We work to rigid specifications of materials and craftsmanship; we test machines to find the size and type better adopted to our purpose than any other. Accuracy is the key to mass production, making possible standardization of parts so that they may be fabricated, assembled and fitted together into smooth-running, efficient articles of use.

A news item in November said that more than 4,000 subcontractors work for a major aircraft engine manufacturer in constructing the 8,854 parts that go into a new jet engine.

In the early days of the automobile there were at least 800 different kinds of lock washers and 1,600 sizes of steel tubing; today there are 16 kinds of lock washers and 17 types of steel tubing. Not only the assembling of an automobile, but the simplification of parts, and the accuracy of making them, are triumphs in engineering and production.

Craftsmanship

We do not know in what stage of the development of man's manufacturing skill the increasingly keen judgment of his growing craftsmanship began to be supported by measurement as we understand it today. It was necessary for him to become a provider of goods before he had grown up to master the arts of manufacture. The first commodities he used were supplied him in ready-made form by nature and his weapons were boulders and wood clubs. We can probably trace the necessity and art of duplication back to our ancient ancestor who increased his hunting efficiency by making all the arrows in his quiver to fit the same bow.

Accurate workmanship calls for the adoption of standard procedures or patterns as a substitute for individual discretion or fancy, but this does not mean that the instinct of workmanship has perished from the earth. When people learned to measure accurately, they found that dimensions could take the place of artistry. Ability to measure accurately gave new talents to unskilled workers. It paved the way for mass production that has raised the standard of living for everyone.

Accuracy depends on standards of measurement, and standards of production depend on accuracy of work. A standard has to be established by appropriate authority or accepted by common consent. It must be permanent, precisely reproducible, and usable in practice. It must pass rigid tests and it must lend itself to definition.

The standards of some goods, such as gold, silver, drugs and food, are set by law. Other commodities, such as textiles, electrical goods, and printing, usually come under codes of ethics framed by the industries, or are tested by rules agreed on by trade associations. When we buy a boiler built to pass the tests of the boiler test code we know what pressure it will stand and what service to expect from it.

Small tolerances

A very real difference may yet be very small. Atoms are no less real because they are invisible to the unaided eye. In parts of a refrigerator, accuracy in the order of thousandths is essential. A publication of General Motors Employee Relations Staff in 1952 pointed out that a carburetor jet a thousandth of an inch too big could reduce a car-owner's gasoline mileage by a mile or more to the gallon. The plunger is fitted to the cylinder of a Diesel engine injector with an accuracy of twenty-five millionths of an inch — 1/120 the thickness of a human hair.

Dr. Percival Gurrey, professor emeritus of the University College of the Gold Coast, referred in a lecture in Toronto last year to the precision-weighing of analytical chemists, whose marvellously delicate balances can weigh the footprints of the fly that walks over their balance-pan; they can weigh a period printed on this page.

When we turn our thoughts from accuracy in the infinitely small to accuracy in the infinitely big, we catch a glimpse of equal marvels. It is shown in geometry that if the ratio of the circumference of a circle to its diameter be written to 35 places of decimals, the result will give the whole circumference of the visible universe without an error as great as the minutest length visible in the most powerful microscope.

Gravitation is one of the great mysteries. The centrifugal force of the earth in its orbit would break a steel cable 5,000 miles in diameter, yet Newton, experimenting with pendulums with bobs of wood and of gold found no difference in the time of swing as great as one part in a thousand. In 1922 another experimenter in the facts of gravitation pushed the precision to six parts in a billion.

Everyday work

It is one thing for the scientist in his laboratory or the astronomer in his observatory to spend days or weeks making a single careful measurement, and quite another for an unskilled factory worker to measure hundreds of pieces in a day with a watchmaker's standard of accuracy.

To do this effectively, the workman must have foolproof measuring instruments. When he is determining whether an engine crankshaft is within allowable limits of size, he does not make micrometer measurements. The figures mean nothing to him. He need test only whether the crankshaft is too small or too big. The margin between the maximum and minimum dimensions is called the tolerance.

The machines and tools that make the parts are set and maintained to cut or grind them within certain limits. The finer the limits the more costly the manufacturing becomes, and so the tolerances or margins must be calculated according to the class of goods produced. It is not always necessary to work so closely on the parts of a large engine as it is on a small mechanism or tool. The crankshaft might have a tolerance of plus or minus 1/10,000, indicating that it is permitted to be larger than standard by this amount, or smaller by the same amount.

