A STUDY OF THE FUNDAMENTALS OF INDUSTRIAL STANDARDIZATION AND ITS PRACTICAL APPLICATION, ESPECIALLY IN THE MECHANICAL FIELD

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PROEFSCHRIFT

TER VERKRIJGING VAN DEN GRAAD VAN DOCTOR IN DE TECHNISCHE WETENSCHAP AAN DE TECHNISCHE HOOGESCHOOL TE DELFT, OP GEZAG VAN DEN RECTOR MAGNIFICUS DR. J. G. RUTGERS, HOOGLEERAAR IN DE AFDEELING DER ALGEMEENE WETENSCHAPPEN, VOOR EEN COMMISSIE UIT DEN SENAAT TE VERDEDIGEN OP DINSDAG 12 SEPTEMBER 1933, DES NAMIDDAGS TE VIER UUR, DOOR

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AAN
DE NAGEDACHTENIS
VAN MIJN OUDERS

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CHAPTER I

EVOLUTION OF STANDARDIZATION

TYPES OF STANDARDS

The attainment of a certain effect or result, or *performance,* was the original basis on which primitive man long ago established the prototype of the modern industrial standard. The first time he chipped off a piece of flint to make a tool, he was concerned solely with the result he could obtain with that tool — splitting, or scraping, or boring — and not with such questions as to what its material consisted of, or whether it had the most effective dimensions.

The use of a tool, say a hand axe, comprised two factors, an *action* and a concrete *physical object.* The performance depended on the basic elements of each of these individual factors, such as the size, shape, weight and sharpness of the tool, and the force applied to it by its user, and on the coordination of these elements. For long ages to come, this coordination would depend solely on the judgment acquired by trying to accomplish the result desired, or in other words, on a performance test. A standard of performance thus became, from the practical point of view, the most primitive and yet the most significant type of standard.

Experience gained in attaining the desired performance supplied definite but still crude instructions for the action and the physical object involved. Gradually, through many generations, these instructions developed into the standards adopted by the tribe for the training of its craftsmen in the making of tools, weapons, and other objects. Observation of performance and of the means of attaining it — the action and the physical object — led to a *method,* that is, a formula expressing the essential features of an action. In the course of time, a collection of actions was linked together into a *process,* and a collection of methods into a *practice.*

Meanwhile, man's increasing intelligence and power to observe and visualize began to enable him to connect causes and effects, and to judge possibilities of performance, instead of performance itself. He began to estimate *capacity* to perform [1]) and to take *measures,* either to cause something to happen, or to prevent something from happening, in case certain events or changes in condition occurred.

[1]) A capacity is a potential performance.

Another step forward was for man to take the initiative by creating a desired *condition*, instead of remaining on the defensive by taking measures against an undesired condition. This was comparable to the step he had taken in earlier days when he began to shape objects to suit the purpose for which he wanted to use them, instead of being satisfied with the crude objects which he found in the state as nature supplied them.

Having started with a requirement of performance and gradually arriving, through observation of cause and effect in practical experience, at a definite method of attaining performance, man often constructed a *conception* of what he did not yet understand. This was done either in an emotional way [1]), or in order to create a tentative basis to work from, a practical solution of the problem being otherwise impossible.

The establishment of a standard on the basis of a conception — in the absence of definite knowledge of facts — is a procedure adopted even in the highest form of modern scientific research. While research constitutes the most essential means of advance into the territory of the unknown — contrasting in this respect with standardization which consolidates the positions after an advance has been made — it uses standard conceptions as a basis for a theory and the carrying out of a coordinated program of investigation intended for checking this theory. This is done while realizing from the beginning that the hypothesis is a tentative level which will be shifted on account of the very findings to which its adoption will ultimately lead. Accordingly, there is no difference in essence between the "engineering approach" and the "scientific approach" to a problem. There is only a difference in the degree to which the investigation of cause and effect can be pushed, due to the fact that engineering often is required to produce results under high pressure of urgency, thus being obliged to set tentative levels based on practical experience without being able to wait for the results of more fundamental research.

The skill of the designer in "composing" a machine on paper involves an intangible element akin to that of the creative power of the artist or the musician. This ingenuity or inventiveness permits him to arrive at solutions which knowledge and reasoning alone would not have produced. While giving due recognition to this fact, it is the task of engineering

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[1]) A characteristic example of emotional conception still active in our machine age is the possessive animism of many workers in regard to the tools used, or machines operated by them. See Joy in Work (English translation of Der Kampf um die Arbeitsfreude), by HENRI DE MAN, page 26 ff.

constantly to replace this element of intuition by definite knowledge of facts as a superior means of controlling results and of building up the art of design. This question which also touches directly on the attitude of the designer toward standardization, will be dealt with in more detail later in this study [1]). Suffice it to say here that even though standardization may transfer the solution of problems from the "intuition" phase to the "knowledge" phase, this will not render the designer's gift of intuition useless. On the contrary, there will always be problems — and their number constantly increases — for whose successful initial solution the faculty concerned is helpful, if not indispensable.

Conceptions, whether they remain valid for a short or a long period of time, cannot be set up without definite basic *concepts*. Mass, force, speed, and time, to mention only a few concepts commonly used in industry, have become measurable values. Other concepts, equally old, are still non-measurable. A case in point is fatigue, a factor of primary importance in the performance of work by human beings about which still too little is known from the physiological and the psychological points of view to express it in terms of measurement.

Inseparably connected with concepts are the means of expressing or representing them. Such means appear, in industrial standardization, in form of the numerous terms and symbols forming the essential language of the engineer and the technologist. This language may become a truly universal one, such as is the case with certain methods of representation used in engineering drawings, and the symbols used in chemistry.

Conceptions of technical and human problems — for example, in cases where the relations between management and labor are involved — are reflected in *attitudes* which often serve as standards to determine the policies of an industrial organization. Standards of this kind may be as important with regard to the smooth and successful operation of an organization as the technical standards adopted for the manufacture of its product. This question leads to the distinction between technical and managerial standards, to be referred to later [2]).

The most important form of standard next to that primitive form, the performance standard, is the *unit of measurement*. It was only this form of standard that made thorough coordination in industry possible by creating a means of expressing the magnitude of concepts which — as far as is known at a given time — constitute the essential features of an

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[1]) This Chapter, page 8ff, and Chapters VI and VII.

[2]) Chapter III, page 40.

object [1]) and thereby detach the possibility of coordination from the necessity of bringing together the factors actually to be coordinated. In other words, measurement first made it possible to have widely separated individuals or groups express their common problems in a definite standard language (terms of measurement) and also to place the data acquired on record so that they might be conserved and transferred to later generations. Measurement thus became the most powerful tool of coordination — which essentially is the unification of the elements controlling the connections of cooperating factors [2]) — and of the conservation of experience and knowledge once acquired.

Measurement is also indispensable in fixing a constant level to serve as a temporary basis for a plan of coordination. Its use is therefore an essential requirement for the carrying out of both of the elementary functions of standardization, namely stabilization and coordination. It serves to express a dimension or quantity in a numerical value, as well as a position relative to a selected standard base or level.

Primitive man was obliged first to proceed by judgment which, continuously increased by the results of practical experience, served to establish a crude basis of comparison. The advent of measurement enabled man to free the objects requiring coordination from the limitations of his personal observation and its unavoidable variations [3]). It thus enabled him to refine comparison to the point where results obtained by different individuals and means became, with close enough approximation, suitable for being considered as identical for all practical purposes.

A prerequisite for the carrying out of a comprehensive scheme of coordination is the unification of the units of measurement themselves. This has progressed to a considerable extent, in so far as the most commonly used units are concerned [4]). However, the world has still to deal with two major groups of these units, namely those most commonly used in the English speaking countries (yard, pound, etc.) and those used in the metric countries (meter, kilogram, etc.)

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1) The term "object" to be taken here in its widest sense, and not in the restricted sense of a concrete physical object.

2) Chapter II, page 14.

3) The error due to the personal factor which always remains present in measurement, how much its magnitude may be reduced, is disregarded here.

4) To cite only one example of previous diversity in units of length: the different yards (Ellen) in use in the state of Baden (Germany) in the beginning of the 19th century numbered 112. See Grundlagen und Geräte technischer Längenmessungen, by G. Berndt (Berlin, Julius Springer, 1929).

This difficulty is attenuated, in so far as length measurements are concerned, by the fact that in both the inch and the metric system industry is using to an even increasing degree limiting values given in several decimal places. This use in the mechanical and related industries is due to the requirements of interchangeable manufacture [1]). As a result, round values have lost much of their importance. This fact, and the agreement on a standard conversion factor between the inch and the millimeter, greatly facilitate the relations in this respect between the two groups of countries [2]).

The establishment of a unit of measurement is merely a matter of agreement, once the essential problem of what should be measured has been solved. This solution depends — in so far as industrial standardization is concerned — on the question as to what factors are found to be essential for compliance with the requirements of the object to be standardized. In other words, while measurement (comparison of objects on the the basis of a definite unit) puts the final touch on the problem of standardization as a technique, the essential problem still consists in the analysis of the result (performance or condition) aimed at, and the compliance with its basic requirements.

It thus appears that the original and most primitive of types of standards, the performance standard, and the most refined type, the unit of measurement, form the extremes in the series of types that have evolved in the course of man's history. The development of industrial standardization work in a specific field must also pass through successive stages, the first of which involves the setting up of a pure performance standard and the last one, the establishment of a unit of measurement. If we review the collection of standards existing in a certain field, it is possible to classify the standards, or the subdivisions of an individual standard, according to the different types mentioned above, namely performance standards, units of measurement, and the other types that have developed between these two [3]).

The performance standard defines only the result to be achieved, without giving an indication of the nature or the magnitude of the factors

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1) Dimensional limits expressed in thousandths or tenthousandths of an inch or in thousandths of a millimeter (microns) are commonly used in the mechanical industry.

2) For industrial use, the standard conversion ratio 25.4 between inch and millimeter has been adopted in the United States (American Standard for Inch-Millimeter Conversion for Industrial Use, B48.1-1933) as well as in Great Britain (Conversion Tables, No. 350-1930, published by the British Standards Institution).

3) Examples are given in Chapter III.

to be used for this achievement. The unit of measurement, on the contrary, serves merely to express the value of these factors, but has no bearing on the question what this value should be.

Although the present study deals more particularly with technical standards, a brief mention of standards of a managerial character may be made for the sake of completing the picture of industrial standardization. In the course of the ages, practices which had proved to be effective became adopted to sustain and protect the tribe, and with the primitive beginnings of the organization of human society, tasks were chosen by, or assigned to, specific individuals. Keeping watch, providing food, tending the fire, and the making of utensils and weapons became so many standard *functions* to be taken care of. When the performance of these functions was assigned to individuals, they contained an element of *duty* and *responsibility*, thus becoming, with their counterpart, a *right*, the forerunners of the modern systematically established managerial standards. Assignment of duties and responsibilities is possible only, however, if a definite scheme of mutual human relationships and standards of *behavior* have become adopted. This kind of standard, while primarily managerial, has its technical aspects just as well as the standard condition. For example, its influence on the surroundings of the worker, and therefore on his work, is becoming better recognized.

HUMAN FACTORS.

To obtain a complete picture of the present status of development of industrial standardization we must also consider various human factors that have exerted a profound influence on its evolution. Prominent among these are certain characteristics of the human leader and the attitude toward standardization taken by the craftsman and the merchant types of men which affect directly the nature of industrial standards set up in practice as well as indirectly (but often decisively) the question whether or not a business organization will adopt standardization as a managerial function.

Leadership

In the early days of the human race, the mind of man developed only gradually to the point where it could apply analytical methods to his problems. Therefore, by the time man began to analyze, solutions based on judgment and intuition which had already become habitual, were crystallized into countless traditional practices. Due to the unending succession of urgent, if not vital, problems, man had not spent any considerable time on efforts to trace the chain of causes and effects in what he had been doing. The solving of new problems had been more urgent than the refinement or explanation of existing practical solutions.

Under these conditions it was natural that leadership became identified with the ability of getting results, rather than with the possession of analytical faculties. Performance alone became the earliest criterion of leadership. Thus the leader himself, as a type, naturally came to believe that his ability to get things done was his main asset rather than any faculty which he might possess to devise methods for getting them done. For many centuries analysis, fact-finding, and planning remained in the background as theoretical instruments that were rather dreary and unattractive to the average "born leader". Short-cut solutions based on judgment and intuition unconsciously combined with inherited tradition and practical experience agreed better with his natural inclinations. This aspect of the evolution of the leader type of man has created a resistance to the introduction of analytical methods in all phases of industrial work. The idea that the conduct of business, or management, could be made subject to measurement, at least to some extent, and that managerial functions could therefore be embodied into a piece of "automatic organization machinery" was contrary to the traditional conception of leadership and the indispensable expert judgment which it was supposed to possess. It was felt, often unconsciously, that standardization, if it actually were able to run part of the business by itself, would take away a corresponding share of the prestige in which the leader of that business had so far taken great pride. This attitude was parallel with that of the craftsman who thought that the introduction of automatic machinery would make his skill superfluous and his services valueless. Unless he had a deeper insight into the significance of standardization, it meant to many an executive that at least part of his judgment could be replaced by managerial standardization embodied into a system of standing orders and instructions, just as physical human motions were standardized and transferred to production machines. Because of long tradition, the leader naturally doubted that this could be done successfully, but still it seemed better to keep standardization at a safe distance rather than to give it a chance of supplanting "personal judgment" and "initiative" in leadership. This comprehensible trait of human nature has probably done more to bar progress in the adoption of standardization as a recognized tool of industrial management than many other forms of resistance encountered in its application. It is no doubt one of the main causes why standardization has not yet been introduced more widely into industrial practice in spite of the fact that for many years the central bodies founded in the most important industrial countries for the special purpose of promoting the use of standardization, have been emphasizing its benefits and offering their assistance in applying its principles.

The inclination of the early type of leader to keep away from standardization particularly affected the application of industrial standardization after the merchant had joined the craftsman as a partner in his business. Before discussing this point we must review some fundamental differences in types developed in earlier stages of the human race.

The Craftsman

Man had to "invent" his way out of the animal world and the abundance of problems which he had to solve furnished a constant spur to activity in this direction. Every improvement in a tool or weapon gave him greater supremacy over his surroundings. Also, the very application of a new invention supplied him with new experiences which he gradually became able to use in a systematic way. Once the human race had evolved to the point where it became interested in the so-called law of cause and effect, there developed a type of man who became intensely fascinated by the workings of this law, even more than by its results. This prototype of the scientist began to differentiate itself from the early leader type which was interested primarily in results.

Somewhere between these two extremes, primitive leader and early scientist, the craftsman gradually developed as a type constantly trying to get better results by using new materials, methods and tools, yet tightly bound by the practical possibilities and limitations of these factors. While he would try out a new invention on the mere belief that it would work, the results would show clearly and immediately whether his guess as to possible performance had been right. Consequently, how little he might know or how much he might assume about the solution of a problem, any move not in accordance with natural laws would sooner or later demand correction. Without impairing the desire of the craftsman to pioneer into the unknown, this inescapable check of practicability gave him an attitude of matter-of-factness which became the inheritance of his modern successor, the engineer. Meanwhile, the craftsman bent on practical results did not escape from the general rule that methods counted less than results. Bound to strive for continuous progress he was more likely to build further on practical achievements than to reverse the process by analyzing solutions found by trial and error. In this desire to get things done he was a close relative of the early type of leader. On the other hand, his struggle with practical problems and his triumph over these tended to imbue the craftsman with an affection for the solving of a problem rather than the ultimate result. In this respect, he was closer to the scientist to whom the solving of a problem is an end in itself. However, the danger lying in the cherishing of a solution is that it may cause a man to adhere to it as his own standard and to dislike parting with it even though there is a chance, or even a probability, that a better solution can be worked out. In the craftsman's case this attitude is directly affected also by the individualistic and creative factor which he must possess to deal successfully with problems not yet solved by analysis, which factor he has in common with the artist. He may value this intuitive power to the extent of applying it also to that part of his work for which facts could very well be secured, with a consequent tendency to neglect the possibility of applying the analytical method essential to research by which sound standardization should be preceded. Thus, the craftsman who by his nature is not unreceptive to the possibilities of standardization is found to possess certain characteristics which may cause him to refrain from lending full cooperation in cases where certain personal views must be given up if a compromise is to be reached for the sake of setting up a common standard. Yet, there is generally a fair chance of getting the average craftsman to yield if the desirability of such a compromise is duly supported by facts.

Since the craftsman as a type is related to the scientist as well as to the primitive leader, he may be expected to possess some traits of both. In fact, one finds that in certain cases he will be inclined to dismiss the analytical approach to a problem as uselessly theoretical and academic, while in others he will oppose too drastic concessions to the layman's taste if these are deemed incompatible with sound technical requirements. The advantages of the combination of the "do-er" and the "thinker" types become apparent in the high class type of craftsman who knows exactly where the value of theoretical considerations ends and practical experience still forms the only reliable working basis.

Craftsman-Merchant Partnership

"Usufacture", or manufacture exclusively for the maker's own use, formed the first stage of industry [1]. Next was the stage of "retail handicraft" in which the craftsman had a surplus of product which he sold to or bartered with others in his immediate neighborhood. Then came the period of "wholesale handicraft" characterized by the splitting up of the functions of manufacturing, selling, and using the product between three separate groups of persons. The task of selling the product to the user was taken over during the so-called independent stage of the "wholesale handicraft" period by the trader who first served as the craftsman's agent, buying his goods and selling them to others. In the course of time, the trader developed into the merchant or industrial entrepreneur, who financed the craftsman's trade by purchasing his materials and later also his tools and equipment, and even his plant, thus becoming the dominant figure in the partnership. Ultimately, this led to the craftsman becoming a worker hired by the merchant. The craftsman was consequently shifted from his home, first to the central workshop (still without power supply) and later on to the power driven factory, for the sake of better supervision and consequent higher efficiency of the manufacturing process.

The partnership between the craftsman and the merchant has influenced the nature of standards set up in different trades as well as the extent to which standardization has been adopted up to the present time by industrial management in general [2]. The craftsman, as a type, had become fascinated by the product and its manufacture on account of the technical problems. The merchant, as a type, became equally fascinated by the possibilities of the product considered as an object of potential sales [3]. To the craftsman the product is an end in itself, while to the merchant it is only a means to an end. The craftsman may spend his life in the workshop and be successful and happy. The merchant's task, on the contrary, consists of getting in touch with prospective customers, in finding out their wishes and trying to comply with them. To do so successfully, he must have the talent for approaching other people which is not necessarily a requisite of the craftsman. No doubt the latter as a

[1]) See Industrial Evolution, by NORMAN S. B. GRAS, whose terminology ("usufacture", etc.) has been followed here.

[2]) See Chapter V.

[3]) We are dealing here with types, in the sense of abstract combinations of certain characteristics. Pure types being "limiting cases", most human beings are a mixture of different sets of characteristics. Just as a merchant may be found actually cherishing the product in a craftsmanlike way, just so some craftsmen are more or less commercially minded. In general, however, the two types are sharply distinguished. The question "Can a good engineer be a good salesman?" comes up for discussion time and again, in the technical press.

leader in technical matters must know "how to handle men" but he has to deal almost exclusively with his own personnel.

Wishing to give the customer what he wanted, the merchant was naturally disinclined to favor the relative limitations imposed on the product by a standard. In a previous period the craftsman, still being his own master, would have adopted a standard for his work from which he did not deviate, even to please a customer. However, such an attitude was incompatible with the primitive merchant's conception of "building up a market". The wider vision that it is possible to develop a market based on standardization of the product did not come to him until much later. He preferred to adjust the product to the greatest extent possible to the wishes of the customer, rather than to lose a customer or forego the chance of making a new one. Even technical soundness of the product might be disregarded on the insistence of the customer — naturally, against the advice of the craftsman. Furthermore, the traits inherited by the merchant from the primitive leader were incompatible with a favorable attitude toward standardization, as explained before. This factor probably has been still more important than the merchant's lack of favor of standardization — or even his opposition thereto — from the viewpoint of sales policy. If he had realized the greater flexibility of a product obtained through standardization of its components, either as simple elements or as sub-units, and its consequent greater adaptability to the wishes of the customer, this might have won his support for standardization. However, the thought that standardization would detract from his prestige as a leader created a pertinent bar to its adoption as an executive function. This attitude which still prevails in many organizations may account at least in part for the lack of general adoption of standardization as a definite managerial policy in industry, evidence of which will be brought later [1]).

Just as the merchant joined the craftsman as a partner in his business ultimately to dominate him, the merchant was joined in a later phase of industrial evolution by the banker — and often dominated by him. The banker is still farther remote than the merchant from the craftsman's way of looking at industrial problems. The product, sales sheet and dividends sheet are the respective performances in which the craftsman, the merchant and the banker are essentially interested. The extent to which the latter two types are interested in the factors on which these performances depend is naturally limited. Consequently, the chance that the banker

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[1]) Chapter V.

will understand the craftsman's problems and way of thinking is still smaller than the chance that the merchant understands the craftsman. Moreover, while the craftsman and the merchant usually work together as members of the same organization, the banker's influence reaches into the industrial concern from the outside, a fact which is not conducive to his understanding of problems of industrial management [1]).

It thus appears that the different stages through which the industrial concern has evolved in the course of time — craftsman, merchant and banker supremacy — have by their very nature been increasingly unfavorable to the recognition of the value of standardization.

SUMMARY

(1) The series of types of standards which have developed in the course of human civilization begins with a performance standard and ends with a standard unit of measurement. These two types are the most essential ones in any kind of standardization work undertaken.

(2) The standard of performance, while specifying requirements, leaves complete freedom in the choice of the means by which these requirements shall be met. The unit of measurement serves to coordinate the factors required for attaining a performance, but is independent of the question what the actual values of these factors should be.

(3) A standard reaches its highest degree of effectiveness when its requirements are stated in terms of measurement.

(4) The abundance and urgency of problems facing man since the dawn of the human race led to the kind of leadership that is based on judgment rather than on analysis of facts.

(5) In the course of human evolution the craftsman developed to a type of man related to the scientist because of his interest in cause and effect and yet forced to use judgment on account of the necessity to produce tangible results. These very results showed him continuously whether or not his judgment had been right, thus keeping a practical check on his activities.

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[1]) An editorial entitled Handicapping Management (American Machinist, May 5, 1932) said in part: "Many high managerial executives in this country are handicapped by rules and restrictions imposed by those who control the finances but who know nothing of plant operation. This leads not only to discord but to actual losses in the operation of many plants. It is time that the value of plant management was fully recognized in our own country."

(6) Accordingly, the craftsman while becoming a matter-of-fact type of man developed a sense of intuition or ingenuity in regard to things mechanical without which human progress would have been less rapid. Being proud of this sense, the craftsman is sometimes inclined to use judgment also in cases where the factors involved in his problems have become measurable and judgment should therefore no longer be relied on.

(7) The fact that the trader — developing later into the merchant or the industrial entrepreneur — joined the craftsman in his business, with consequent division of labor along technical and commercial lines, was bound ultimately to result in supremacy of the merchant in the control of industrial activities. In a later phase the merchant in his turn became dominated in many cases by the banker.

(8) The craftsman's tendency to adhere to certain standards of quality adopted by him for the material and workmanship of the product may naturally conflict with the merchant's tendency to comply with the wishes of customers in so far as these involve frequent non-essential changes in the product and possibly even the departure from sound technical practice.

CHAPTER II

ESSENTIAL FUNCTIONS OF INDUSTRIAL STANDARDIZATION

Industrial standardization essentially consists of the performance of two functions. One is the establishment of a temporary constant level of requirements or conditions under which the practical industrial application of a basic idea will be possible, technically as well as economically. The other function is the coordination of all factors whose harmonious working together is required for complying with the conditions determined by the temporary level of stability. Coordination is the unification of such elements of these factors as will secure their harmonious working together. In combining the two functions care must be taken to leave sufficient facility for making a shift from one temporary level to the next one, if and when this becomes necessary due to progress made in the art.

PROGRESS-TIME CURVE

Industrial progress due to new basic ideas (discoveries and inventions) plotted against time is represented by a continuously rising curve. The practical application of such basic ideas cannot follow such a curve. The development of each of them into the regular manufacture of a product or some other industrial activity requires time for building up the necessary machinery, figuratively, and in most cases literally speaking. The best that can be attained is the approximation of the progress-time curve by a broken line. The horizontal parts of this line represent levels on which practice will be based during successive periods of time, independent of the rise made in the meantime by the progress curve. The vertical parts represent the shifts from each level to the next one. The graph in Fig. 1 representing the development of a manufactured product [1]) from the moment of its basic conception will illustrate this point. This development may be divided into three main phases. The first phase begins with the conception of a basic idea (A), which may be the result of invention or

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[1]) The curve representing the development of a composite product may be considered as resulting from the combination of similar curves applying to its elements which at a particular time may or may not be in the same phase of development.

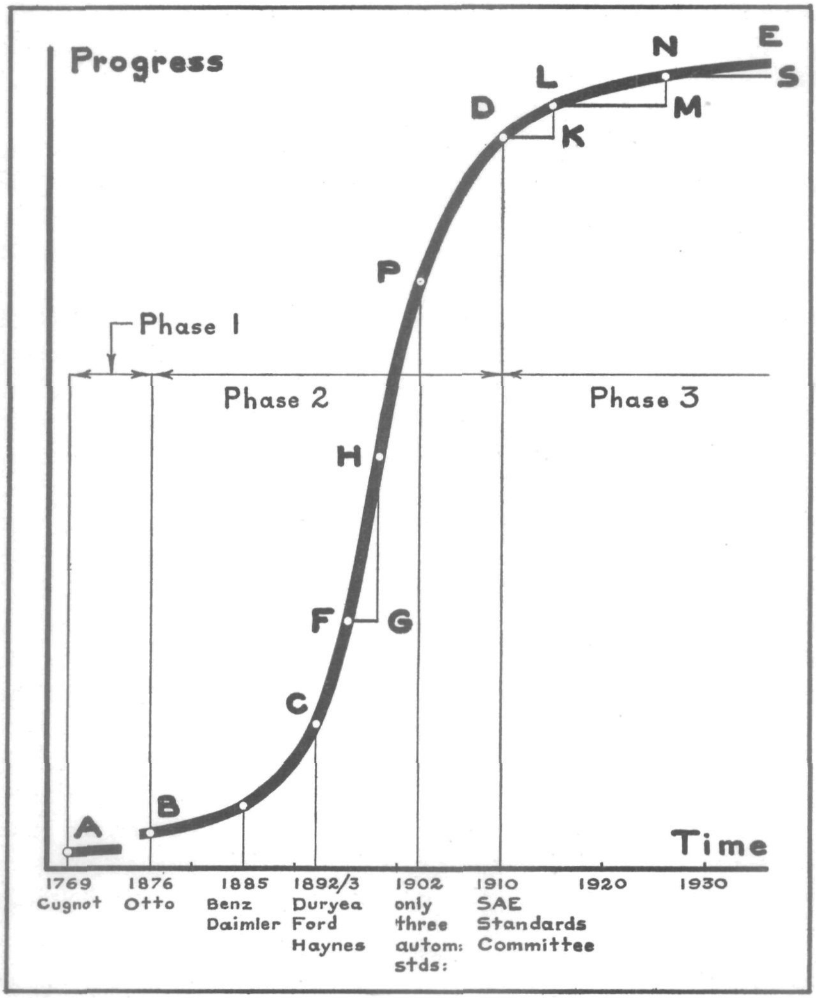

Fig. 1. Progress-Time Curve.

discovery. For a long period of time this basic idea may remain unsuitable for practical application because certain indispensable elements are still lacking. There may be a gap in the technical solution or the technical solution may be complete but still too expensive for economic application. In both cases the world has to wait for one, or perhaps more further inventions or discoveries [1]). Once the chain of elements required for the practical application has been completed, the basic idea becomes the beginning of an actual industrial development (B). This is also the end of the first main phase AB which might be called the "latent" phase.

From the point B on, the rate of progress will increase. At first, many problems of secondary importance have still to be solved [2]), but the product is being manufactured and tried out in practice, be it still in very small numbers (stage BC). At C the product has found a market and manufacture is started in greater volume. Mutual induction between the efforts of industry to perfect the product and the results of practical experience gained with its use cause a steep rise of the progress curve from then on. Improvements follow each other in quick succession. The entire second main phase BD might be called the "development" phase whose early portion BC still has an entirely experimental character. During it, the product acquires a definite form as to its essential features.

From D on, only minor improvements are made [3]). Accordingly, the progress curve flattens out and approaches the horizontal direction asymptotically. This third main phase DE might be called the "saturation" phase [4]). In general, it is not possible to determine exactly the point where the second phase changes over into the third. (Contrasting herewith, the transition from the first phase to the second is often quite distinct). The third phase may last until a further basic improvement causes a new rise in the progress curve, or until the manufacture of the product is abandoned because the latter is superseded by a competitive one.

A progress-time curve of the kind described cannot be recorded in an exact manner, as it is impossible to assign a definite progress rating to each development causing a rise in the curve [5]). It is possible, however,

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[1]) The basic form of the present airplane (monoplane) was known to be suitable for mechanical flight about ninety years ago. In 1842 Stringfellow built a model driven by two propellers which was the first to make a flight (Enc. Brit., 14th Edit., Vol. 1, page 243). However, the airplane as a means of transportation had to wait for the development of an engine with a high enough power-to-weight ratio.

[2]) For example, the ignition and the carburetion systems of the gasoline engine, in its early days.

[3]) For example, the bicycle in Europe during the last 30 years.

[4]) The "saturation" is meant to apply to the progress in the art, and not to the market of the product.

[5]) In the evolution of the automobile industry, for example, we may single out the several steps leading up to the present type of gasoline engine; the application of interchangeable manufacture and continuous flow production; the development of special machine tools and of alloy steels; and the results of the research work on fuel problems carried out during recent years.

to determine its general shape on the basis of the considerations mentioned above. This is sufficient for our present purpose, namely to determine that point of the curve where industrial standardization may successfully be started. In practice the decision whether this point has been reached must be taken on the basis of the conditions observed to exist in each individual case. This is due not only to the fact that the progress cannot be rated in an exact manner, but also to the circumstance that the state of the art is only one among several factors influencing a program of standardization. Business policies of interested groups may delay the undertaking of standardization work well beyond the point where it becomes feasible in so far as technical progress is concerned.

The progress curve and the temporary levels or standards show at a glance what it means to have no standards at all, as well as the consequences of adhering to a standard for an unduly long period of time. If there are no standards at all, the progress curve will dictate continuous changes, thus preventing the full development of any particular form of the product. Adhering to a standard too long means that the gap between the progress curve and the level of the standard is allowed to become too wide. This situation will make the adjustment to the progress curve, once it must be made, extremely difficult. Also, the delay suffered in making this adjustment may result in a permanent loss of business through obsolescence of the product or through its being overtaken by a competitive product.

WHEN STANDARDIZATION CAN BEGIN

The graph in Fig. 1 shows that standardization cannot be applied before the point D of the progress curve, the beginning of the third phase, has been reached [1]). During the first phase AB, there is not yet any question of an industrial development properly speaking. This is true even though a considerable amount of research data on basic facts may have been collected by the industry concerned. The second phase BD is at first an experimental one. Its part CD is characterized by rapid development involving frequent changes and considerable improvements of a more or less fundamental nature. If a standard were set up during this phase, say at F, revision would become necessary shortly afterward, say at G.

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[1]) It may be possible to standardize certain components of a product before standardization of the entire product can be undertaken. The individual curves of these components have then reached their respective points D without this being the case for the composite curve.

No coordination, the second function of standardization, can be started on the basis of a level of conditions which itself remains stable for only a relatively short period of time (FG). When the beginning D of the third phase has been reached, a large market had been secured for the product. The rate of the latter's improvement, at least in respect to essentials, has slowed down. Agreement has been reached, explicitly or implicitly, on the type, the performance requirements, and in many cases even on the main dimensions that are most desirable for the product with a view to its practical use, but due to lack of coordination of such agreement, no definite and general uniformity exists as yet. However, conditions are now favorable for the successful undertaking of this coordination. If D is the point where it is started, this means that industrial practice will temporarily follow the horizontal line DK instead of the progress curve DE. In the meantime, basic progress continues to move along this curve. The increasing distance between the latter and the level of the standard DK creates a growing "pull" which tries to force industry off the adopted level DK, so that it may adopt the latest improvements. As long as the benefits derived from the existing standardization plan [1]) still exceed those to be gained by changing over to the new practice, the standard DK will hold its own. As soon as the stability of the standard is overcome, a new standard, say LM, will be set up as a revision. Provision must therefore be made, in setting up the original standard, to permit such a change to occur without undue hardship when the "pull" toward improved practice becomes strong. Else the result will be that industry abandons the old standard in its actual practice. This clearly indicates that there is a fundamental danger of over-stabilization in standardization work which may be due to different causes to be discussed in detail later [2]).

When a new standard LM has been established, the same phenomenon is repeated. The graph shows that if the "pull" required for a change in the standard remains the same — being equal to KL, in terms of progress — the standard LM will remain valid for a longer period of time than the standard DK. The same statement will be true for each subsequent revision of the standard, such as NS. Finally, the time comes when the progress curve runs so closely to the latest standard level that

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[1]) To be discussed more in detail in the following chapters.

[2]) The change from one standard to another under the influence of progress in the art may be likened to the shift in position of an engine governor which occurs when the speed of the engine has increased a certain amount.

no tendency to depart from this level develops. In this way, a "stabilization of the standard" may ultimately result, unless special causes, such as a change in the demands of the buying public, upset this condition.

PROGRESS-TIME CURVE OF THE AUTOMOBILE INDUSTRY

We shall briefly review the evolution of the automobile industry to get a concrete example of a progress-time curve of the composite type. The significant phases of this curve may be established with fair approximation as follows.

First phase AB, Fig. 1

Going back as far as CUGNOT, who built and operated a steam tractor in 1769, we may take this year as point A, the beginning of the first phase. The most important step toward the further evolution of this steam vehicle to the modern automobile may be taken to have consisted in the practical application of BEAU DE ROCHAS' principle of the four-stroke cycle in OTTO's gas engine of 1876. The year 1876 (point B) may therefore be taken as the end of the first or latent phase AB, and the beginning of the second or development phase BD.

Second phase BD, Fig. 1

The experimental stage BC of the second or development phase BD is marked, for example, by the achievements of BENZ and DAIMLER, who about 1885 built and operated a motorcycle and a car driven by a gasoline engine. This initial stage is considered as having ended, and actual industrial development as having begun, around 1892, for the following reasons. In 1892 and 1893, DURYEA, FORD, and HAYNES completed and operated their respective first cars driven by gasoline engines. It is true that at first the increase in production was slow and that it took about ten more years before automobiles began to be manufactured in any considerable quantity in the United States [1]), but in France, PANHARD and LEVASSOR began to manufacture for the market as early as 1893, building 350 cars during that year [2]). In 1896, there were still only four makes of cars in the United States: the Duryea, Ford and Haynes cars, and the imported Benz car. The development of the production of passenger

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[1]) The Ford Motor Company, founded in 1903, made and sold 1708 cars during the first year (Enc. Brit., 14th Edit., Vol. 9, page 491).

[2]) Information from SAE files.

automobiles in this country up to 1910 is shown in Table 1. It was accompanied by a steep rise in the progress curve represented by its portion CD in Fig. 1.

TABLE 1

Production of Passenger Automobiles in the United States, period 1895 to 1910 [1])

Year	*Number*	*Year*	*Number*
1895	4	1903	11,235
1896	25	1904	22,419
1897	100	1905	24,550
1898	1000	1906	33,500
1899	2500	1907	43,300
1900	5000	1908	63,500
1901	7000	1909	127,731
1902	9000	1910	181,000

Third phase DE, Fig. 1

The year 1910 may be taken as the beginning of the period during which standardization in the automobile industry came into its own (point D in Fig. 1). In this year the Society of Automotive Engineers appointed the first standardization committee in the automotive industry comprising sixteen divisions dealing with such matters as: Aluminum and Copper Alloys; Ball and Roller Bearings; Carburetors; Frame Sections; Iron and Steel; Sheet Metals; Springs; Wood Wheel Dimensions and Fastenings for Solid Tires; and so on [2]).

How in 1910 the time had become ripe for comprehensive standardization work is shown by the following facts. In 1902, there were only three automobile standards, dealing with the spacing of tire lugs and holes; rim sections; and lamp brackets. The progress curve shows that in 1902 (point P), conditions were becoming more favorable for standardization, but that a standard was not yet likely to remain valid for any considerable length of time. The steepness of the progress curve began to decrease, but only around 1910 did standardization crystallize out as an important factor in the manufacture of automobiles. Significant in

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[1]) Facts and Figures of the Automobile Industry, published by the National Automobile Chamber of Commerce, editions 1929 (figures up to 1900) and 1930 (figures from 1900 to 1910).

[2]) History of Automotive Standardization (SAE Journal, June 1930).

this connection were two outstanding events just prior to 1910. One was the famous demonstration of the possibility to maintain perfect interchangeability of parts [1]) in the manufacture of an automobile, made by HENRY M. LELAND in 1908 with his Cadillac car [2]). The other event was that in 1908 HENRY FORD started to manufacture his Model-T car (adopted by him as a standard for mass production) by the continuous flow production method, applied by means of conveyors. This system

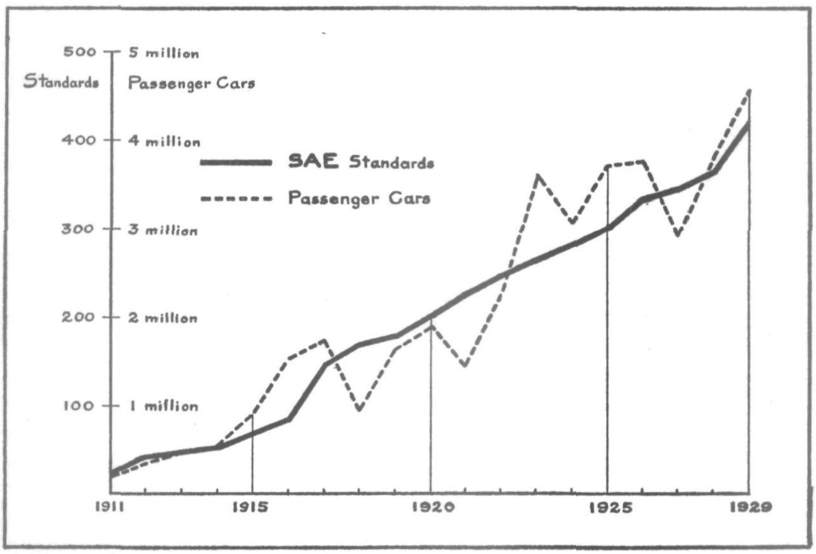

Fig. 2. Graphic presentation of data given in Table 2.

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[1]) For the general significance of interchangeability in the mechanical industry, see Chapter IV, page 49 ff.

[2]) "Three cars were chosen at random from the warehouse of the Cadillac agency in London, the cars were taken to Brooklands track and completely dismantled and the parts were placed in one conglomerate heap. Duplicates from the stock of spares were substituted for 69 parts in the pile; then three complete sets of parts were taken from the main heap without regard to the cars from which they were originally taken, and three 'new' cars were assembled. The only tools allowed were wrenches and screw-drivers; no files or emery cloth. After being assembled, all of the cars were started with a few turns of the crank and were driven several hundred miles on the track." The astonishing character of this achievement at that time is proved by the fact that the Cadillac car was awarded the Dewar trophy on this count (SAE Journal, May 1932).

called by its very nature for a high degree of standardization of the product as well as of the method of manufacturing it. The Model-T car remained in production until 1927, more than 15 million being made during the 19-year period of its existence. The short life of the Model-A standard adopted in 1927 and replaced in 1932 by the first V-8 model, which again was superseded in 1933 by another V-8 model, contrasts strongly with the long life of the original Ford car model and shows, among other things, how the demands of the public have changed.

The above mentioned facts prove that the automobile industry has well advanced into the third phase DE of the progress curve (Fig. 1). In this connection it is interesting to compare the growth of the SAE standards, during the period from 1911 to 1929, and the growth of the annual production of passenger cars in the United States during the same period, as given in Table 2 and represented by the graphs in Fig. 2 [1]).

TABLE 2

Growth of Number of SAE Standards (cumulative) and of Annual Production of Passenger Cars in the United States, Period 1911 to 1929

Year	*Number of SAE Stds.*	*Passenger Car Production*	*Year*	*Number of SAE Stds.*	*Passenger Car Production*
1911	20	199,319	1921	229	1,456,963
1912	40	356,000	1922	251	2,276,251
1913	46	461,500	1923	269	3,625,969
1914	53	543,679	1924	286	3,189,109
1915	70	895,930	1925	304	3,735,171
1916	87	1,525,578	1926	338	3,781,956
1917	149	1,745,792	1927	349	2,936,939
1918	171	943,436	1928	368	3,814,310
1919	181	1,657,652	1929	425	4,587,400
1920	206	1,905,560			

[1]) Source of figures: SAE Journal, June 1930, and Facts and Figures of the Automobile Industry. No doubt, the development of the standardization work in the automobile industry has been influenced to a certain extent by standardization undertaken by the mechanical industry in general. However, the automobile industry, with its outspoken mass production character, has been one of the leading groups in developing the technique of standardization.

BASIC AND OTHER STANDARDS

Usually, the extreme condition of stabilization will be reached in actual practice only in so far as standards for fundamental features or "basic standards" are concerned. Changes in details will probably continue to be made as long as the product is being manufactured. Such details can be laid down in standards which are of less importance than the basic ones and may be called secondary standards, tertiary standards, etc., depending on their place in the general picture. In undertaking a program of standardization work, it is desirable to carry this distinction in mind and to establish a classification of the requirements of the work (and consequently of the standards to deal with these requirements) on the basis of their essential significance. The individual standards should be subdivided into groups, so that those embodying the most important features may remain valid for a longer period of time than those referring to details. This will make it possible to undertake the revision of the standardization program in regard to details at more frequent intervals and with less disturbance than would otherwise be permissible on account of the difficulties inherent to every transition. Referring to the graph in Fig. 1, intermediate detail revision means a closer approach to the progress curve of the broken line followed by industrial practice.