To determine the suitability of the part, the workman has a limit gauge. To test outside dimensions, as of a shaft, he will use a gauge consisting of two pairs of jaws, each provided with two measuring surfaces. Two of these surfaces are set apart a distance equal to the high limit of the part, the distance of the other pair equalling the low limit. A shaft passing between the surfaces of the high limit jaws and not able to pass between the jaws of the low limit is acceptable. Similarly, he will test inside dimensions by using two cylindrical plugs representing the high and the low limits of the hole.

Measurement

To determine the standards we need measurements. Some of these have come down to us from antiquity, and still serve us well: we have added other measurements and refinements to match our needs.

The cubit of Noah's time was the length of a man's forearm, the distance from his elbow to the end of his middle finger. The yard of later years (still used for rough estimates) was the distance from finger tips to the tip of one's nose.

We found, as time went on, that it doesn't make much difference how long the yard is. What really matters is that we all mean the same thing when we speak of a yard. Not all men's arms are the same length: we need a measuring instrument of precision.

King Edward I took a step forward in the 13th Century when he ordered a permanent measuring bar made of iron to serve as a standard yardstick for his kingdom. The French later based a measurement scale on the assumed constancy of the earth's size, and in Newton's time the British turned for precise standards to the swing of the pendulum.

The metric system was not, as is sometimes said, an invention of the 18th Century. It was suggested by Mauton of Lyons in 1670, but it was the French government of 1793 that put the metric system into general use. The metre was one ten-millionth part of the distance from the North Pole to the Equator when measured on a straight line running along the surface of the earth through Paris. The mathematician Laplace saw the metric system as one that "had the grand and sublime idea of assuring eternally the uniformity so desirable in weights and measures on a basis which could be accepted by all the peoples of the earth."

Not many years later, some natural philosophers meeting in Paris speculated that the metre could not be reproduced if the form or size of the earth were changed by collision with a comet. Sir Humphry Davy proposed as a natural standard the diameter of a capillary tube of glass in which water would rise to a height exactly equal to the tube's diameter. Jacques Babinet suggested that a wave length of light in a vacuum would be better, and through the development of British, Dutch and German scientists and Dr. A. A. Michelson of the University of Chicago, and his colleague Professor E. W. Morley, this plan became widely accepted.

The most precise measurements of length are made with light waves. They measure distances too small to be seen with powerful microscopes. In *Scientific Monthly* of January, 1949 the Chief of the Spectroscopy Section of the United States Bureau of Standards said this: "Although a wave of green light (mercury 198) is only 1/50,000 inch in length, it can be reproduced within 1/100,000,000 of its length, and length measurements with light waves can be made with this accuracy."

It seems a long way from the cubit of Noah's time to the metre of 1793 and the light ray of today. None of us can live effectively under old standards of measurement and accuracy. We have to accommodate ourselves to the new conditions, with allowance for the tolerance of the particular job that is ours.

Accuracy in business

The very life of a business depends upon the accuracy with which records and statistics are measured. There is little tolerance allowable between "will do" and "will not do", between "success" and "failure" in even the biggest industrial concern.

It was, a few years ago, a common pastime in business organizations to collect vast quantities of informational data with a view to submitting it to analysis some day when things were not so busy. Probably some of the printed and mimeographed forms devised then for collecting statistics are still being issued, filled in, and filed.

But there is a new spirit abroad, and many executives are seeing to it that what data is being collected within their companies has a clear purpose in mind. They know that the more comparisons they are able to make the more qualified they are to act intelligently. They know that small samples give poor measuring standards that lead not to the accuracy of sensible conclusions but to the treachery of inspired guesses.

Take index numbers, for example. It is scarcely possible to be respectable in finance or government nowadays unless one produces at least one index number. Index numbers are a special kind of average indicating the level of something at a given point of time in relation to the average level of the period on which the index is based.

Caution is needed in interpreting an index. Was its base big enough? Were conditions constant? While its figures may be quite correct, extraordinary events or unusual conditions may affect one or both of the periods compared, resulting in a change that does not reflect the normal trend. Seasonal businesses can no more compare the index of their sales in summer and winter than they can connect the number of neckties sold with the number of refrigerators.