A practical illustration of this principle is the separation between a standard for screw threads as used on bolts, nuts, and other products, and the standards relating to dimensions of these products other than dimensions of the threads, such as the width across flats and the height of bolt head and nut. Due to this separation, changes in the latter dimensions may be made without influencing the standard on the screw threads, and conversely [1]).

In exceptional cases the desire to maintain the validity of a basic standard during a relatively long period of time leads to the decision that it shall not be revised within that period. A case in point is the recommendation made by technical committee No. 3, on Fits, of the International Standards Association (ISA), to the effect that the values of the manufacturing limits and the permissible wear of limit gages laid down in a system of fits between cylindrical parts developed by the committee,

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[1]) Such changes have been made, for example, in the previous edition of the present American Standard for Wrench Head Bolts and Nuts and Wrench Openings (B 18.2 —1933).

shall not be changed during the next ten years [1]. The values in question have, generally speaking, only an indirect influence on shop operations and were the result of considerable discussion. Their constancy during a definite period of time was therefore deemed highly desirable, even though it was realized that progress would probably be made during the next period of ten years in two main respects, namely the further refinement in the accurate sizing of gages and the use of materials offering greater resistance to wear, such as tungsten carbide.

The principle of grouping standards according to their essential significance has particular value from the viewpoint of the integration of industries as part of the efforts made toward the building up of a stabilized economic system which must be supported by a framework of industrial standards resting on a lower structure of basic standards of universal scope applicable throughout different industries, such as the standards for the most commonly used units of measurement [2]; standard systems of inspection, testing, and rating; standards for screw threads, for fits between cylindrical parts, for paper sizes, for preferred numbers to be used as a guide in setting up standard series of various kinds; and so on.

ELEMENTARY AND COMPOSITE STANDARDS

Standards may also be subdivided into *elementary* and *composite* standards, independent of their classification as basic standards, secondary standards, etc. Mention of this subdivision is made particularly because of its practical importance in the mechanical industry. Here, a general distinction can be made between standards for elementary component parts (such as steel balls, cylindrical pins and washers) and standards for products of a more complicated nature (which may be single parts or assemblies, or even complete machines or apparatus) or composite standards. The demarcation line between elementary and composite standards is not alway quite distinct and may also depend on the viewpoint from which the standard in question is considered. For example, a standard for a screw commonly used by the entire mechanical industry will

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1) Resolution No. 7, adopted by ISA technical committee No. 3 at its meeting held in Stockholm, 1930.

2) The fact that the most important of these units are defined by *law* in the different countries and not by their respective *industrial* standardizing bodies, is immaterial in regard to the present consideration.

probably be considered as an elementary standard by the designer who specifies such screws simply by referring to the standard. However, on account of the independence of the specifications for the screw thread and those for the further dimensions of the screw, the standard may also be held to be a composite one.

The more elementary a standard is, the more chance it has of being suitable for several lines of products and possibly for several branches of industry. At least from the engineering viewpoint, the few requirements covered by a truly elementary standard can generally be unified for a considerable range of applications. It is unlikely that such a unification will be possible for all of the features covered by a composite standard because the requirements of different groups, either in regard to individual features of the product or to combinations of them, will vary. However, in many cases it will be entirely satisfactory in practice if the dimensions are unified that govern the connections of the product with others. The significance of this "connectability" and the necessity of assigning the totality of requirements to be complied with, to a group of standards in such a way as to secure the greatest flexibility of the entire system, will be discussed later [1]).

BALANCE BETWEEN STABILIZATION AND COORDINATION

One of the most difficult problems in standardization is the establishment of the correct balance between its two sub-functions, the determination of a temporary constant level of conditions, and the coordination of the factors on the basis of these conditions. The difficulty lies in the fact that the two functions are different in their essential character and yet mutually dependent. While the selection of a temporary level of conditions concerns primarily the change in conditions *through time,* coordination has for its immediate purpose the adjustment of conditions *at a certain time.* The two functions are mutually interdependent because a level of fixed conditions or requirements can be adopted only if it is known that the factors through whose cooperation these requirements must be met, can be properly coordinated at the time the level in question is adopted. Conversely, no plan of coordination can be carried out without there being definite knowledge of the goal toward which the efforts must be directed. Therefore, one must work from both ends of the problem toward its ultimate solution. In this respect, an industrial standardization program may be considered

[1]) See this Chapter, page 26 ff.

as engineering design on an enlarged scale. The designer of a machine begins by making definite assumptions which serve as a tentative basis for the determination of the details or the component parts of his design. In working out these details in an effort to harmonize their fitting together for the correct functioning of the whole, he may find that the lack of knowledge regarding some particular factor prevents proper coordination. The original assumptions made by the designer must then be revised accordingly. Therefore, in setting the goal, knowledge of the means by which that goal can be attained is pre-supposed. The most skilful designer is he who can best determine in advance the level of optimum result attainable with the means presently at his disposal.

The balancing of the two functions, selection of a constant level and the coordination of factors on the basis of that level, is particularly difficult because each of these two functions involves again the striking of a compromise between two requirements of an essentially opposite nature. The choice of a level of definite requirements must secure a stable basis for the plan of coordination without a shift to a new level becoming too difficult. The function of coordination is to adjust the cooperating factors to each other so as to make them comply jointly with the definite requirements. Yet, the greatest possible freedom must be left as to the manner in which this compliance is effected. In other words, while the two functions have for their primary purpose to stabilize and inter-connect, respectively, they must do so at the same time with the maximum possible amount of flexibility.

NEED FOR FLEXIBILITY

In selecting the temporary level as the first step in setting up an industrial standard, or in starting a more comprehensive program involving the establishment of a series of standards, it is necessary to formulate the standard(s) in the minumum number of basic requirements, thus keeping the plan of coordination as flexible as possible. First, this will permit the maximum number of solutions of the problems involved to be applied; and second, it will make revisions of the temporary level as easy as possible. The more tightly the different factors to be coordinated are tied together, the more difficult it will be to make a change in one or a few of them without causing more or less serious disturbance in the others. Also, a shift in the level of the standard becomes more difficult. With elastic connections between the coordinated factors, it is possible to make a partial change in the coordinated plan without disrupting the connections between the revised part and the part that remains unchanged [1]).

In addition to the elements on whose unification the proper interconnection of the factors concerned depends, other elements belonging to these factors may be unified. It is obvious, however, that these additional *elements, while contributing nothing to the excellence of the connection* between the factors involved, do increase the resistance to a revision of a standard. Therefore, such elements, non-essential in so far as the interconnection of the cooperating factors is concerned, should preferably be left free so that their selection may be decided on by those who have to comply with the requirements of the standard.

SUBDIVISION OF REQUIREMENTS

Flexibility for the purpose of getting the maximum number of possible solutions of given requirements will be obtained by subdividing the minimum requirements among as large a number of factors which together are to make up the coordinated plan of solution, as is compatible with practical requirements. An interesting illustration of this principle is the development of the *unit type* machine tool during recent years. The increased intensity of output by mass production methods, of which the automobile industry presents one of the most striking examples, led to the design of special machine tools. While the older types of so-called "standard" machine tools were suitable for adaptation to a rather wide range of work, both as to type and size, these special machines were designed for performing in a minimum period of time a number of operations on a workpiece having a definite shape and dimensions, or at best on workpieces whose shape and dimensions lie within relatively narrow limits. A condition for the economic use of such special machines is that the product for the manufacture of which they have been designed is continued to be manufactured during a long enough period of time to write off the full value of the machine. A change in the product of the kind turned out by such machines may make the latter obsolete and often practically valueless. Greater flexibility in this respect was obtained by combining different units, such as a foundation bed, spindle heads, a table, a speed box, and so on, into a machine suitable for the purpose

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[1]) The physical embodiment of this principle typical for the mechanical industry, is the adapter serving to provide connections with two elements made to different standards. For example, two parts having external screw thread A and internal screw thread B, respectively, may be connected by means of an adapter having internal thread A and external thread B.

Ja B

most important at a given time, the combination permitting of being disassembled and rebuilt into a new combination when a change in the product demands it [1]). Possibly, some of the units will then have to be replaced by different ones, but at all events the original machine has considerable salvaging value, while a special machine might have to be scrapped under the same conditions.

Considering a machine tool built for a definite purpose as the physical embodiment of a standard, we have here a practical demonstration of the flexibility of a standard obtained through subdivision of its requirements. Lack of such flexibility has been pointed out by production men in the automobile industry in regard to the fixed center distance of the spindles of multiple-spindle drilling and boring machines. It has been stated that the great cost of changing such expensive cylinder-boring equipment has led to the maintenance of the original center distances in cases where a new engine having larger cylinder bores actually called for an increase in center distance, an undesirable reduction in water passage area between the cylinders being the result. Adjustable center distances would therefore be required in such machines [2]).

Another case where the need for standardization combined with flexibility in changing from one standard to another, has been strongly felt and in some cases successfully solved, is the textile machinery industry. The textile industry is subject to seasonal changes in the production of a specific article (plain, fancy, light, heavy), as well as to changes in the material of which the product is made. The question whether a mill makes a profit may therefore depend on its capacity to adapt itself to such changes.

One builder of textile machinery applied standardization to silk looms which so far had been built on 16 different frames and whose component parts were in general not interchangeable. The result was: (1) one frame designed to serve as the base for the common models heretofore built on 12 different frames; (2) one group of parts arranged in the form of sub-assemblies constituting a series of mechanisms common to all

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[1]) Distinction is sometimes made between "standard" units which are made for stock; "semi-special" units whose design is on file, to be executed only when orders come in; and "special" units which are designed to order. (See for example: Milling Machines Made from Standard Units, by E. J. Kearney, American Machinist, December 20, 1928). This subdivision is interesting in connection with the classification of standards, previously dealt with in this Chapter (page 23).

[2]) How the Design Engineer Views Manufacturing, by Alex Taub (SAE Journal, Oct. 1932).

models; and (3) one group of parts arranged in the form of sub-assemblies, each of which is a mechanism peculiar to the construction of a given model. Similar progress is reported to have been made in cotton and worsted looms, the results obtained in one large installation of the new cotton looms being a saving in the cost of weaving (including labor and overhead) of 34 per cent; a reduction of second quality product by 50 per cent; and an increase of the average rate of production per loom of 11 per cent. In addition, the mill, at the time busy on marquisettes, was in a position to alter its looms by changing the necessary attachments and to weave such fabrics as dress goods, fancy handkerchiefs, towels, rayon crepe, and even gingham, if this would come into demand again [1]).

LIMIT OF SUBDIVISION

As a practical illustration of the limit beyond which further subdivision of a standard would not be useful, the case of ball bearings may be referred to. These component parts, standardized for the purpose of the widest possible use in mechanical and other equipment, are composite products themselves, usually consisting of two races, a number of balls, and a cage. However, the manufacture and marketing of these sub-components as separate items, with the idea that they should be assembled by the user, would evidently be prohibitive from a practical standpoint. This aspect of standardization may be formulated by saying that as a matter of principle, units which in practice are used in their entirety in assembly and for replacing worn, lost, or damaged units, should be standardized only in regard to such details as affect their assembly with other components.

A system of component parts supplied to and used by the purchaser as a unit, is a composite product to its manufacturer. The phrase "used in their entirety" therefore implies that the manufacturer who builds up a product out of elementary parts, must standardize the latter — in so far as the dimensions controlling their assembly are concerned — if he is to

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[1]) Modern Textile Machinery, the Result of Research and Comprehensive Engineering, by ALBERT PALMER (Mechanical Engineering, June 1931). In connection with later discussions in this study, it is interesting to note that lack of interchangeability of parts existed in the original machines, "first, because the parts were not designed in a manner such that modern machine tools could be used; and second, because the variety of parts rendered the use of expensive jigs and fixtures impossible under the existing scale of prices. In other words, a complete lack of standardization was an obstacle to giving the silk industry improved, flexible machinery at a price not exceeding or lower than that of the existing machinery."

obtain the greatest possible flexibility in his product and its manufacture. Such procedure will also lead directly to attainment of the maximum degree of interchangeability between the total number of parts involved in the manufacture of all types and sizes of products made by the particular plant concerned. The main advantages of this interchangeability — to be discussed in more detail later [1]) — are the facility of manufacturing the parts in large lots or in continuous flow production, and the ready assembly of the component parts into the final product.

A practical illustration of this point is furnished by the standardization of flanged valves, such as globe valves, to be used in pipe lines carrying steam, water, gas, or other fluids. Proper connection of a valve with the adjacent pipes demands the unification of the following features of the pipes and the valves as minimum requirements: the diameter of the pitch circle of the bolt holes; the position of the bolt holes relative to the longitudinal center plane of the valve; and the diameter of the bolt holes [2]). Considering the valve as as composite product, standardization can also be applied to its internal parts, particularly to the dimensions controlling the assembly of these parts with each other and with the valve housing. To the builder of the pipe line, these internal parts usually have no importance as they do not affect the assembly of the pipe line. However, their standardization may be of interest to the user of pipe lines who wishes to be able readily to replace a damaged valve part, say a disk or a seat, preferably without being bound to use a replacement part made by a particular manufacturer. This applies especially to users of pipe lines who may be cut off temporarily from supply, as in the case of a ship at sea or in a foreign port where replacement parts are not available [3]).

LATERAL UNIFICATION

The amount of detail into which the requirements formulated in a standard should go thus appears to depend on the particular place which

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[1]) Chapter IV.

[2]) For the sake of simplicity it is assumed here that the flanges have plain faces. Otherwise, the unification of dimensions must be extended to the projections and recesses of the flanges. As a matter of logical design, the outside diameter of the flanges of the valve and the pipes will also be unified, but strictly speaking this is not necessary for securing proper connections between the several parts.

[3]) It has been found desirable in general practice in the United States and Germany to limit national standardization of the dimensions of a flanged valve to those controlling the assembly of the valve as a complete unit with other elements and to leave freedom in the details of the internal construction.

the group using the standard occupies in the production scheme. Every group having a place in the line of integration of components into a specific product has a need for a number of standards which are of no direct interest to the next group in the line which uses this products as a complete unit.

The fact that the group at the beginning or small end of the line has an interest in the standardization of elementary components is also of great importance in connection with the possibility of unifying components used by groups belonging to different lines of product integration. Unification of this kind might be called "lateral" unification on account of its direction relative to the flow of the product integration in the different branches of industry concerned. This lateral coordination is of no direct interest, technically speaking, to each individual line of integration. For example, the automobile industry has no direct technical interest in the question as to whether the machine tool builders use, or do not use, the same kinds of ball and roller bearings or threading tools, and conversely. However, from the economic point of view, the lateral coordination is indirectly of the greatest importance to all branches concerned. Agreement on a unified standard reached between them increases the advantages of interchangeable manufacture to those making the components, with ultimate benefit also to the users of these components.

SUMMARY

(1) Industrial standardization consists of two main functions: the establishment of a temporary constant level of requirements or conditions, and the coordination of the factors involved in complying with these requirements or conditions. The two functions are mutually dependent in that the former lays the basis for the latter, and that coordination on this basis must be practicable. The establishment of a standard therefore requires careful balancing of the two functions.

(2) The standardization of an object can be undertaken successfully only when its industrial development has progressed to the point where no considerable change takes place anymore in regard to the elements controlling the interconnection or coordination of the factors which represent partial solutions of the entire problem involved and whose cooperation is required for compliance with the standard.

(3) A standard while based on a temporary constant level of requirements or conditions should be kept flexible enough to permit a shift to a new level without excessive resistance, if and when progress in the field concerned demands it. Maximum flexibility in this respect is obtained by subdividing the requirements that will secure the total result aimed at by the standard, among the maximum possible number of components. This maximum depends on the degree to which subassemblies are used as complete units.

(4) Practical application of standardization calls for the combination of component elements into standard units or subassemblies with which the final product is to be built up. The degree of complexity to which such combinations should go must be determined in each individual case. The criterion to be used in this respect is that the inter-connections of the units must permit of being kept unchanged as long as possible without hampering progress in the art, while internal changes of the units must be possible without disturbing their inter-connections.

(5) It is desirable to classify the separate requirements of each standardization problem according to their significance in relation to the entire problem. A group of basic standards expected not to call for a change during a relatively long period of time should serve as the foundation of other groups of standards. The essential significance of a specific group of standards diminishes, and the revision of such a group becomes accordingly less difficult, as the nature of its object is more special.

CHAPTER III

DEFINITION AND CHARACTERISTICS OF A STANDARD

If we keep in mind the various types of standards that have been developed in the course of man's evolution [1]) and the essential functions of standardization [2]), we can define a standard as follows:

> A standard is a formulation established verbally, in writing or by any other graphical method, or by means of a model, sample or other physical means of representation, to serve during a certain period of time for defining, designating or specifying certain features of a unit or basis of measurement, a physical object [3]), an action, a process, a method, a practice, a capacity, a function, a performance, a measure [4]), an arrangement, a condition, a duty, a right, a responsibility, a behavior, an attitude, a concept or a conception.

This definition comprises three fundamental points, as follows:

(1) a standard is a formulation;

(2) it serves to define, designate or specify certain features of one or more of the objects enumerated in the definition;

(3) it serves in this capacity during a certain period of time.

FORMULATION

A standard is defined here as a formulation because in its perfect form it is "the result of putting ideas into a clear and definite form of statement or expression" [5]).

In the early days of civilization before man could write, simple standards referring to the skill of the craftsman were transmitted verbally and by

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[1]) Chapter I.

[2]) Chapter II.

[3]) To be understood as applying to shapeless objects, such as certain materials, as well as to objects that have a definite shape, such as the products of the mechanical industry.

[4]) To be understood here as a potential action or condition, such as a measure taken to start production at a certain time or a measure taken to establish a safe condition in a plant, but not in the sense of a "unit of measurement".

[5]) Webster's New International Dictionary.

samples or models of the work done. The tradition which thus grew up in regard to different necessities of life (tools, weapons, household utensils, and so on) may therefore be considered as a form of more or less unconscious standardization which might last through several generations[1]). When the object concerned was a simple one, a verbally specified standard might be sufficient for handing over from one generation to another. A more complicated object would require the visual representation of the standard by a drawing, model or sample. Physical means other than a complete sample or model would also be used in a later period, such as the mold in which a casting could be made, or some other object that formed the counterpart of the object to be standardized [2]). In all of these cases, there existed a possibility of changes being made, often unintentionally, unless the *original* sample or model was handed over from one generation to another. In the case of standards of length where such changes were very disturbing, the difficulty was later removed by making a prototype and keeping this in a central deposit, as the "master bar" [3]).

Great progress was made in this respect when man began to keep records, first in form of drawings, then in symbols, and finally in writing, that is, in symbols whose original and individual meaning had evaporated in the course of time. Graphical methods of this kind made it possible to set up a standard that could be transmitted from one individual to another without any change in its formulation. Standards thus became more suitable for remaining unchanged during long periods of time. Also, they could be better enforced through the possibility of referring to a record.

DEFINITION, DESIGNATION OR SPECIFICATION

A standard must be more than a "formulation". The latter concept,

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[1]) It may be held that "unconscious" standardization is a concept incompatible with the idea of a clear and definite statement, or in other words, with the idea of a formulation. The term "habit formation" might therefore be preferred in this case. Standardization in general has been called the "habit forming process of industry", see The Place of Standardization in Modern Life, by A. W. WHITNEY (paper presented at the First Pan-American Conference, Lima, Peru, 1924).

[2]) The modern limit gages illustrate this point. They embody the counterpart of such dimension as must be kept to one side of a limit, or between two limits. See also Chapter IV, under Interchangeability.

[3]) In the 17th century such a bar ("toise") was embedded in the outside wall of the Grand Châtelet, in Paris, in order to permit everybody to check his own standard. See Grundlagen und Geräte technischer Längenmessungen, by G. BERNDT (Berlin, Julius Springer, 1929).

while connoting a clear statement or expression of ideas, does not imply that such a statement or expression contains anything specific about the objects referred to. The statement that "the material should be of the best quality" is quite clear as to the desire of the party making the statement, but it does not say anything definite about the quality of the material.

One of the two functions of standardization — the establishment of a temporary constant level of requirements or conditions — implies the exact fixation of the different items of the standard by definition, designation or specification. The other function of standardization — the coordination of the factors whose co-working is required for compliance with the stabilized conditions — contains the factor of unification of the elements controlling this coordination. This unification is essentially based on measurement — the most exact form of specifying values.

The degree of exactness with which the requirements of a standard are formulated therefore determines the latter's effectiveness as a guide leading toward agreement between different parties. Special importance is attached to this point as a standard usually is the result of a compromise often reached after long and difficult negotiations. To leave doubt about the meaning of its specifications is to defeat, at least in part, the purpose for which the standard is set up. While at first sight this statement might seem to be superfluous, a survey of the field will show that the necessity for a standard to formulate its requirements in a definite, unequivocal manner is still too often neglected. This applies even to the establishment of standards that are widely used by industry at large.

Strictly speaking, an individual may set up a standard exclusively meant to be followed by himself. This applies, for example, to standards for the quality of workmanship to which a craftsman adheres merely on account of pride in his work. However, in such a case the individual may be considered to act in a dual capacity, namely as the establisher of the rules as well as the one who is to follow these: he lays down the law to himself. This exceptional case may well be disregarded further as this study is primarily concerned with the coordination of the activities of different individuals or groups. In this form, standardization is most commonly applied in our present industrial system.

DEFINITION OF CONCEPTS IN A STANDARD

Standard specifications, in stating the requirements to be fulfilled, make use of concepts ranging from the most essential ones understood only by experts, to simple ones comprehensible to every layman. To be clear, it may be necessary for the standard explicitly to define certain concepts. To what detail this should go, or how complicated or special any term used in the standard is allowed to be, is a question to be decided in each individual case. It may be necessary to "translate" a standard which is perfectly clear to the engineering department into more simple and detailed terminology for the benefit of the workshop.

Some standards, before stating their requirements, give a series of definitions of the most important terms used in the specifications — a very effective means of creating a basis of common understanding of the problems involved. The American Standards dealing with the most commonly used coarse and fine screw threads [1]) and with milling cutters [2]) are examples of this practice. The former standard begins by defining a screw thread as follows:

> "A ridge of uniform section in the form of a helix on the external or internal surface of a cylinder or cone".

It would seem that this definition goes into as much detail as anybody who has to use this standard may reasonably expect. It is not necessary, for example, to state more specifically that the cylinder and the cone referred to have circular cross-sections at right angles to their axis. Nobody will think, in connection with screw threads, of any other kind of cylinder or cone, the cylinder applying to all threads for bolts, (machine) screws, and nuts, and the cone to taper pipe threads [3]).

In addition to the concepts whose definition is assumed to be indispensable to those who must use the standard, there often are others of equal importance which are assumed to be silently agreed on by everyone concerned. However, in assuming "silent agreement", great care should

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[1]) Screw Threads for Bolts, Machine Screws, Nuts and Commercially Tapped Holes (Bla-1924).

[2]) Milling Cutters (B5c-1930).

[3]) It even may be held that those using the standard do not need this definition. Evidently, it has been added for the sake of completeness, preceding as it does a series of other definitions indispensable for unifying the terminology on the subject.

be used, as it is often found that experts in a certain field have adopted different terms for the same concept [1]).

While keeping foremost in mind that a standard is set up with the purpose of securing a certain performance and of creating definite indications for doing so, those in charge of developing the standard must be relied on to use great insight and skill in striking the correct balance between what should be specifically stated in the way of definition and what may be considered as self-explanatory.

SPECIFIC REQUIREMENTS

A standard can be specific only in so far as its requirements can be expressed, directly or indirectly, in terms of measurement or comparison. The inclusion of any clause which formulates a requirement without giving a basis of measurement, comparison, definition or interpretation — as the case may require — forces those who have to be guided by the standard to use their own judgment. While the fact that such a clause draws attention to a particular point may be called an advantage — as this is then more likely to be given consideration — the disadvantage is that each one concerned will probably interpret the clause in his own way. There is, of course, a chance that all will agree on a common interpretation which then may informally become a supplement to the standard, but the probability is greater that the several interpretations will vary and that the standard will thus lead to controversy instead of avoiding it, as it should do [2]). Therefore, if it is deemed necessary or desirable to have a standard refer to requirements which for some reason cannot be definitely specified, or whose specifications must be left to those using the standard, the necessity of making additional agreements should be clearly stated in the standard, instead of clauses being inserted which

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1) This appeared to be the case with nomenclature for lathe tools, when several prominent experts were asked for advice. "Not only were different designations used for a particular function of the tools, but what was more important, even the designations 'left hand' and 'right hand' were not used in the same manner. What was called a 'right hand straight turning tool' by one expert, was designated by another as a 'left hand straight roughing tool'. A tool called in one reply a 'left hand side boring tool' was called a 'right hand hook tool' in another, and again, a 'right hand boring tool' in a third reply." (ASA Bulletin, March 1932). A subcommitte on Nomenclature of Tools has taken up the matter under ASA procedure.

2) This danger exists primarily in regard to the essential elements of a standard, namely the technical terms used in it. The desirability of defining these terms in the introduction of a standard has already been discussed. However, we are referring here to complete clauses rather than to simple terms, as will be shown in the examples given later on.

do not contain anything tangible to serve as a definite basis of agreement. A few examples will illustrate this point. They refer to the concepts "workmanship" and "finish" which are frequeently made the subject of non-specific clauses.

The following clause appearing in a standard under the heading Workmanship and Finish:

> "The bolting material shall be free from injurious defects and have a workmanlike finish." [1])

does not convey any more information than the general requirement that workmanship and finish shall be satisfactory.

The requirement that

> "The castings shall be sound, clean, free from sand, of workmanlike finish and soft enough to machine well." [2])

is somewhat more specific, although the nature of the requirement regarding the "soundness" of the castings and of their "machining well" are entirely left to judgment — which may vary considerably. There are not yet in existence any generally adopted standards for machinability, but the question arises whether nothing more definite could have been laid down in the standard, such as a Brinell hardness figure. Also, it seems that at least the kind of material of the tool should have been stated. Should castings be accepted by the purchaser if they "machine well" with a tungsten carbide tool, but not with a carbon steel tool? This is evidently not the intention.

So far as the clause on "soundness" is concerned, proof that a better effort toward being specific can be made is furnished by another standard on castings where it says:

> "The castings shall be true to pattern, and free from gas holes, cracks, flaws, and excessive shrinkage. In other respects they shall conform to whatever points may be specially agreed upon between the manufacturer and the purchaser." [3])

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[1]) ASTM Specifications for High Temperature Bolting Material (A96-31). The same requirement appears also in several other ASTM standards, for example those on Cold Rolled Axles (A22-21); Steel Forgings (A18-30); High Speed Tool Steel (A92-26); Alloy Tool Steel (A115-28); and Steel Pipe Flanges (A105-28).

[2]) ASTM Specifications for Gray Iron Castings for Valves, Flanges, and Pipe Fittings (A126-30)

[3]) ASTM Specifications for High-Test Gray-Iron Castings (A88-31). It is interesting to note that the second sentence of this clause contains an explicit recommendation to have more specific requirements set up between the parties in each individual case.

Evidently, the terms "true to pattern" and "excessive shrinkage" still call for further definition.

In another case, a step in the direction of greater definiteness has been made by formulating the requirements of Workmanship and Finish as follows:

> "The castings shall conform substantially to the patterns or drawings furnished by the purchaser, and also to the gages which may be supplied in individual cases. The castings shall be made in a workmanlike manner. A variation of $^1/_8$ in. per ft. will be permitted." [1]

Although the requirement "shall conform substantially to the patterns" does not seem to give more information than the requirement "true to pattern" in the previous example, we find here a definite statement of a maximum permissible variation of $^1/_8$ inch per foot. It is not stated, however, whether this variation is permissible in the minus direction; in the plus direction; or in the minus, as well as in the plus direction [2].

The examples cited are given only to show the general need for paying more attention to the requirement that a standard should be specific. Not only should a standard be a specific document *in principle* — such questions as cannot be defined by agreement of the parties being left out rather than referred to in general but intangible specifications — but also the interpretation of the standard, once it has been adopted by the parties as the basis of an agreement or contract, may become as important as the interpretation of the claims of a patent [3].

Especially, a standard approved as a national standard by the central industrial standardizing body in a country — such as the American Standards Association in the United States — may be quoted in cases of litigation as a reference having the highest authority in the field concerned,

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[1]) ASTM Specifications for Malleable Castings (A47-30).

[2]) Upon investigation, it appeared that the clause was intended to specify a permissible plus or minus variation of $^1/_{16}$ inch per foot, or a total tolerance of $^1/_8$ inch.

[3]) While in principle the clauses of a standard and the claims of a patent must both be specific, there is an essential difference between the reasons leading to their formulation. The clauses of a standard should be formulated on the basis of the minimum of requirements and be kept as flexible as possible in order to permit the maximum number of acceptable solutions to be applied. Patent claims, while also based on specific ideas, should be formulated in the most general manner possible so as to reserve all, or at least the maximum possible number of solutions, to the patentee, thereby blocking, or restricting to the greatest extent possible, the solutions remaining at the disposal of others. A standard, therefore, should leave open as many solutions as will answer its requirements, while a patent tends to control as many solutions as possible.

due to its having been established by a group of men most expert on the subject. Also, even though no case of litigation may be involved, it is possible that in the normal relationship between purchaser and supplier the question arises as to how compliance with indefinite clauses should be ascertained, or in other words, on what basis the necessary inspection or testing should be carried out.

For these reasons, those in charge of drafting industrial standards should be as careful about the way in which they formulate them as if they were engaged in the drafting of patent claims. In both cases, questions may always come up where judgment, possibly based on customary practice regarding undefinable concepts, has to be used. However, the standardizer should go as far as he possibly can in avoiding the need for judgment and interpretation.

PERIOD OF VALIDITY

The part of the definition stating that a standard is a formulation established to serve "during a certain period of time" hardly needs further explanation. A standard is set up in principle as a temporary constant level of requirements and therefore is meant to remain valid during some time. When a series of identical machines or ships are built at the same time without there being the intention of building other machines or ships to the same specifications some time in the future, these specifications do not constitute a standard. This point deserves some attention because it has become a trade habit with certain firms to designate their product as "standard" for the sole reason that it represents the type which they are making for the time being. If the term is used on account of the fact that the product has been made for a longer period of time while maintaining interchangeability between successive designs in so far as their assembly with other equipment is concerned, there is some justification in the use of the term "standard". But when a firm has chosen its type for the current year, definitely knowing that next year's model will be neither the same nor interchangeable with the present one, there is evidently no ground for the use of the term "standard".

TECHNICAL AND MANAGERIAL STANDARDS

The several concepts to which standards may refer, according to the definition of a standard given at the beginning of this chapter, may be classified under two main headings: technical standards, and managerial standards. For the purpose of this study, a technical standard will be defined as a standard whose specifications concern solely the technical factors of the problem involved, and not any factor depending on the human element. In other words, a technical standard relates to such items as materials, tools, methods of work, and safety measures — the latter only in so far as they depend on the nature, performance and arrangement of the physical objects concerned. A managerial standard will be defined here as a standard specifying such matters as to who shall be responsible for carrying out a certain activity or shall be in charge of it; when such activity shall be carried out; and how workers shall behave — in so far as this behavior affects the work [1]. Generally speaking, a technical standard specifies *what* shall be done and *how* it shall be done, while a managerial standard specifies *who* shall do it, *when* it shall be done, and sometimes *why* it should be done [2].

A complete program of industrial standardization must comprise technical standards, managerial standards, and combinations of the two types, such as safety codes.

A classification of the different concepts to which standards may refer [3], into the two main groups will be helpful in determining what standards should be established through the care of a standards department in a company of the kind to be dealt with later in this study [4], and what standards should be developed by other departments, such as the planning department [5]. Also, the classification will give us a better view of the relation of each kind of standard to the ultimate purpose of all standardization which is the attainment of a definite performance [6].

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[1]) Specifications of behavior may be found, for example, in several safety codes. See this Chapter, page 47.

[2]) The specification as to "when" an action or activity shall be carried out, is a purely technical item of a standard if it concerns the sequence of steps involved in a technical process. For example, the specification that "all parts shall be ground after hardening" involves a *technical* "when", while the specification that "tools shall be ground within 24 hours after having been delivered to the toolroom" involves a *managerial* "when".

[3]) See the definition of a standard, page 33.

[4]) Chapters VI and VII.

[5]) For example, the planning department, in charge of the planning of the performance of work is directly interested in the standards resulting from time and motion study, a matter falling outside the scope of the standards department to be discussed in this study.

[6]) Chapter I.

CLASSIFICATION OF CONCEPTS

Some of the concepts listed in the definition of a standard as given earlier in this chapter belong solely in the class of technical standards, while others belong exclusively in the class of managerial standards, and still others in either class, depending on the nature of the object referred to. For example, safety codes usually are standards of the mixed class, containing as they do specifications concerning tools, equipment, buildings, lighting, and other purely technical factors, as well as specifications relating to the duties, responsibilities, and behavior of the workers. A safety code for foundry work [1]) contains the following "technical" clause: "All single shank ladles shall be provided with sheet metal shields", as well as a "managerial" clause specifying: "Bottom poured ladles and all other types that are suspended by bails shall have daily inspection of bails and trunnions."

The different concepts will be briefly reviewed on the basis of their classification as items for technical or managerial standards.

(*a*) *A unit or basis of measurement*

The classification of this concept depends on the object to which it refers. Units of length and the zero point of a temperature scale (a basis from which to measure) belong in the technical class. In the field of management, units and bases of measurement are used to determine the ratings of workers which control their earnings or promotion.

(*b*) *A physical object*

If the worker is placed in a class by himself — or, in other words, if he is not considered as belonging to the general class of "physical objects" — industrial standards relating to physical objects are of the technical type. They may be subdivided into two main groups, namely standards dealing with the properties of materials, and standards dealing with the dimensions of those manufactured products whose shape and size are essential for their use, such as all of the products of the mechanical industry. Examples are specifications for metals and other materials (such as steel, bronze, rubber, bakelite), lubricants, paints, varnishes; and dimensional standards for the component parts of the products of the mechanical industry (such as ball bearings, bolts, screws, and nuts).

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[1]) American Standard Safety Code for the Protection of Industrial Workers in Foundries (B8-1932).

(*c*) *An action*

The specification of an action is to be classified either as a technical or as a managerial standard depending on the nature of the action. Such items as "start motor" and "drill two holes $\frac{1}{2}$ inch" given on a standard instruction card as details of a machining operation, are technical. On the other hand, a standard instruction relating to an action like "report completion of work to foreman" belongs in the managerial class.

(*d*) *A process*

In the field of industrial standardization, a process generally belongs in the technical class. It is true that a process has previously been defined as a collection of actions [1]) and that, strictly speaking, a series of managerial actions (see above, under *c*) constitutes therefore a process belonging in the managerial class. For example, the collection of standard rules governing the manner in which a standard shall be set up by an organization, or jointly by a group of organizations, actually is a standard managerial process or standard procedure. Legislation is a form of this type of standardization. However, from the viewpoint more particularly dealt with in this study, the most important kind of standard processes are those relative to the manufacture of materials, and of semi-finished and finished products. In the mechanical industry, a main subdivision of such technical processes may be made along the following lines: rough-shaping (such as casting, forging, rolling); finish-shaping (such as turning, grinding, milling, reaming); treatment, including heat treatment of alloys, plating, painting; and assembly of the component parts.

(*e*) *A method*

A method being the formula expressing the essential features of an action [2]), a standard method may belong either to the technical or to the managerial class. Standard technical methods are, for example, those governing the manner in which a component part of a machine is computed for strength and rigidity, and the method by which the result of such computation is recorded on a drawing (arrangement of views and cross-sections; indication of materials, dimensions, finishes, etc.); methods of inspection and testing applying to materials or finished product; and so on. A standard method of testing the natural disposition or the skill of a

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[1]) Chapter I, page 1.
[2]) Idem.

worker belongs in the managerial class of standards. This class is of special importance to the employment service of an industrial concern.

(*f*) *A practice*

While a process is a collection of actions, a practice is a collection of methods [1]. Accordingly, a standard practice may belong in the technical or the managerial class of standards. When a company has adopted the policy of testing every lot of material purchased, this policy represents a standard managerial practice. The methods of testing adopted by the testing department form together a standard technical practice. Similarly, the policy of making the component parts of the manufactured product interchangeable, for the purpose of satisfactory servicing the product in operation in the field, is essentially a managerial standard, while the corresponding technical standard practice consists of setting definite manufacturing limits for the parts and their checking by means of limit gages [2].

(*g*) *A capacity*

A capacity is essentially a potential performance [3]. In other words, a capacity indicates what results may be expected of the functioning of a specific object. Therefore, standards of capacity may belong to the technical as well as to the managerial class. Technical standards of capacity are those relative to the capacity to deliver power, of steam, internal combustion, and hydraulic engines, and of electric motors; to the capacity of vessels to hold, and the capacity of transportation equipment (conveyors, cranes, trucks, tank cars, pumps, blowers, etc.) to move materials of different kinds (solid, fluid, or gaseous); to the capacity of production equipment to deliver a certain volume of product per unit of time; and so on. Managerial standards of capacity are laid down in the test requirements for different jobs.

(*h*) *A function*

A standard function may belong either to the technical or the managerial class. The manner in which a safety device shall function is a purely technical item which may be laid down in a standard specification without

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1) Chapter I, page 1.
2) See Chapter IV, under Interchangeability, page 50.
3) Chapter I, page 1.

any reference being made to the details of the construction of the device. On the other hand, the specification of one or several functions forming part of a particular job constitutes a managerial standard. Thus, the job of an inspector of the product may comprise the function of investigating the causes of rejection of product as well as the function of inspecting, i. e. the actual making of the check on the acceptability of the product.

(i) A performance

Performance standards also are of the technical or the managerial type, depending on the nature of the performance. The standard performance required of materials under specific conditions (temperature, humidity, acidity, etc.) which depends among other things on their physical and chemical properties, is a standard of the technical type. The performance requirements for manufactured product also belong in this class. Managerial standards of performance usually are more difficult to establish, due to the complicated nature of the human element. Where the results can be measured directly in volume or quality of work accomplished, the correlation of technical and managerial performance may be relatively simple. However, the further away a job gets from being "standardizable" in its elements, the more difficult becomes the measurement of the effectiveness with which it is carried out, and consequently the setting up of standard requirements or job specifications also becomes more intricate.

(j) A measure

It depends on the nature of the action or condition aimed at whether a standard measure belongs to the technical or the managerial class. Protective devices specified (not necessarily in detail) in safety codes for machines presenting a hazard to life and limb of the worker, embody measures belonging in the class of technical standards. Measures protecting the workers from danger (such as a "no smoking" rule applying to a shop where inflammable or explosive substances are kept) are managerial standards.

(k) An arrangement

An arrangement specifying the positions of several objects relative to each other or to a basis of reference, without necessarily giving the exact dimensions governing these positions, constitutes a technical standard. Examples are the arrangement of the controls of a machine tool or automobile, the several dials on the instrument board of an airplane, and the keys of a typewriter or linotype. A standard arrangement is often adopted to cause the operator of the machine or device to acquire automaticity in the performance of his motions, both mental and physical. (Habit formation is a kind of standardization, see Footnote 1, page 34)

(*m*) *A condition*

A condition, in the sense of a status of affairs, may refer to technical as well as to managerial matters. Typical technical standards of condition are those concerning the appearance of the product, or the extent to which equipment has become worn or damaged (a question important in connection with standards of maintenance); or the effect of heat treatment on steels and other metals, such as a hardened or annealed condition. Standards referring to conditions of lighting, heating, and ventilating in a workshop are also of the technical type.

(*n*) *A duty*
(*o*) *A right*
(*p*) *A responsibility*
(*q*) *A behavior*
(*r*) *An attitude*

These five types of standards are grouped together here because they are exclusively and typically managerial standards, even though technical items may also be involved. The following examples serve as illustrations.

A duty: "When the eyes of employees are liable to injury by dust, flying chips or molten metal, they shall wear suitable safety goggles which shall be provided by the employer." [1])

A right: "In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time [two weeks]" [2])

A responsibility: After having emphasized the safety of operation inherent to automatic and semi-automatic methods of feeding presses, a safety code says in part, referring to the feeding devices, knockouts and

[1]) American Standard Safety Code for the Protection of Industrial Workers in Foundries (B 8-1932). Two different duties are contained in this clause.

[2]) ASTM Specifications for Steel Pipe Flanges (A105-28) and other ASTM standards.

guards: "the die designer, maker and setter should be held responsible for them and should have the element of safety constantly in mind during the designing, construction, and placing of the dies." [1]

A behavior: "The practice of riding chains and crane loads shall be forbidden." [2]

Examples of a standard attitude are the attitude of a government toward the question as to who shall be entitled to patent rights for an invention (applicant, or inventor); and the attitude of the management of an industrial concern toward the employment of union labor.

(*s*) *A concept*

Concepts laid down in standard definitions and represented by symbols and abbreviations may refer either to technical or managerial matters. Examples of typical technical concepts are an ideal stress; entropy; controlled quality [3]. Managerial concepts include a task, "standard" time, obsolescence.

(*t*) *A conception*

Technical standard conceptions are temporarily used by the research man (in science as well as in industry) and the designer as a basis to work from [4]. Examples are the theories adopted in regard to natural phenomena, such as light; electricity; structure of matter; strength and fatigue of metals. Standard conceptions are also used as a basis for solving problems of management. Thus, different standard systems of wage payment have been developed, all of which are based on a conception of what is believed by their authors to be the best incentive for the worker to spend the greatest possible amount of care and effort on his work.