The "cost of living" is so closely connected with the "standard of living" that an index prepared for families in the $4,000 a year class has no even shadowy application to the shopping experiences of the wife of a man in the $15,000 a year class.

To deal accurately with any information demands a wealth of background knowledge: to know why something came about is as important as to know what happened. Measurement and standards and mathematics are not to be unduly worshipped, though they cannot be neglected by even the person in private life. St. Thomas Aquinas said it neatly: "An angel perceives the truth by simple apprehension, whereas man becomes acquainted with a simple truth by a process from manifold data." And worldly-wise Plato made the point that one must be able to see the truth accurately in order to judge his distance from it if he is practising deception.

Need for vigilance

No matter how carefully facts are collected, no matter how accurately they are tabulated, there comes a time when they must be subjected to assessment and judged as to significance. It is a mischievous error to assume that prolonged accurate mathematical calculations assure infallible judgment. We need traffic rules for the flow of information, and thoughtfulness to relate the selected numerical results to new ideas and new situations.

Many a proposition that seems self-evident at first glance turns out to be false when carefully scrutinized without prejudice. Business executives know that obviousness is the enemy to correctness. They must be slow to believe what they most wish should be true. They need to challenge and criticize and be cautious, to make sure that what is given them as a basis for their decision is not only numerically accurate but accurate in view of all the circumstances.

Pilate was no jester when he asked: "What is truth?" for we have not yet agreed on an everyday-life standard. We allow a certain tolerance, plus or minus exact truth, depending on business, social, and other features in our environment.

Accurate speech

We cannot divorce accuracy in ideas and plans and arithmetic from accurate speech. The only link between the engineers who design things and the men who make them is the blueprint that contains the dimensions and specifications; the only communication of ideas between people is by language.

We need to take care in our language, written and spoken, not against bad grammar but against what is much worse, loose, generalized, garbled and inaccurate thinking in words. The person or the book wrongly named, the date a week or ten years off, the statement that demonstrates that since a thing is not black it must be white, the column total a cent out — these are not almost right: they are altogether zero in the scale of accuracy.

General statements should be analysed to find their real worth. "Business is good" is a general statement that does not mean at all what is conveyed by the statement: "business is 15 per cent better than in this period last year". The fiction, so widely accepted and thoughtlessly repeated, of "total darkness" in the Arctic winter was exploded by a scientist's measurements at Point Barrow. His record showed that, though the sun does not climb above the horizon for about two months, there are several hours of good daylight every day.

The first principle in accuracy is to know, the second is to learn the art of interpretation, the third is to form a judgment or to admit that enough evidence is not available and that judgment must be suspended. In all these the crucial point is the tolerance: how much leeway shall be allowed between absolute accuracy and passable accuracy? How sure must we be that our interpretation is the only accurate one? How certain are we of the rightness of the judgment we are about to hand down?

How much tolerance?

Either the love of accuracy or the liking for wide tolerance may act like a drug that, given in small doses by competent practitioners, can be greatly beneficial, but when used immoderately can be harmful or deadly. Accuracy must be used as a tool. If it is allowed to become master, life will turn into a wearying affair of insignificant detail, endlessly refining the measurements of everything from the physical properties of the elements to the spiritual achievements of geniuses.

The Weights and Measures Act of Canada, 1951 — that prosaic document — while providing penalties for infringement of certain standards, wisely allows a margin that it calls: "the amount of error that may be tolerated in weights, measures, weighing machines and measuring machines."

Tolerance in everyday social and business life distinguishes what is essential and what is not, and allows the unessential to go as it will. Prudence consists in knowing how to distinguish the occasion. For most household measurements "a little over" or "a little under" is a close enough judgment for practical purposes. To be accurate within a million years would take high honours in certain fields of geological reconstruction of the past. Scientists working in the field of spectroscopy use what are called angstrom units, each of which is less than four billionths of an inch.

Business people need to find their own level of accuracy, dictated by the nature of their product, their individual standards, and the quality of their workmen and associates.

Just as the precision of measurement can be taken as a measure of mankind's material progress, so can it be a factor in the development of a business. Accuracy is a first-class business principle when it takes into account the tolerance that must be allowed in some cases due to the limitations of machines and men, and the tolerance that can be allowed in other cases when relaxation of demands will make the work go more smoothly without lowering the quality of the product.

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