SUMMARY

(1) A definition of the concept "standard" shows that a well "designed" standard should clearly and completely define, designate, or specify

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[1] American Standard Safety Code for Power Presses and Foot and Hand Presses (B11-1926).

[2] American Standard Safety Code for the Protection of Industrial Workers in Foundries (B8-1932).

[3] See Chapter IV, page 63 ff.

[4] Chapter I, page 2.

certain features of one or more of a number of concepts (enumerated in the definition) and also that a standard should remain valid for a certain period of time.

(2) The requirement that a standard shall be clear and specific may involve the necessity of giving in the introduction of a standard a series of definitions of the terms used. These definitions should go into as much detail as is required for the understanding of the standard by all those having a major interest in it.

(3) A large number of standards widely used by industry contain indefinite clauses which are not suitable as a sound basis of agreement and, on the contrary, may easily lead to controversy on account of difference of interpretation.

(4) If it is necessary to call attention in a standard to a requirement which cannot be stated in definite terms, it is preferable to have the standard recommend explicitly that the point in question be settled in each individual case between those concerned rather than to use an indefinite clause.

(5) Each of the several concepts listed in the definition of a standard as given in this chapter may be classified as having a technical or a managerial character, according to the definitions given of these characters. Sometimes the character depends on the subject to which the concept refers.

(6) Conversely, all industrial standards may be classified as being of the technical, the managerial, or a mixed (technical and managerial) type, depending on the nature of the concepts to which their specifications apply. This classification offers a basis for the assignment of the different types of standard to different departments of an industrial organization. The technical standards should be referred to a standards department of the kind dealt with later in this study.

CHAPTER IV

NOMINAL VALUES AND LIMITS

In the previous chapter it was found that a standard, if it is to serve as a sound basis for coordination, should be specific in stating its requirements and that it should preferably express the latter in terms of measurement.

The most commonly used method of stating a requirement in terms of measurement is to express it in a single numerical value. For example, the machine designer may find that a flange calls for eight bolt holes. Furthermore, he may find that to provide sufficient strength, rigidity and bearing area, the diameter of a cylindrical pin should be one inch, and that the pin should be made of a kind of steel having, among other properties, a carbon content of 0.20 per cent.

Practical experience has shown that among the three requirements just stated, only the first one (eight holes) can be met in practice with the same mathematical exactness with which it has been stated, while the other two requirements can only be approximated. A pin with a diameter of one inch may be aimed at, but the result of even the most painstaking efforts will be a pin with a diameter slightly different from one inch. It may measure 1.0001 inch, or 0.9999 inch, or its deviation from one inch may even be less, but to expect that a diameter of "exactly" one inch can be obtained is equal to expecting that somebody will draw a mathematical point on paper. Similarly, no steel manufacturer can be expected to supply a steel with an "exact" carbon content of 0.20 per cent, nor could any purchaser of steel undertake to say whether such a percentage is actually present. This could be done only if the measuring devices and methods were perfect and no error was made in observation, all of which are ideal but not practicable conditions. However, if two limiting values of 1.0000 and 1.0003 inch are specified for the diameter of the cylindrical pin, and two limits of 0.15 and 0.20 per cent of carbon content for the steel of which it is made [1]), a practical basis for compliance with the requirements in question has been established.

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[1]) As specified, for example, for SAE steel 1020.

In addition to the question whether the way in which a standard has been formulated is specific enough, it now appears also to be necessary to see whether the standard has not been formulated in a way which is too specific because compliance with its requirements would depend on mathematical exactness. The need for considering this question could have been foretold on the basis of the need for flexibility which a standard should possess [1].

INTERCHANGEABILITY

The perception that "exact" dimensions could not be established in the composition or shaping of physical objects — such as the manufacture of materials and the products made of them — came to man only in a gradual manner. The skilled handicraftsman of old prided himself on being able to work to "exact" dimensions. This meant that he dimensioned things with a degree of accuracy greater than that with which he could measure them. Use of modern measuring instruments would have shown the deviations from the dimensions which he had adopted as a "standard" to work to. However, as all details of the manufacture had his personal care — the dimensioning of the components as well as their assembly — the craftsman could easily take care of the coordination of these components by fitting each pair together individually. Starting with two parts each having a certain excess of material, he would carefully remove a minute layer from each part until one fitted the other just as tightly, or loosely, or again, without any apparent tightness of looseness, as the particular workpiece demanded.

After steam power had increased the speed of production and decentralized manufacture by specialization, the craftsman's practice had to be replaced by one that was better suited to the new conditions. For two reasons his method of individually fitting mating parts was incompatible with serial production, and still more so with mass production. First, it required much time and thus considerably reduced the gain in speed of production obtained by the use of mechanical equipment. Second, a regular and continuous flow of component parts through assembly into the final product can be kept up only if all parts of a given kind are equally well suited for their purpose. They must be *interchangeable,* if the necessity of individual fitting is to be avoided.

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[1]) Chapter II, page 26.

Through a period in which a so-called "standard" gage was used in an effort to keep the actual size of a part in a definite relation to its nominal size, a rational and practical solution was developed consisting in the use of limit gages. It had become evident that variation in the size of a part can be restricted but not avoided, and also that a slight variation from the basic size which a part originally was intended to have, could be tolerated without its correct functioning being impaired. Consequently, it was realized that interchangeable parts need not be identical parts, but that it is sufficient if the significant dimensions which control their fits lie between identical manufacturing limits. Accordingly, the problem of interchangeable manufacture evolved from the making of parts to a would-be "exact" size, to the holding of parts between two limiting sizes lying so closely together that any intermediate size would be acceptable [1]). The distance between these manufacturing limits, called the tolerance, may consist solely of a permissible plus variation; or of a minus variation; or again, of a plus variation *and* a minus variation which may be equal or unequal.

This development meant essentially that an exactly defined "basic" condition — expressed by one numerical value — had been replaced by two limiting conditions, any solution giving a result lying between these two limits being acceptable. One standard level was replaced by two standard limiting levels enclosing a zone of acceptability or tolerance. Each extreme condition was physically represented, in manufacturing practice in the mechanical and related industries, by a limit gage; and a workable scheme of interchangeable manufacture, indispensable to mass production methods, thus became established.

We find here another practical demonstration that a workable standard must be specific as well as flexible. The basic size of a workpiece represents the element of specific ness of the standard, while the tolerance — leaving a margin for variation between the manufacturing limits — represents the element of flexibility.

DEGREE OF ACCURACY

An increasing amount of practical knowledge was obtained about a number of factors that appeared to require control to limit the variation

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[1]) Statements requiring holes to be made "exact" or "standard" or "to size", may still be found on workshop drawings in a number of plants. Such statements suggest that the dimensions concerned are exacting, but in the absence of limiting values their meaning depends on interpretation instead of being specific.

in size of parts. Methods of sizing were refined through improvements in the design of machine tools, such as the accuracy of fitting between their components, greater rigidity, better dynamic balance of moving parts and automatic sizing devices. Measurement had to be refined continuously to keep ahead of the required accuracy of sizing by improvement in existing methods and devices (micrometers, limit gages, comparators) and the application of new ones (light wave comparators, electric contact gages, etc.). The basis of measurement was more accurately defined by the adoption of a standard "reference temperature" at which all industrial precision measuring instruments and gages are required to give correct readings or to have their nominal size, as the case may be [1]. The reference temperature of 20 C (68 F) has now been adopted as a national standard in all industrial countries [2]. Even the manipulation of limit gages has been standardized to a certain extent. Thus, to avoid the error of measurement due to the deformation caused by forcing a snap gage over the workpiece, a standard practice of using this type of gage has been adopted in Germany [3].

In this way, it has become possible to hold machine parts between increasingly close limits. The diameter of the piston pin of a Model-A Ford car (nominal diameter 1 inch, or 25.4 mm) was permitted to vary only within a tolerance of 0.0003 inch (about 7.6 microns) [4]. A company specializing in the manufacture of wristpins for airplane engines (nominal diameter $1^3/_8$ inch, or about 35 mm) succeeds in keeping these pins within a tolerance of 0.00005 inch (about $1^1/_4$ microns). However, this accurate size control is made possible only by keeping the temperature

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[1] For deviations from nominal gage sizes, see Tolerances on Limits, page 60.

[2] Until a few years ago, France and Great Britain used the reference temperatures of zero C (32 F) and 62 F ($16^2/_3$ C), respectively. Their adoption of the temperature of 20 C was largely due to the fact that a recommendation for an internationally unified system of fits between cylindrical parts was being developed under the auspices of the International Standards Association (ISA), this recommendation comprising the adoption of the temperature of 20 C.

[3] The German national standard DIN 2057, Manufacturing Limits for Working and Acceptance Gages, specifies: "The size of a snap gage is considered to be equal to the diameter of a measuring disk over which the gage will just pass, in slightly greased condition, under the influence of its own weight, provided this be at least 100 grams". The intention is that the snap gage, when used to check the workpiece will also be left to the influence of its own weight, with a minimum of 100 grams.

[4] See A Standard Inch-Millimeter Conversion Factor for Industrial Use, by C. E. Johansson (Industrial Standardization, Jan. 1933).

of the coolant which floods the workpieces while they pass through the centerless grinder, within definite limits.

Experience has also shown that interchangeable manufacture applied to serial and mass production has at least one thing in common with old-time handicraft: close accuracy is difficult to get. It requires either careful proceeding by the machine tool operator in removing the metal — lest he "overshoot the mark" — or, in case the metal removing operation is automatic, the machine has to be accurate and remain accurate in its operation, otherwise the parts will show excessive variations in size. Every additional step in the direction of greater accuracy has to be paid for more highly than the previous one and consequently manufacturing cost goes up rapidly when tolerances become small. When cost is plotted as the ordinate against the manufacturing tolerance as the abscissa, cost will asymptotically approach the vertical axis. Accordingly, it has become a principle of good engineering — from the combined viewpoint of technical effectiveness and economic production — to use the largest manufacturing tolerances compatible with good performance of the product. This principle applies not only to the sizing of machine parts but also to the manufacture of any product, certain properties of which (such as weight, tensile strength, hardness, resistivity, conductivity, or content of a certain chemical element) must be kept between fixed control limits. These limits can be brought more closely together but can never be made to coincide, and at some point the increase in manufacturing cost may appear to prohibit a further reduction in tolerance.

SELECTIVE MATCHING

The principle of selective matching may be explained by its particular application in the mechanical industry which is selective fitting. This serves as a means of obtaining a correct fit between mating parts whose sizes cannot be held, for technical reasons, between the manufacturing limits required by such a fit, or for which the maintenance of the corresponding small tolerances causes excessive cost [1]). Selective fitting is, therefore, applicable in many cases where variation in the character of a fit must be kept small, whence the manufacturing limits of each of the mating parts must lie closely together.

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[1]) Individual fitting between the parts concerned would be another solution, but this method is not suitable for mass production.

Selective fitting is applied by dividing the tolerance on each mating part into an equal number of zones and by mating the parts belonging to corresponding zones. The diagrams in Fig. 3 illustrate this. The left hand diagram represents the tolerance A on a hole size and the tolerance B on a shaft size. When mated, the parts have a clearance varying between 5 and 20 tenths [1]). It may be desired to refine the fit by reducing the variation in clearance, which is 15 tenths, to 6 tenths. If now, reduction of the tolerances is either technically impossible or too costly, the purpose can be achieved as follows. The tolerance on the shaft is changed to the tolerance of 9 tenths shown on the right hand side. The hole and the shaft tolerances are each divided into three zones of 3 tenths, and holes falling within the tolerance zones *a1*, *a2* and *a3*, respectively, are mated in this order with shafts falling within the tolerance zones *c1*, *c2* and *c3*, respectively. The finer fit is obtained without reducing the original tolerances. On the contrary, the original shaft tolerance is increased. The refinement is paid for, however, by the cost of checking all of the parts for size, and of sorting them. Also, they must be kept sorted as long as they are not assembled. Cost of sorting may be reduced by mechanizing it in a way similar to that of automatic gaging [2]).

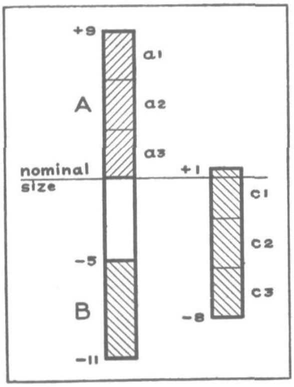

Fig. 3. Selective fitting.

Whether selective fitting should be applied where interchangeable manufacture, although possible, is costly, must be decided in each individual case by weighing the advantage of lower cost (if any) against two disadvantages inherent to the application of selective fitting.

One disadvantage is that there is no control of the number of parts falling within each sub-zone of the tolerance. It may happen that an excess or a shortage of parts belonging to a specific sub-zone is found to exist. In the former case, the parts in question have to be put in storage. In the latter case, it may be necessary to make up for the shortage by a

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[1]) The term "tenth" is used here, for the sake of simplicity, to designate 0.0001 inch (2.54 microns).

[2]) See page 65.

temporary tightening of the manufacturing limits to cause a larger percentage of parts to fall within the sub-zone concerned. However, this will increase manufacturing cost.

The other disadvantage concerns the standardization of maintenance and servicing. Replacement of parts, after the product has left the factory, is possible only under one of two conditions. Either the mating parts must be marked to show the tolerance zone to which they belong, or both

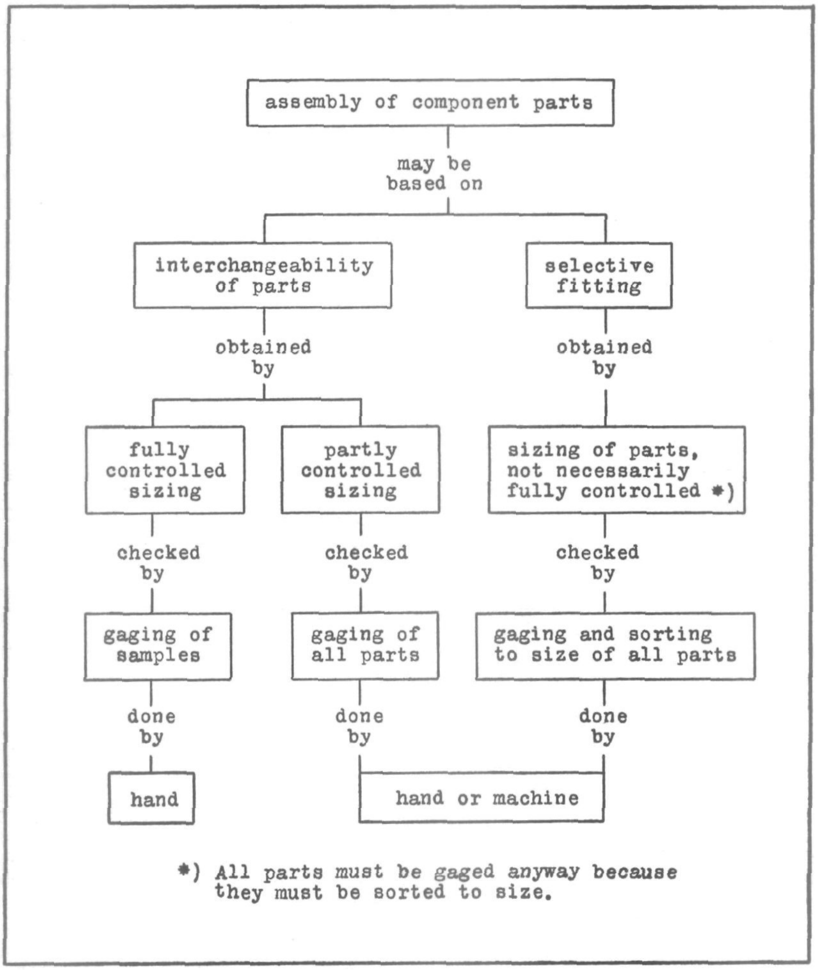

Fig. 4. Maintenance of quality in assembling.

mating parts must be replaced at the same time by a new set which also has been fitted together by selection. For example, in the automobile industry where "selective assembly is still considered the most practical method of fitting pistons into cylinders" [1]), the pistons and cylinders are marked [2]).

A diagram of the two principal methods of maintaining quality of assembling in the mechanical industry is shown in Fig. 4. In general, it can be said that under a set of given conditions determined by the nature of the product, improvements in the technique of size control resulting in a decrease in cost of maintaining a specific degree of accuracy, will tend to swing the balance toward the side of interchangeable manufacture. This applies particularly where the sizing operation is directly controlled by an automatic gaging device built into the machine tool. Also, where elimination of motions in assembling operations is a matter of primary importance — for example, in continuous flow production — the extra operation of sorting the parts may become a factor whose elimination through application of interchangeable manufacture will reduce the total cost of manufacture, in spite of the higher cost of more accurate sizing.

On the other hand, selective fitting could often be applied where difficulty now exists because the manufacturing limits that *should* be maintained lie more closely together than those that *can* be maintained. This is bound to result in an excessive percentage of rejections, or — still worse — in constant trouble with the assembled product. Where interchangeability of parts is no primary requirement, selective fitting often could improve the situation.

Selective matching, applied in form of selective fitting in the mechanical industry, may also be applied in other manufactures, for example on the basis of color, finish, etc.

REPLACEMENT STANDARDS

The wear to which a number of components of a machine or other product of the mechanical industry are subject during their periods of use gradually changes their actual sizes, thus causing all clearance fits to

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[1]) Modern Motor Methods, by FRED. H. COLVIN (Amer. Mach., Jan. 4, 1933).

[2]) Marking Sizes and Weights on Automobile Pistons, by A. W. DILTS (Amer. Mach., Nov. 9, 1932).

become looser. Consequently, it is logical to set not only standard control limits for the manufacture of the parts, but also limits for the extent to which parts are permitted to wear. Also, the wear of a part may make it necessary, when its mating part is replaced, to hold the latter's size between limits different from those maintained for new parts of the same kind. For example, a replacement pin to be mated with a worn bushing should logically be held between a set of limits higher than those between which the original pin was held when it was manufactured.

This principle is essential in problems of replacement, such as those that occur in the servicing of passenger automobiles and the maintenance of truck fleets [1]). A proposal has been made to develop a general code of maintenance standards [2]) to include, among other things, (1) limits to be maintained in the manufacture of new parts intended for being assembled with a clearance fit; (2) wear limits up to which these parts are known to give satisfactory performance without their condition requiring special attention; and (3) scrap limits which the parts gradually approach after having exceeded the wear limits mentioned under (2).

Railroads have a similar problem of maintenance. "Locomotive repairs, according to a well-known authority, are the largest single item of railway expense. Data of 1929 show that repairs cost nearly twenty per cent more than fuel and electric power for all locomotives. Repairs almost equalled the total wages of all road and yard men." [3]) However, no general standard practice for wear limits has as yet been developed in this field. A recent article tabulated the practices followed by 12 American railroads in regard to repair and replacement of 20 locomotive parts. This practice shows wide variation. A valve motion bushing is renewed by one railroad when its bore has worn oversize 0.008 inch, and by another railroad when it has worn oversize $\frac{1}{8}$ inch [4]). The German Federal Railways has given the problem attention in the maintenance of its standard type locomotives. Distinction is made there between interchangeable parts held between definite limits in order to secure specific fits, and sets of mating parts only one of which is held between definite

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[1]) Facts and Figures of the Automobile Industry (1930) lists 12 organizations in the United States having a fleet of more than 1000 trucks. The list is headed by the American Telephone and Telegraph Company with 16,000 trucks.

[2]) Repair and Junking Standards, by JOSEPH GESCHELIN (SAE Journal, April 1932).

[3]) Locomotive Repairs — the Largest Item of Railroad Expense (Editorial, American Machinist, Oct. 12, 1932).

[4]) Wear Limits of Locomotive Parts (American Machinist, March 24, 1932).

manufacturing limits while the other part is given an excess of material. The purpose of this arrangement is to permit the part with excess material to be fitted to the other, whether this is new or worn. The choice between the two systems is decided on the basis of cost "not only of the manufacture of the parts, but also, and more particularly, of replacement." [1])

For the sake of completeness, the difficulty in making replacements inherent to selective assembly, is mentioned here again. This has been discussed before [2]).

SAFETY FACTOR

A safety factor is used to secure satisfactory performance under conditions whose occurrence, or whose influence, can only be estimated. The adoption of a safety factor may consist in either of two measures, as follows:

(1) the standard (nominal) level of a requirement may be raised, or

(2) the limits between which the variation in quality of the product or performance which has to comply with the standard requirement is controlled, are brought more closely together.

Both measures may be used in combination, as illustrated by the graph in Fig. 5. The line A represents the estimated standard (nominal) requirement, with limiting requirements B and C. The estimated requirement may be, for example, the yield point of a steel corresponding to a multiple of the maximum computed stress. The choice of this multiple value is an example of the adoption of a safety factor of the type mentioned above under (1).

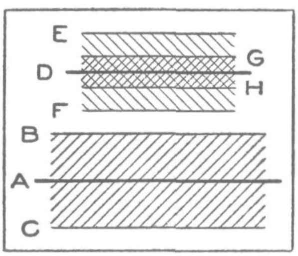

Fig. 5. Use of safety factor.

A steel with a yield point of the standard (nominal) value D and a variation in quality controlled between the limits E and F is evidently satisfactory for the purpose. Even the lowest permissible quality F still lies above the maximum limiting requirement B.

[1]) Der Austauschbau bei den typisierten Lokomotiven der Deutschen Reichsbahn (Interchangeable Assembly Applied to the Standard Type Locomotives of the German Federal Railways), by Iltgen (Sonderheft zu Glasers Annalen, July 1, 1927, page 70).

[2]) See under Selective Matching, page 53.

Yet, it may be decided — we shall see below, why — to keep the low limit of quality still higher above the maximum limiting requirement by narrowing the quality limits of the steel to G and H. This measure is an example of the adoption of a safety factor of the type mentioned under (2) [1]).

The use of a safety factor of the type mentioned under (1) is unavoidable in any case where no sufficient data are available to serve as a reliable basis for determining the maximum requirement.

The use of a safety factor of the second type is an expression of doubt as to whether the quality — assumed to be controlled—will actually stay within its limits, or in other words, as to whether the quality control is reliable [2]). In this connection, it should be realized that if quality is *not* controlled, there is no reason for the adoption of a safety factor of the second type, as this will not in principle prevent quality from falling below the low limit of requirement. We may therefore conclude:

(*a*) that actual control of quality makes the application of a safety factor of the type mentioned under (2) superfluous, and

(*b*) that lack of control of quality cannot be compensated for by the safety factor of the type mentioned under (2).

These conclusions are based on the assumption that a safety factor is adopted — as its name implies — to be *certain* that performance of the product will be satisfactory. However, in cases where the product or the performance is not controlled, the use of a safety factor may increase the probability of getting satisfactory results, but it will never fully guarantee this [3]).

The considerations mentioned show the importance of control of quality for the most economic utilization of a product, particularly a material. The tolerance zone of controlled quality may lie closely to the tolerance zone of required performance [4]). In the use of materials, such as metals and alloys in the mechanical industry, this means either that no

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[1]) An example of its application in practice is found in the purchase of special material selected among product all of which would meet the requirements of the purchaser, the purpose being to have greater certainty of obtaining high quality.

[2]) See Maintenance of Quality, page 63.

[3]) This is similar to inspection or testing by sampling of product whose quality is not controlled. This does not guarantee satisfactory quality, but it may reduce the percentage of rejections. See under Maintenance of Quality, page 63.

[4]) Theoretically, the limit F (or H, as the case may be) in Fig. 5 may coincide with the limit B.

higher grade of material need be used than is necessary for the maximum requirement (computed or estimated); or, if the quality of material is given, that the quantity of material to be used for complying with a specific requirement is a minimum. In either case, the result is economy in production.

These conclusions, both as they affect the problem of manufacturing and the technique of industrial standardization, show the importance of knowing in each particular case whether it is possible to control quality, how the existence of this possibility (if any) can be found out, and where the optimum degree of control lies. A discussion of these questions will follow later [1]).

TOLERANCES ON LIMITS

Compliance with a standard requirement may be so close to one of the limiting values between which the compliance is allowed to vary, that it is impossible to determine whether it has not actually exceeded the limit. The answer to the question whether it has or not may depend on the variation in the result of the measurement caused by the personal factor of the observer. Also, certain limits which are physically represented by devices, such as gages, are subject to variations resulting from inaccuracies in manufacture and from other causes, such as wear. In setting standard limits, the influence of possible variations in them must therefore be considered. Just as an "exact" nominal size must be supplemented by a tolerance to become a practical formulation of a standard requirement, so a limiting value must have "flexibility" added to it in the form of a tolerance, even though this "tolerance on a limit" can be small as compared to the tolerance on the nominal or basic value.

When a purchaser specifies a requirement, and a manufacturer tries to comply with it, the question arises whether the possible variations in the limits should be permitted to narrow the tolerance granted the manufacturer, or whether the purchaser should increase the tolerance on the nominal value by an amount equal to the maximum variations of the limits. In the mechanical industry, for example, the problem appears in this form: Shall the manufacturing tolerance on the limit gages and their permissible wear lie inside the tolerance on the workpiece, or should they lie partly or wholly outside this tolerance? In the former case, the tolerance on the workpiece is reduced by the amounts of the deviations of the limit

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[1]) See under Statistical Method, page 67.

gages from their respective nominal values, or, as it is sometimes expressed, the manufacturer is "robbed of part of his tolerance". In the latter case, the purchaser will occasionally have to accept parts whose size exceeds — be it only to a slight degree — the nominal limits specified in the standard.

The American Standard on fits explicitly states that "the extreme sizes for all plain limit gages shall not exceed the extreme limits of the part to be gaged" [1]. However, the proposed international system of fits developed by a technical committee of the International Standards Association (ISA) specifies a bilateral tolerance on the Not Go gage and a tolerance on the Go gage lying within the tolerance on the workpiece, while the Go gage is permitted to wear slightly past the Go limit of the workpiece [2]. In final analysis, the difference in attitude concerns the manner in which the standard requirements are formulated rather than being an essential difference. If the extreme limits between which the workpiece is allowed to vary according to the ISA proposal, are considered as its nominal limits, all variations in gage size fall within these limits [3].

In specifications for materials, the same question comes up in connection with limiting values for the content of a specific element.

"For example, suppose the specification requires not above 0.040 per cent of phosphorus in the steel, and the analysis shows 0.043 or 0.045 per cent. Shall the material be rejected? .... Two ways of meeting the difficulty have been suggested. One is to have it part of the specifications, and to have the producers clearly understand it, that the limits of the specifications cover the inevitable and unavoidable errors of testing; that is, the manufacturer should work far enough within the limits of the specifications, so that the inevitable and unavoidable errors of testing would never lead to the rejection of a shipment. The other way is to make the limits of the specifications sufficiently narrower or wider, as the case

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[1]) American Tentative Standard for Tolerances, Allowances, and Gages for Metal Fits (B4a-1925), Section 1, Direction of Tolerance on Gage.

[2]) Report of ISA technical committe No. 3, on Fits, April 1932 (graph Pas 773, page 34).

[3]) This viewpoint has been taken in France where the attitude toward permissible gage variations is in principle the same as in the United States. When a French national standard for fits was set up, the ISA system was adopted but the *form* of the French standard is such as to maintain the principle of keeping gage variations within the tolerance on the product (see the French standard sheets CNM 501 to 539, published October 1932).

may be, to cover these unavoidable and inevitable errors of testing and then allow for them in deciding whether to accept or reject." [1])

After having thus stated the two possible attitudes — which parallel the respective attitudes taken in regard to limit gaging practice as referred to above — Dr. DUDLEY, then chief chemist of the Pennsylvania Railroad Company, said in part, referring to his laboratory:

"The latter procedure [giving an extra tolerance to take care of errors of measurement] is the one we have always followed in our laboratory. An illustration will make the whole matter clear. For certain purposes steel containing 0.04 per cent of phosphorus will give us perfectly satisfactory results in service. But knowing as we do that chemists will differ and that there are inevitable and unavoidable errors in the analysis, we make the upper limit of phosphorus in the specification 0.03 per cent, knowing that such steel can readily be obtained in the market without undue hardship to any one. It is evident we have by this procedure sufficient margin to cover inevitable and unavoidable errors in the determination, without raising questions which involve contention and hair splitting. It is infinitely better, it seems to us, to so draw the specifications that the service will be protected by a sufficient margin to afford good strong fighting ground, and when a rejection is made, stand by it to the bitter end." [2])

Independent of the weight of the arguments which may be brought for or against either attitude, the principal point is that the standard shall state clearly which attitude is to govern the dealings between the parties. Although the question concerns limiting cases only, whose frequency may therefore be low, the consequences of misunderstanding on this point may be serious and costly. In cases where delicate fits are involved, it may depend on the question which of the two attitudes described is taken whether workpieces shall be accepted or rejected.

USE OF LIMIT SYSTEMS

In a very large majority of cases, standardization problems involving the adoption of manufacturing limits have so far been dealt with by industry solely in a practical way. In most manufacturing concerns where a limit system is used, this is based at best on expert knowledge of the accuracy required for correct performance of the product in question,

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1) The Enforcement of Specifications, by CHARLES B. DUDLEY (The Life and Life-Work of Charles B. Dudley).

2) Idem.

and the possibilities and limitations of the manufacturing equipment and methods. In the mechanical industry, knowledge of these factors will provide a basis for the choice between the system of complete control of quality and the system of reduced variability of quality combined with 100 per cent inspection; between the use of interchangeable assembly and selective assembly; and other problems discussed in this chapter.

As to the use of manufacturing limits, industrial concerns may be divided into three classes. One class comprises those concerns that possess and use the necessary data for adopting suitable control limits. To the second class belong those that have adopted certain manufacturing limits, but do not maintain them in actual practice, knowingly or unknowingly. There are some companies where a condition of this kind is not only known to exist, but given formal recognition by the fact that the engineering department and the manufacturing department use different tables of tolerances, those of the manufacturing department being of course the largest. Conditions of this kind are partly responsible for designers doubting the actual maintenance of quality by manufacturing concerns in general and for their adoption of a safety factor even in cases where proper control of quality of product has been duly secured [1]). Finally, there is a third class of concerns where manufacturing limits have not yet been given any consideration at all. There are still too many of these.

MAINTENANCE OF QUALITY

Maintenance of quality [2]) means here the condition where the product delivered by the supplier is held between the limiting requirements established for it by a standard. Where standards for manufactured product are concerned, maintenance of quality may in general be obtained by two principal methods. One is control of the manufacturing process to such an extent that the product will have a quality varying only between the desired limits. The other method consists of reducing the variability of the quality of the product by partial control of the manufacturing process, and the elimination by inspection or testing of the products whose quality falls outside the desired limits.

Where quality is controlled, only a periodical check-up on the product

[1]) See under Safety Factor, page 58.

[2]) The term "quality" should be taken here in a wide sense. It may mean the suitability of a material for the purpose it should serve as well as the quality of performance of a worker expressed in managerial units of measurement (see Chapter III, page 42). In the present study, "quality" will be thought of primarily in regard to the dimensions of machine parts or the properties of materials.

is required to make sure that control still exists. This may be done by inspecting or testing samples from time to time [1]). The system of reducing variability of quality combined with elimination of non-standard product requires a check on the quality of all of the product manufactured, or "100 per cent inspection", if strict maintenance of quality is to be guaranteed. The application of any system of inspection or testing that is less comprehensive, such as the inspection or testing of samples, involves here a risk because product of unsatisfactory quality may slip through. In actual manufacturing practice, this risk is taken in many cases where such a slipping through cannot have any serious consequences. If the variation in quality is reduced to such extent that slips of this kind do not exceed a certain small percentage of the total volume of product manufactured, the system just referred to may be adopted on account of the lower cost of maintaining the wider tolerances sufficient for the reduction of variability in quality, as compared with the higher cost of maintaining the smaller tolerances necessitated by complete control of variability.

Obviously, a system involving a risk of this kind must not be adopted if strict maintenance of quality is a matter of primary importance. This applies primarily to any manufacturing problem where the safety of human lives depends on the quality of the product, and also where defective quality would cause serious disturbance either in the assembly of the product or in its performance after assembly. The choice of solutions is limited, in such cases, between complete control of quality and reduced variability of quality combined with 100 per cent inspection.

An instance where the principles underlying a system of securing strict maintenance of quality of manufactured product through complete control of variation in quality has been given special attention is found in the telephone industry. This will be discussed in more detail later [2]).

An example of the application of the other principle is the manufacture of the Wright airplane engine where "a number of major parts, such as crankcase sections, receive 100 per cent inspection on each operation" while each engine part "is given a 100 per cent final inspection" upon completion [3]).

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[1]) Sampling becomes particularly important where quality cannot be checked by any simple and inexpensive method, or where quality can be measured only by destroying or using up the product. In such cases — where 100 per cent inspection is out of the question — complete control of quality of the manufacture of the product appears to be the only way of securing strict maintenance of quality.

[2]) See under *Statistical Method*, page 67.

[3]) Inspection Methods and Quality Control in the Manufacture of Aircraft Engine Parts, by Hugh W. Roughley (ASME Transactions, MSP-50-15).

Each rail made for the New York Central lines is checked before shipment by the company's inspectors stationed at the rail mills, and later again jointly by these men and the New York Central inspection forces. The same procedure is followed in the case of steel wheels [1]).

Sometimes in manufacturing practice, the application of one of the two principal methods of maintaining quality is obviously preferable; in other cases a choice must be made based on the merits of the individual case. These three possibilities may be amplified as follows:

(1) Complete control of quality of the manufactured product is possible, technically as well as economically. The product can be held between definite manufacturing limits in plant operation at a cost lying below the point where it would become excessive. The practical possibilities range here between two extremes, one of which is the condition that control of quality does not require any special measures, variation in quality remaining as it were "naturally" between close enough limits. This condition will exist only where the work is not exacting. The other extreme condition in this class exists where variation in quality can be barely kept between the desired limits without cost becoming prohibitive. Between these extremes, there is a condition where the cost of complete control of quality is equal to that of the alternative method, i. e., reduction of variation in quality combined with 100 per cent inspection. If any doubt exists whether a particular case lies on one or the other side of this point of equality, the costs of both methods should be weighed against each other. In considering the second method (involving 100 per cent inspection) the question whether the cost of inspection can be lowered by assigning this function to an automatic machine is important [2]).

(2) Complete control of quality of the manufactured product is possible technically, but prohibitive from the economic point of view. While it is possible to hold the product between close enough limits, this can be done only at excessive cost. A practical solution may often be found here by applying the principle of selective matching [3]).

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[1]) Materials Inspection Stressed on New York Central (Railway Age, July 1930). What 100 per cent inspection means in this case, is shown by the fact that the rail department of the New York Central lines inspects about 225,000 tons of rails and more than 30,000 steel wheels per year.

[2]) See Automatic Machine Gaging, by C. W. ROBBINS (The Bell System Technical Journal, Oct. 1928).

[3]) See under Selective Matching, page 53.

(3) Complete control of quality of the manufactured product is technically impossible. The required limits lie so closely together that no amount of effort, care and time — and consequently, cost — will be able to hold variation in quality between these limits. Selective matching — which was optional from the technical point of view in the class of work mentioned under (2) — is here the only method of getting satisfactory results in strict maintenance of quality.

Progress in the art of manufacturing causes a constant shift of cases originally falling in class 3 to class 2; and cases originally falling in class 2 to class 1. It has been stated that in 1881, the machinists working in the machine tool plant of the Warner and Swasey Company, Cleveland, Ohio, were disturbed by the novel requirement of "working to a sixty-fourth of an inch" [1]). Contrasting with this, many machine parts made in mass production are now regularly held within a tolerance of 0.0002 inch (about 5 microns) and in exceptional cases even within as small a tolerance as 0.00005 inch [2]). Another example of progress made during a period of 25 years, is found in the experience of the Lamson and Sessions Company, Cleveland, Ohio. In 1904 this firm manufactured each week about 3 million bolts and an equal quantity of nuts. At that time "there were two micrometers in the plant . . . . One of these micrometers had been hand-made by a toolmaker for his own use, and the other was in the desk of the superintendent, who did not know how to read it . . . . Various classes of dies and tools were made in each of the [five] toolrooms, with no general standard . . . . In some cases, the only standard was in the eye of the toolmaker" [3]). Nuts were fitted to the bolts, or conversely, and consequently there was no interchangeability. In 1929, the same company made 10 million threaded pieces per day in five plants located in different parts of the United States, maintaining perfect interchangeability without any difficulty, all bolts and nuts being threaded to the American Standard limits [4]).

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[1]) Fifty Years of Industrial Progress, by JAMES HARTNESS (Machinery, March 1929) who wrote in part: "Of course, many dimensions in those days had to be just as accurate as the dimensions in the shops to-day, when a good fit was required; however, these fits were not obtained by actual measurements, but by the slow process of filing and fitting".

[2]) See under Degree of Accuracy, page 52.

[3]) Standardization as Developed in the Lamson & Sessions Company, by GEORGE S. CASE and A. E. BUELOW (Industrial Standardization, Oct. 1931).

[4]) American Standard for Screw Threads for Bolts, Machine Screws, Nuts and Commercially Tapped Holes (B1a-1924). Even product with very close tolerances (class 4 according to the American Standard) commonly used, for example, by the airplane industry, is regularly made as a commercial product by the company.

STATISTICAL METHOD

Until not so many years ago, even the companies most advanced in the practical use of limit systems decided on the adoption of the values of the limits by using the empirical method in each individual case. However, the three fundamental questions to which the use of manufacturing limits eventually must lead were not — and could not be — answered until the statistical method had been applied to them. These questions are: whether it is possible to control quality in each particular case; if this is possible, how it can be found out; and where the optimum degree of control lies.

The application of the statistical method to the solution of these problems is a development of the last 10 or 12 years during which a considerable amount of work in this field has been done, notably in the United States and Germany. Investigations carried out in actual manufacturing practice have been used to supplement and check the theories of the statisticians in regard to this matter [1]).

The statistician divides the causes to which variation in quality is due into those which can be found and those which — at least for the time being — remain unknown. The former, called *assignable causes*, can be eliminated, with consequent reduction of variability. As there is evidently no way of eliminating or reducing the influence of unknown causes by systematic procedure, the variations in quality due to the combined influence of the unknown causes must be accepted as something inevitable. In other words, they must be considered as being due to chance. Accordingly, unknown causes are called *chance causes*.

The three questions referred to above may therefore be stated in a more general way as follows:

(1) Is it usually possible to find assignable causes of the variation in quality of a manufactured product and to eliminate these assignable causes to the point where the variation due to the system of chance causes remains within fixed limits? — If such limits can be established, this means that the point can be reached where variation may safely be left to chance, or where quality becomes controlled [2]).

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1) For a review of these developments, see Report of the joint committee on Application of Statistical Method in Engineering, organized by the American Society of Mechanical Engineers and the American Society for Testing Materials (Mechanical Engineering, Nov. 1932).

2) "Controlled" meaning here "kept within definite limits", as against the obsolete meaning of "kept to an exact value".

(2) If control of quality through elimination of assignable causes is possible, can a criterion for the existence of this possibility be found? — Only the detection of such a criterion will make it possible to proceed with the elimination of the assignable causes in a systematic manner, contrasting with the method of trial and error which so far has been commonly followed in the adoption of manufacturing limits.

(3) If the state of control of quality has been reached, will it be possible to bring still more closely together the limits within which variation remains, through further elimination of assignable causes? — The traditional method of adopting limits does not indicate, in principle, whether the point of control of quality has actually been reached. In practice, the elimination of causes of variability usually stops at a point where satisfactory *reduction* of variability has been obtained, leaving unanswered the question whether or not this point represents the maximum attainable degree of reduction of variability. Yet, this matter has great practical importance. If the attainment of control of quality also indicates the fact that all assignable causes have been eliminated, then no immediate effort need be made to bring the control limits still more closely together [1]).

Experiments carried out by the Bell Telephone Laboratories for the purpose of finding the answer to these questions have shown that ordinarily a state of control of quality can be reached through elimination of assignable causes, and further, that the possibility of such elimination is indicated when the values fall outside adopted control limits. The results of these experiments, therefore, answered the questions listed above under (1) and (2). Furthermore, it appeared that each elimination of assignable causes made it possible to keep variability within control limits lying more closely together than those previously adopted. In other words, the approach to the state of control appeared to be accompanied by a decrease in the percentage of defective material ("per cent defective" or "fraction defective"), and consequently by an increase in the average quality of the product.

The results of one of the first large-scale experiments of this kind undertaken by the Bell Telephone Laboratories are represented in the graph of Fig. 6. This case was described in part as follows:

"About thirty typical items used in the telephone plant and produced

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[1]) Progress in science or industry may result in the transformation of chance causes into assignable causes. In the course of time a further narrowing of the limits may therefore become feasible. Hence the restriction — "no *immediate* effort".

in lots running into the millions per year, were made the basis for this study. As shown in this figure, during 1923—24 these items showed 68 per cent control about a relatively low average of 1.4 per cent defective. However, as the assignable causes, indicated by deviations in the observed monthly fraction defective falling outside of control limits, were found and eliminated, the quality of the product approached the state of control as indicated by an increase of from 68 per cent to 84 per cent control by

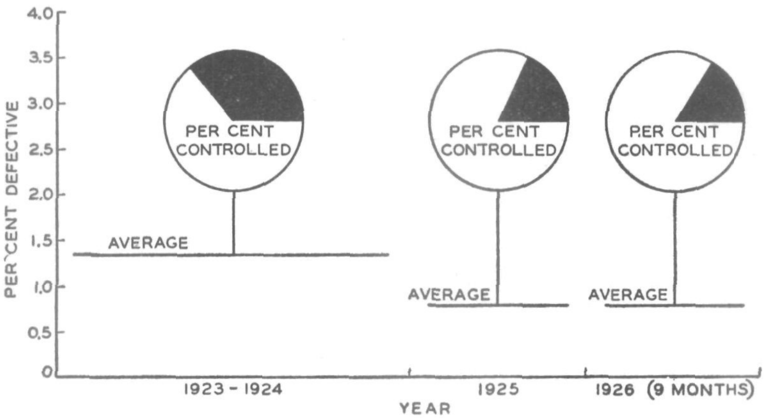

Fig. 6. Evidence of improvement in quality with approach to control.

the latter part of 1926. At the same time the quality improved; in 1923—24 the average per cent defective was 1.4 per cent, whereas by 1926 this had been reduced to 0.8 per cent. Here we get some typical evidence that, in general, as the assignable causes are removed, the variations tend to fall more nearly within the limits, as indicated by an increase from 68 per cent to 84 per cent." [1]).

These findings, although giving the answer to questions (1) and (2) listed above, did not yet answer question (3). While the values, after a number of assignable causes had been eliminated, appeared to fall within fixed limits, this did not furnish proof that no further assignable causes could be found. Investigation of this question led to the conclusion that once the state of control has been reached, there usually is no practical

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[1]) Economic Quality Control of Manufactured Product, by W. A. Shewhart (Bell Telephone System, Monograph B-496). See also Dr. Shewhart's book, Economic Control of Quality of Manufactured Product (New York, D.van Nostrand Co., 1931)

Figures 6 and 7 by courtesy of the Bell Telephone Laboratories.

advantage in any effort to reduce variability still more. That is, the reaching of the state of control appears also to indicate that variability should be left to chance. The graphs in Fig. 7 show the results of one of the experiments made by the Bell Telephone Laboratories on which this conclusion is based. The values plotted represent measurements of the electrical insulation resistance of a material whose possibilities were being investigated. These graphs show that in this case also most of the observed values at first remained within relatively wide limits (left hand graph, Fig. 7) while after the assignable causes had been weeded out, all values

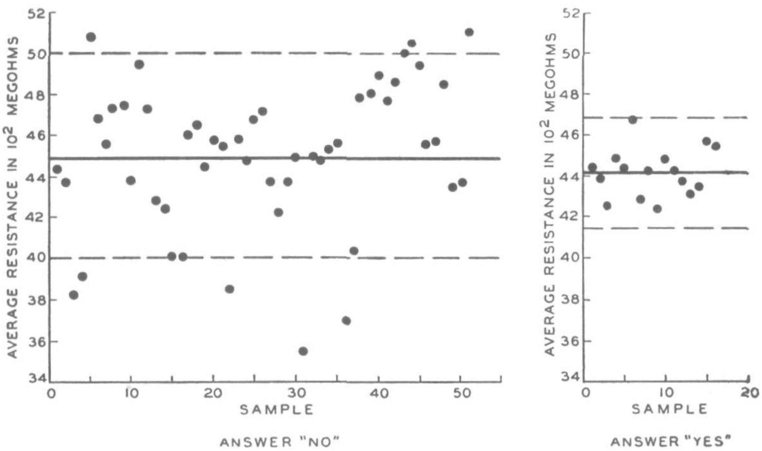

Fig. 7. Should these variations be left to chance?

remained within narrower limits (right hand graph, Fig. 7). On account of this fact, it was assumed "that it was not feasible for research to go much further in eliminating causes of variability. Because of the importance of this particular experiment, however, considerably more work was done, but it failed to reveal causes of variability. Here then is a typical case where the criterion indicates when variability should be left to chance." [1]).

The experiments made by the Bell Telephone Laboratories thus led to the general conclusion that it appears reasonable to believe that an

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[1]) Idem.

ultimate state of control of quality can be reached and that it is possible to find criteria indicating how it can be reached, and when it has been reached. The advantages inherent to a state of control — which have been discussed before in connection with such matters as interchangeability, inspection, sampling and the adoption of a safety factor — affect directly the capacity of the product for technical performance as well as the cost of manufacture.

REVISED CONCEPTION OF A STANDARD

The theory of controlling quality between fixed limits calls for revision of the conception of standardization as developed earlier in this study [1]. If it is not possible to comply with an elementary requirement — concerning, for example, one dimension of a machine part — specified in terms of a single numerical value, then it is also impossible to comply with a set of requirements or conditions represented by a definite level or standard. Therefore, it appears that in general each of the horizontal lines representing standards in the graph of Fig. 1 must be replaced by two lines representing the extreme conditions still permissible as deviations from the "basic" standard level [2]. This amended conception of a standard — which now appears to have spread out to a standard *zone* — is shown in the graph of Fig. 8 representing part of the third phase of an industrial progress-time curve of the kind shown in Fig. 1, during which phase standardization can be successfully undertaken. The original "basic" standard levels are each accompanied in Fig. 8 by two limiting sets of requirements. The standard is now complied with by any point lying between these two limits and instead of following the basic standard level, compliance may follow any curve between the limits. It has been assumed in Fig. 8 that the limiting conditions are brought more closely together with each revision of the standard, because a larger number of assignable causes of variability are gradually eliminated [3]. For example, the constant improvement of machine tools results in the maintenance of closer tolerances at increased speed of production.

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[1] Chapter II.

[2] To avoid confusion, it may be mentioned that the term "basic" standard level used in this discussion has nothing to do with the question whether or not the standard is a "basic standard" (see Chapter II). In the latter term, the word "basic" connotes a degree of general significance, while in the term "basic standard level" it designates a reference line from which permissible deviations are measured.

[3] See under Statistical Method, page 67.

The revised conception of a standard shows an important practical advantage consisting of the greater facility of revising a standard formulated in terms of two limits as compared to a standard represented by a single basic line. The graph in Fig. 8 shows that, if a certain relationship exists between the steepness of the progress-time curve, the size of the maximum permissible variations from the basic standard level, and the periods of time elapsing between two consecutive revisions, a smooth

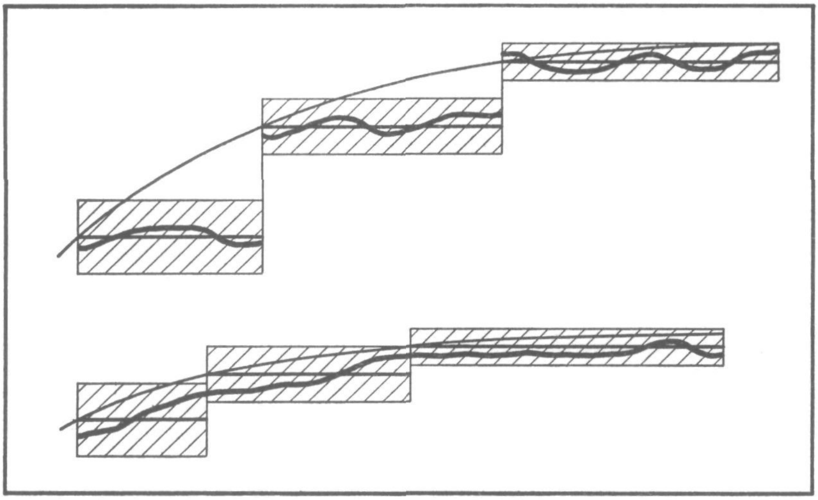

Fig. 8. Abrupt and smooth transitions between a standard and its revisons.

transition from one standard to the next becomes possible. The necessary conditions are the possibility of holding the values specified by the standard between closer limits than the standard actually calls for, and the fact that these closer limits are not farther apart than the distance by which the tolerance field of the existing standard overlaps the tolerance field of the revised standard. In the absence of either of these two conditions, it is impossible to control the trend of the values within the tolerance field of the standard to such a degree as is required for "steering" the value in question from one tolerance field into the other, in Fig. 8.

Roughly speaking, the practical possibilities of making a smooth transition of this kind depend on a relatively high frequency of revision of the standard; relatively large permissible variations from the basic standard level [1]); and the existence of the degree of control referred to above. It appears that this combination of conditions is rather exacting.

High frequency of revision is essentially incompatible with the basic idea of standardization. Thus, the question arises whether smoothness of transition in revising a standard, if partly paid for by increased frequency of revision, is not too dearly bought. The answer cannot be given in general but must be determined in each individual case, after weighing the advantages of smooth revision against the disadvantages of relatively frequent revision. The one important point to be considered here is the *possibility of making a smooth transition at all, under specific conditions,* while the original conception of an "exact" standard level — now called a "basic" standard level — did not permit of smooth transition under *any* condition. Interchangeability of product made in accordance with either of two consecutive standards will lead in practice to permanent interchangeability in all cases where the time during which each standard remains in force before being revised considerably exceeds the useful life of the product. Such permanent interchangeability [2]) may be well worth the price of more frequent revision of the standard. Here again is a case where two opposite principles must be considered to get the best compromise.

The graph in Fig. 8 also shows that smooth transitions between subsequent revisions of a standard result in a curve of actual conditions which closely approximates the progress-time curve. This shows that while the basic principle of standardization is to replace the progress-time curve by a broken line consisting of standard levels and abrupt transitions from one level to another, the use of control limits — originally introduced as a concession to the impossibility of working to "exact" values — appears to make it possible to follow the progress-time curve more closely. Incidentally, the graph also clearly shows the fallacy of the argument, still too often heard, that standardization hampers industrial progress.

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[1]) We find here new proof that flexibility of a standard is desirable. Elasticity between its component parts promotes the facility of shifting the actual conditions within the limiting conditions determined by the standard.

[2]) The term "permanent" applies here only under the condition stated, namely that the product wears out or is used up within a period of time which is relatively short as compared to the period during which the standard or its revisions remain valid. Otherwise, there may not be interchangeability between products made to the original standard and those made to its second or later revisions.

This appears to be true only if revision is postponed during an unduly long period of time.

UNIFICATION OF STANDARDS

The principle underlying the possibility of smooth transition from an existing standard to its next revision may also be successfully applied in some cases where two different standards for the same object are desired to be unified. A level midway between them may be the goal. By revising each of the existing standards periodically in the direction of that level, as shown in the graph, Fig. 9, it is sometimes possible to attain unification without causing any disturbance in the fields controlled by the two original standards. For example, the angle of the American Standard

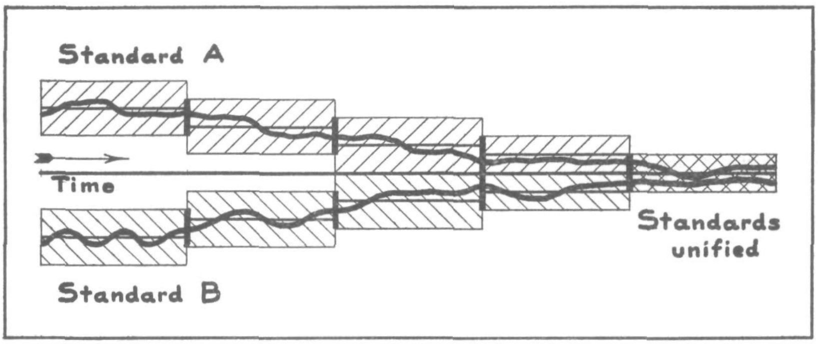

Fig. 9. Unification of two standards through smooth transitions between their revisions.

screw threads being 60 degrees, and the angle of the British Standard Whitworth screw threads 55 degrees, the suggestion has been made to let these angles decrease and increase, respectively — or gradually "grow" toward each other — with the purpose of arriving ultimately at the unified value of 57 $^1/_2$ degrees. Unfortunately, there is a serious obstacle to the unification of the two screw thread systems in question, because the American $^1/_2$ inch screw has 13 threads to the inch, while the British screw of the same size has 12 [1]).

An important case where smooth transition from several existing

[1]) The nature of this obstacle may be judged from the fact that in 1926 the production of $^1/_2$ inch bolts in the United States was reported to amount to 167 million per year (Minutes British-American Screw Thread Conference, New York, April 1926).

standards to a single unified one is succesfully being carried out is the proposed *international* system of fits developed under the procedure of the International Standards Association (ISA). Several national standards on this subject were in existence at the time the work was undertaken (in 1928) and it was made a definite condition that the unified system to be developed should secure interchangeability between parts made to its specifications and those made to the corresponding limits of the existing national standards. This condition having been fulfilled, a country like Germany, where a national standard system of fits has been well introduced into practice (a few years ago it had been adopted by a thousand firms), is now able to change over without difficulty to the new international system.

SUMMARY

(1) A requirement specified by a standard in terms of measurement can usually be complied with only if two limiting values are given.

(2) The recognition of the fact that no "exact" dimensions can be established in practice has led to the use of interchangeable parts, based on the adoption of two manufacturing limits defining a tolerance zone for each exacting dimension.

(3) Experience taught the fact that cost of manufacturing rises rapidly with reduction in tolerances. Accordingly, the use of the widest tolerances that permit the product to give correct performance became a principle of sound engineering.

(4) Economy in manufacturing sometimes makes it necessary to keep the manufacturing limits wider than the product actually requires. Inspection must then do what partial control leaves undone. Where fits or other "matching" of components is concerned, selection of components may help out.

(5) Maintenance standards present some special problems in connection with limits for replacement parts, especially in cases where one of two mating parts, although worn, remains in use.

(6) Inspection by sampling and the use of a safety factor clearly show the importance of controlled quality of product.

(7) Even limits are variable, and due consideration should therefore be given to the manner in which the influence of their variations is taken into account.

(8) In the great majority of concerns using manufacturing limits, these are adopted at best as a practical compromise between the requirements of the product and the possibilities of the manufacturing equipment.

(9) Statistical method applied to manufacturing has given criteria for making a systematic approach to the state of control of quality and for determining when this state has been reached. Also, it has been shown that there is no practical advantage in trying to narrow the control limits further, once variation can be left to chance.

(10) The adoption of limiting requirements in a standard, instead of a single "basic" requirement, gives the possibility, under specific conditions, of making a smooth transition from a standard to its revision.

(11) The possibility of smooth transition between a standard and its revision may be used for the purpose of unifying two different standards by letting them "grow" toward a common standard.

CHAPTER V

DEVELOPMENT OF THE PRACTICAL APPLICATION OF STANDARDIZATION

An industrial organization must be visualized as a complicated mechanism demanding that due attention be paid to the proper coordination of the component parts, if it is to perform effectively. The component parts are the different departments in charge of technical, commercial, and financial operations. The subdivision may be carried down the line to the individual workers: their technical capacities and performances must be coordinated as well as their duties and responsibilities, and even — to a certain extent — their personalities. The human element is thus deeply involved in any scheme of standardization even where this concerns purely technical matters independent of the attitude taken by human beings toward them.

TECHNICAL AND MANAGERIAL COORDINATION

The evolution of industry in its technical aspects shows great similarity with the evolution of problems of management. In the early days of handicraft, one man designed, manufactured and inspected the product. Moreover, as he actually handled each individual workpiece (no operations being assigned to a machine with consequent automatization of their performance), he also inspected each component part going into the assembled product. A similar intimate contact existed in the early forms of industrial organizations. The contact between the master artisan and the apprentices or journeymen was direct and continuous, and instructions concerning the product and its manufacture took form in the same individual manner as the product itself.

The introduction of steam power changed this situation fundamentally. The greater power and the higher speed of production of the machine and its ability to work without interruption and during longer hours than man, focused attention on the loss of time caused by the changing from one operation to another [1]), and by the fitting of component parts to each

[1]) As early as 1776, ADAM SMITH, in his The Wealth of Nations, said that one of the causes of a high production rate per man is "the saving of the time which is commonly lost in passing from one species of work to another".

other when they were assembled. This loss of time greatly reduced the advantages accruing from the use of machines. The difficulty was overcome by the manufacture of each individual part in large lots and, later on, in continuous flow; and by making the component parts interchangeable through holding between definite manufacturing limits the dimensions which control their proper fitting [1]). Production of individual parts in large lots required a high degree of standardization of the factors controlling the rhythm with which the components must flow through the different stages of the manufacturing process to be assembled into the final product. [2]) Interchangeability of parts requires standardization of the units, methods, and apparatus involved in the measurements of length and of the accuracy of production machines, as well as standardization of the materials involved [3]).

As an extreme development in this direction, we now see a mechanical plant (A. O. Smith Corporation, Milwaukee, Wis.), functioning as a single huge machine, turn out 10,000 automobile frames per day, or one every 8 seconds. All operations for the shaping as well as for the assembly of the component parts are performed automatically, the actual manufacture of a frame — which consists of some 125 parts and requires 500 to 600 operations — taking 50 minutes, and cleaning and painting (spraying, baking, and cooling) another 40 minutes. More than 100 tons of steel flow through the plant every hour and a half [4]). Referring to this achievement it was said:

"Still more significant is the fact of manufacturing the more than 100 parts for a frame in as many different places in the plant, to have them meet at one place on schedule, to piece them together at the rate

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[1]) See Chapter IV, under Interchangeability.

[2]) Evidently, a plan of coordination comprising scheduling, routing, etc. is needed also in a properly managed plant engaged in single unit or serial production. In this case, planning cannot be as thoroughly standardized as in (at least temporarily) unchanging mass production, but standardization can be applied to elements common to different kinds of work (materials, component parts, cutting times, tasks, etc.).

[3]) Bar stock fed to automatic screw machines must be held between definite limits, else trouble will occur when it passes through the machines. Each part passing through a machine and temporarily held fast while being operated on, must properly "fit" the holding device of that machine. This requirement may call for greater accuracy in the dimensioning of the part than is necessary for its essential performance.

[4]) Handling Materials in an Automatic Frame Plant, by A. W. Redlin (ASME Transactions, Vol. 52, No. 21). The operation of this plant requires about 200 workers of whom only about 50 touch the product, but the company in question has a staff of about 1000 research engineers.

of a complete unit every 8 sec., and to repeat this accurately 10,000 times in succession every day. Visualize what it means to produce springy, flexible-steel stampings so accurate and so uniform that any one piece will match any accompanying frame part so perfectly that no interference occurs, and so that all holes line up exactly. This is not only desirable, but absolutely necessary since only a fraction of a second is available to put in all the rivets" [1]).

An interesting contrast with this strong concentration of a comprehensive scheme of coordination in a single plant is presented by a vast plan coordinating a large number of individual manufacturing units spread over a wide area. HENRY FORD is reported to be "actively engaged in decentralizing his gigantic organization for producing automobiles, breaking it up into separate but interlocking units which eventually, according to his plan, will operate in small communities throughout the country .... His plan calls for maintaining, as the heart of his industry, a great central plant manufacturing the motors and other vital parts, but the functions of much of the present plant will be taken over by thousands of small factories, each making some part of his car and shipping it to the nearest assembly plant. Of these assembly plants, Mr. FORD now has thirty-eight in various parts of the country. He describes his object as being twofold: Greater economy in operation and the resuscitation of the rural regions by permitting them to produce industrial as well as agricultural goods." [2]). Seven village industries have already been established along the River Rouge, and a total of 5,300 manufacturers scattered all over the country are making parts for the Ford car.

DECENTRALIZATION OF MANAGEMENT

From the viewpoint of management, the industrial organization became decentralized by the advent of steam power in a way similar to that in which the manufacture of the complete product was subdivided. Consequently, the solutions of the problems arising from the decentralization were likely also to be similar in the two cases. In fact, as we see it today, the principle of functional management, as first expounded by FRED. W. TAYLOR, is the logical counterpart of the use of special machines in the technical end of an organization. Coordination of the functions of workers

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[1]) Idem.

[2]) Small Unit Plants Ford's Final Goal, by HAROLD N. DENNY (N.Y. Times, Feb. 5, 1933).

by specifying their tasks, duties and responsibilities — including proper tolerances [1]) and checks on performance — is essentially not different from the coordination of the performance of machine parts by specifying the dimensions or other values — with corresponding tolerances — controlling their proper connection and joint performance, and the inspection and testing of the product and its performance. The most important difference between the technical and the managerial problems is that the elementary components of the respective systems — human beings in one case, and machine parts in the other — vary widely in the extent to which their capacities and performances can be defined, determined and controlled. The natural desire for a certain freedom of action and individuality of expression limits the degree to which the average human being is willing to have measurement and control applied to his activities and behavior, even though long centuries of training have caused the human race as a whole to accept a considerable degree of systematization as a matter of course. This is why the principle that the performance of human work could and should be subjected to analysis, measurement, planning, and checking (the same way as the performance of machines) met with such a heavy resistance when TAYLOR first expressed it about fifty years ago. And while the workers — in the sense of "employed" — opposed his philosophy on the ground that carrying it out would "make machines out of men" and that they would be "driven" by a system of the kind proposed, the executives as a class began by disregarding it partly because too much prestige and power was meant to be assigned to "standardization" of functions, according to the principles of scientific management. This attitude may be traced to the evolution of human leadership in general and also to the evolution of the industrial organization, as discussed before. [2])

LAG OF MANAGERIAL COORDINATION

As a consequence, the coordination of industry in respect to its managerial aspects has lagged far behind the coordination of its technical functions. One reason for this is that the requirements of technical coordination were often inescapable as their disregard would result in the manufacture of a

[1]) Instead of the term "tolerance", the term "allowance" is commonly used in managerial problems — as in time study work — but the basic idea is the same, namely to leave a margin covering non-controllable (and in many cases non-controlled, even though controllable) variations in the values concerned.

[2]) See Chapter I, under Human Factors.

product of such low quality as not to be marketable or even usable. In other words, observance of technical coordination appeared in many cases to be a fundamental condition for the continued existence of the manufacturing establishment. Another reason is that technical standardization did not give rise in a direct manner to the delicate question of possible curtailment of the individual freedom of the human being in doing his work. Finally, matters of a technical nature were generally handled by men of the craftsman type who were accustomed to work either to definite rules dictated by the possibilities and limitations of the so-called laws of nature, or to rules purposely set up as a working plan by others or themselves.

It is therefore significant, but not surprising, that the principles of scientific management were first developed by an engineer and not by the merchant type of executive. This is true in spite of two facts. One is that in principle the human element had always played an important part in the task of the merchant, even long before the latter's influence in matters of industry had become so strong as to dominate his partnership with the craftsman. The other is that some system had already been developed in the commercial and financial activities of the business just as well as in engineering, when TAYLOR first applied his analysis of doing work. However, methods of bookkeeping and related functions were still in a primitive condition [1]), and so were in general methods of design and production. Many shops did not have any drawings because they worked from patterns, nor did they have any toolroom system — let alone records and standards. The reason why scientific management came up first in the technical field may be ascribed to the basic difference between the craftsman and the merchant types of man in their attitude toward the fundamental problems involved in the manufacture and sale of the product, and their approach to these.

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[1]) ". . . . from 1880 (as a matter of fact, from the end of the Civil War) nearly up to the nineties, except in the very largest companies, the office consisted almost entirely of a single bookkeeper . . . . Until 1880, the size of a business depended entirely upon the ability of the proprietor to carry in his head a multitude of facts relating to his business. When this burden became too great for his mental capacity, the company stopped growing. It is true, there were records of financial transactions in the books — such accounting records had been made for centuries — but it had not occurred to very many business men to record other than financial facts." (The First Half Century of Office Management, by W. H. LEFFINGWELL, paper read before the National Office Management Association, June 5, 1930).

F. W. TAYLOR'S WORK

More curious, at first sight, is the fact that it also took TAYLOR a long time to convince the engineers as a group of the soundness of the new principles which he advocated. When he joined the American Society of Mechanical Engineers in 1885, the interest of executives in management affairs was focused entirely on wage payment systems. Still in 1895 TAYLOR had "to cloak under discussion of that subject an argument concerning the necessity of measuring performance as the essential basis for any system of wage payment. His piece-rate system was discussed — on the whole unfavorably — but practically no attention was paid to his concept of the measurement and control of a day's work. This concept was ignored apparently as impracticable" [1]).

Presenting his paper on Shop Management eight years later (1903), its discussion "also failed to stimulate sympathetic interest in the idea that a day's work could be measured" [2]). TAYLOR thus came to the conclusion that: "You cannot persuade any set of men, employers or employees, to adopt the principle of scientific management immediately" [3]). In his paper on Shop Management TAYLOR said, referring to Standards:

"The adoption and maintenance of standard tools, fixtures, and appliances down to the smallest item throughout the works and office, as well as the adoption of standard methods of doing all operations which are repeated, is a matter of importance, so that under similar conditions the same appliances and methods shall be used throughout the plant. This is an absolutely necessary preliminary to success in assigning daily tasks which are fair and which can be carried out with certainty" [4]).

The performance of an organization as a whole being the integration of numerous daily tasks carried out by individuals, standardization is also "an absolutely necessary preliminary to success" of the business as a whole. Viewing our economic system as a conglomerate of business organizations, it appears that its stabilization is not possible without better coordination between its component parts, while this coordination again is dependent on the establishment of some stable level to serve as a basis for planning. Therefore, the two essential functions of standardization must evidently play a major part in whatever scheme may be developed

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[1]) H. S. PERSON, in Scientific Management in American Industry (published by the Taylor Society, 1929), page 7.

[2]) Idem.

[3]) Ibid., page 32.

[4]) Shop Management, F. W. TAYLOR, paragraph 269 J, Standards.

for business stabilization — a problem which in the last few years has become more important than ever.

A turn in the general attitude toward standardization has come with the greater amount of attention given scientific management shortly before the war [1]) and the establishment of national standardizing bodies in more than twenty countries since the war. These organizations act as central agencies for the promotion of standardization as a managerial function as well as a measure of national economy. The basic principle adopted by almost all of these bodies is to leave the establishment of national industrial standards to the joint action of manufacturers, users and distributors of the product, and independent experts whose cooperation is sought for the sake of their technical advice. Such developments indicate a start in a new direction: that of greater cooperation toward integration within an industry, and between industries.

If it is realized how many centuries the old order of things in industry has been growing up; how much inertia has come to be involved in existing conditions; and how recently, in relation to the time industry has been developing, TAYLOR'S new philosophy was expounded — then it is clear that the significant results that have already been achieved by the national bodies are only a faint indication of the tremendous possibilities of standardization.

Under these conditions, one might expect to find standardization widely applied by the industries of the world, whether the units be large or small. Since the essence of standardization is coordination — once the basic plan on which standardization shall be undertaken has been chosen — its influence must pervade the organization. There is no particular size of organization where the need for standardization begins; this need exists in *every* organization [2]).

SITUATION IN THE UNITED STATES

It will be shown that the situation in an industrial country of primary importance like the United States, known for the development of its mass production methods which are impossible without systematic standardization, appears upon closer investigation to be surprizingly far from the

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[1]) The Hearings Before a Special Committee of the House of Representatives, in 1912, relative to Taylor's philosophy of doing work, awakened a general interest.

[2]) The managerial set-up by which it should be taken care of, and accordingly the size of the personnel in charge of standardization activities, will naturally vary with the kind and size of the organization.

point where standardization is made a definite business policy by the management of the average industrial plant.

Taking the year 1925 as an example, the figures given in Table 3 apply to the volume of production of the manufacturing establishments in the United States.

TABLE 3

Manufacturing Establishments in the United States (1925) [1]

Volume of Product per Establishment in 1925 (*in Dollars*)	*Number of Establishments*	*Value of Products* (*in Dollars*)	*Per Cent of Establ.*	*Per Cent of Total*
5,000 to 20,000	55,876	628,373,403	29.8	1.0
20,000 to 100,000	68,951	3,272,196,872	36.8	5.2
100,000 to 500,000	42,209	9,576,090,022	22.5	15.3
500,000 to 1,000,000	9,771	6,870,112,293	5.2	11.0
1,000,000 and over	10,583	42,366,941,140	5.7	67.5

The total value of products of all establishments was close to 62,714 million dollars, and the total value added by manufacture, 26,778 million dollars.

Rounding these figures for the sake of simplicity, we get the following picture. In 1925, ten thousand large manufacturing establishments, each making product with a value of at least one million dollars, had together a production of 42 billion dollars, or two-thirds of the total production of manufactured goods in the United States which amounted to 63 billion dollars [2]. Independent of the nature of the business of these concerns (whether they make machine tools, automobiles, or textile products) each of them required, on account of its very size, a well organized system of coordination, both from the technical as well as the managerial point of view. It would, therefore, seem reasonable to expect the existence of a standards department at least in each of the 10,000 large companies under consideration here. The balance of the manufacturing establishments (those of smaller size) are completely disregarded in this consideration. Yet, this balance amounts to about 177,000 establishments, including more than 9000 each of which manufactured products with a value of $ 500,000 to $ 1,000,000 in 1925 (see Table 3).

[1] Statistical Abstract of the United States, 1932, pp. 730, 731.

[2] In the U.S. one billion equals one thousand millions, while in Europe the term "billion" designates one million millions.

With reasonable certainty it may be held that the number of manufacturing establishments in the United States which have a standards department is only a relatively small fraction of 10,000. This belief is based on the following evidence.

The American Standards Association (ASA), the central industrial standardizing body in the United States, and a federation of some forty technical societies, trade associations, and departments of the Federal Government, has been in existence since 1918. During this period of time, it has kept a record of those companies that have been in touch with the ASA through an engineer or any other individual in charge of the companies' standardization work. However, the records of the ASA show less than 100 names of such companies or about one per cent of the establishments that made one million dollars' worth of products in 1925 [1]). Even if we assumed that the records of the ASA were only one tenth complete, there still would be a vast difference between the number of standards departments in companies that should have one, and the number in actual existence. It is very improbable, however, that the ASA records should fall short of the complete truth to such an extent. If a company of the size mentioned has a standards department, this will almost certainly get in touch with the ASA, at some time during a period of 10 or 15 years, about some standardization subject [2]).

In 1930, the Committee on Stabilization of Industry for the Prevention of Unemployment, appointed by FRANKLIN D. ROOSEVELT, then Governor of the State of New York, made a canvass of the industry in that state. Out of 598 firms which replied, 292 had some plan for the stabilization of their operation. However, only *seven* firms reported a definite program of standardization [3]).

A few years earlier, the U. S. Department of Commerce made a canvass of technical societies, trade associations, State governments, and the Federal Government, to determine the amount of money spent by

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[1]) In 1923, there were 10,327 of these large concerns; in 1929, their number was 11,763. For 1927 no figure is given, but the total value of products of all manufacturing establishments in this year differed by only 4 million dollars — out of nearly 63 billion dollars — from the value given for 1925. Therefore, it seems safe to assume that the number of these large companies has never been below 10,000 in the period 1923—1929.

[2]) This statement is based on the fact that the ASA has completed about 230 projects leading to the approval of American Standards and has about 200 more in course of development. Also, the ASA has on file more than 10,000 foreign national standards for the information of American industry. Inquiries regarding these are regularly received from companies interested in the export of their products.

[3]) ASA Bulletin, May 1931.

these respective bodies on standardization in 1926. Some of the results are given below [1]):

Inquiries sent out	396
Replies received	272
Replies reporting expenditures and stating amounts	95
Replies reporting expenditures but giving no amounts	31
Inquiries unanswered	110

The total amount of money spent for standardization work in 1926 reported by those replying "including such items as executive salaries, office expenses, conducting conferences, publication, research, travel, etc." was very close to 7 million dollars, about $4^1/_4$ million of which was accounted for as the share of the Federal Government [2]). Deducting the latter amount, less than 3 million dollars was spent by the private organizations which replied to the canvass. In judging this figure, it should be kept in mind that not all manufacturing establishments are members of a trade association; that 31 organizations reported expenditures but did not state the amount; that some organizations which spent money on standardization may not have been reached by the canvass; and that the total expenditures reported did not include those made by individual companies since the latter were not comprised in the figures supplied by technical societies and trade associations [3]). Therefore, the figure of about 3 million dollars reported by those who did answer the canvass is in all probability only part of the total amount spent in 1926 by American industry as a whole. Yet, considering the important role played by many trade associations in developing trade standards and setting up standards affecting more than one industry, it is significant that the amount of 3 million dollars is less than 0.005 per cent of the total value of products manufactured in the United States in each of the years 1925 and 1927 [4]), not to mention the fact that there is also a tremendous

[1]) Data not published by the Department of Commerce, but given in Appendix K of Industrial Standardization, published by the National Industrial Conference Board, 1929.

[2]) The exact figures are $ 6,994,186.23 and $ 4,250,500.00.

[3]) For example, the estimated cost of the standardization work carried out by the Society of Automotive Engineers (SAE) in 1928 was $ 15,000 contributed by individual companies and $ 33,800 by the Society (see SAE Journal, June 1930), but these figures do not include the amounts spent by the automobile manufacturers on the establishment of their company standards.

[4]) The Statistical Abstract of the United States (1932) does not give the total value of manufactured products in 1926. In 1925, this figure was 62,714 million dollars; in 1927, it was 62,718 million dollars.

field for standardization outside the manufacturing industries, such as the railroads and the electric light and power industry.

A more positive indication of the extent to which trade associations have not given attention to standardization is found in a list of 87 trade associations and technical societies reporting no expenditures for standardization work in 1926. Among these organizations are: American Boiler Manufacturers Association; American Iron and Steel Institute; Associated Metal Lath Manufacturers; Association of Manufacturers of Wood Working Machinery; Automotive Wood Wheel Manufacturers Association; Electric Hoist Manufacturers Association; Elevator Manufacturers Association of the United States; Foundry Equipment Manufacturers Association; Grey Iron Founders Association; Leather Belting Exchange; National Association of Fan Manufacturers; National Association of Manufacturers of Heating and Cooking Appliances; National Boiler and Radiator Manufacturers Association; Power Transmission Association; Road Machinery Manufacturers Association — to mention only a few in the mechanical or related fields. In all of the branches of industry represented by the trade associations mentioned, the nature of the product would fully warrant carrying out standardization work as a trade association activity, independent of what is being done by individual companies. A single example will support this statement. More than 2,000 different kinds, types and sizes of grader blades, and about 1,000 different drag plates for roadbuilding machinery are on the market today [1]). Here is an excellent opportunity for standardization work to be carried out by a trade association, or still better perhaps on a national scale. In fact, public authorities like municipal and state governments should have a great interest in work being done along these lines.

Such situations furnish ample evidence that the adoption of standardization as a managerial policy has been badly neglected. While in a relatively small number of organizations [2]) standardization has been developed into a valuable managerial tool, it is still in a primitive stage of development as far as industry at large is concerned. At first sight this is the more remarkable since standardization is definitely recognized as one of the basic elements of scientific management. However, this philosophy — as TAYLOR himself called it — has not yet been adopted by industry at large as an indispensable means for the attainment of optimum results in performing its

[1]) Product Engineering (April, 1932).

[2]) These do not belong exclusively to the group of organizations with the largest production referred to above.

activities. In sizing up this situation in the United States, H. S. PERSON, managing director of the Taylor Society, wrote:

"In the United States, there is great variety of plants, nature of processing — continuous, intermittent or variable — and as to the kind and quality of management. There is a small proportion of large mass-production establishments employing many workers, and with enormous output. Some of these have been strongly influenced by scientific management, some moderately, and some very little. There is a very considerable proportion of medium-sized plants, some of which may have continuous processing in one or more departments although they would not be classified as mass-production establishments. Many of these also have been influenced by scientific management. The dominant proportion of establishments — chiefly, although not altogether, of small size — have managements representing inherited patterns modified by casual imitation. Among all of these classes can be found only a small handful of deliberate, patient, well-rounded developments of scientific management." [1]).

Under these conditions it seems fair to say that it will still take a number of years to have standardization generally recognized and adopted on the merits of its principles. In the meantime, its adoption in practice is constantly making progress because an ever increasing number of business executives are detecting the economic advantages of standardization, such as reduction of manufacturing cost and elimination of waste. Even the economic by-product of the safety movement — essentially carried on for the purpose of protecting the worker — becomes an important factor in its promotion. However, it is often difficult or impossible to show the economic advantages of standardization before it has been introduced into a company, especially if this has managed its business so far without using standardization. In such a case, a vicious circle will probably be at work because lack of technical standardization prevents accurate record keeping and standard cost accounting, while lack of proper cost accounting makes it impossible to estimate the savings which the introduction of standardization will bring. While the capacity of an improved production machine to save labor and money can be demonstrated in a short period of time, this is not usually true in the case of the advantages of standardization. Consequently, many executives hesitate to invest as much in a standards department as they would readily spend on a new piece of

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[1]) Scientific Management in American Industry (published by the Taylor Society, 1929), pages 12—13.

production equipment whose effectiveness can be summarily shown. Yet, the possibilities of standardization appear to be the same in principle as those of an automatic machine. Both will relieve man's mind and body from effort and fatigue.

This lagging of the general adoption of a principle in one application (the technique of standardization) behind its adoption in another application (the automatic production machine) must have some deeper causes. Some of these lie in human factors influencing business management, as previously discussed [1]).

However, while engineering has been leading in applying analysis, measurement and synthesis to the performance of its work, general business management now begins to swing toward the same procedure. Progress of standardization work, necessarily slow in the early phase, will become increasingly rapid and furnish one of the most effective means of controlling business fluctuations between the closest limits which the ever remaining "chance causes" will permit to maintain.

SUMMARY

(1) Specialization and consequent decentralization of industry has created the need for systematic coordination in managerial as well as in technical matters.

(2) Technical coordination in industry has preceded managerial coordination because observance of the former appeared to be indispensable for the manufacture of satisfactory product, especially in mass production. The necessity of coordinating managerial functions is less obvious to the average business executive.

(3) The failure of industry at large to adopt more rapidly the principles of scientific management — and consequently of standardization as one of its major factors — than it has done since FRED. W. TAYLOR expounded them, is partly due to lack of appreciation of the value of measurement, and partly to certain fundamental attitudes of the human being toward standardization.

(4) There is ample evidence to show that the degree to which industrial standardization has been adopted by manufacturing establishments in the United States as a systematically applied managerial function represents only a small fraction of what might be expected in view of the benefits which may be derived from its application.

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[1]) Chapter I, page 6 ff.

(5) As long as standardization has not met with more general and better understanding of its intrinsic merits by the average business manager, the best way of promoting its adoption is to show the savings that can be made by its application. To do so in advance is difficult in an organization where standardization has not yet been introduced at all.

(6) The results so far attained by standardization work accomplished by progressive industrial organizations and under the procedure of the national standardizing bodies in more than twenty countries give only an indication — important though they may be — of the possibilities of standardization for the integration of industries as a factor in stabilizing the economic system.

CHAPTER VI

STANDARDIZATION IN A MANUFACTURING CONCERN

In discussing the possibilities of industrial standardization, one generally arrives at a point where the choice between different solutions must be made on the merits of each individual case because of the great variety of combinations that may occur between technical, commercial, and managerial problems and conditions as well as the attitudes of the industrial groups concerned. However, if we focus our attention on a particular branch of industry, such as manufacturing in the mechanical field, we get a more definite picture of the problem of coordinating different activities which permits us to formulate certain principles to be observed in organizing and carrying out industrial standardization in practice. The question *what* functions of a manufacturing concern in the mechanical industry call for coordination through standardization will be dealt with here first, while the question *how* this coordination may be accomplished and in its turn fitted into a more comprehensive scheme of industrial standardization, for example on a national scale, will be discussed later [1]).

SUBDIVISION OF COORDINATION

In order to be effective, standardization must logically pervade the entire organization all of whose activities are linked together, either directly or indirectly. However, on account of the fargoing subdivision of the modern industrial organization along specialized lines, the very coordination of the different functions, technical and managerial, has become such an extensive task as to require subdivision in many cases. An industrial organization of any considerable size needs several coordinating agencies each of which must harmonize the cooperation between two or more departments. The central coordination is then taken care of by the executive management or by a central planning department, as the case may be.

A manufacturing concern in the mechanical industry needs first of all

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1) Chapter VII.

coordination of the several functions involved in production, the principal ones of which are design, manufacture and inspection. The respective departments in charge of these functions will be jointly designated in this discussion as the "production group". Systematic coordination is also required for harmonizing the functions of the merchandising, sales and advertising departments, which will be jointly called the "distribution group". The production and distribution groups must be coordinated with each other and with other departments and groups, such as the research, planning, and purchasing departments.

STANDARDS DEPARTMENT

The present study is primarily concerned with standardization in the production group. For the purpose of this discussion, a standards department will therefore be defined as the department in charge of coordinating the functions of the engineering, manufacturing and inspection departments [1]. Accordingly, the task of such a standards department will comprise:

(1) the development of company standards for coordinating the design, the manufacture and the inspection of the product;

(2) the coordination of the functions of the production group with those of other departments and groups within the company through cooperation in the development of standards of common interest to these departments and groups;

(3) the coordination of the company's standardization work with that of other organizations (companies, trade associations, technical societies and the national standardizing body) through cooperation in the development of standards intended to be used by industrial groups larger than the individual company.

Once the requirements for the performance and possibly also for the appearance of the product have been specified, the joint problem of the production group whose solution must be coordinated by the standards department with the activities of the distribution group is in general:

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[1]) In some companies the term "standards department" is used for the department in charge of the standards and methods of measurement, sometimes in combination with the carrying out of experiments and tests for research purposes and as routine checking of the quality of materials and products.

(1) to design the product in such a way as to make it meet its performance requirements at the lowest possible manufacturing cost. This is done through functional and production design carried out by the engineering department;

(2) to manufacture the product in accordance with the design;

(3) to control the manufacture of the product so as to maintain the desired quality. This is done by inspection of the components during the manufacturing process, supplemented if necessary by inspection of the finished product in assembled condition [1]).

DESIGN

The design of a product of the mechanical industry may be divided into:

(1) Functional design, to be subdivided into:
 (*a*) Basic design
 (*b*) Service design
 (*c*) Auxiliary detail design

(2) Production design

Functional design is concerned solely with the manner in which the product is expected to comply with its performance requirements. Consequently, the type of standard most important in functional design is the performance standard which specifies the limiting conditions of the service the product is expected to give in actual use. These requirements must be met by the combination of basic design, service design and auxiliary detail design.

Basic design relates to the essential functions of the product and may be embodied in an experimental model the dimensions nor the materials of which are used in the product ultimately manufactured. Standards for dimensions and materials should be set up in the basic design only in so far as they are indispensable for the correct performance of the product. More detailed specifications should be left to service design or production design, both to be discussed later. This rule is based on

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[1]) Depending on the nature and size of the organization, the inspection and testing of purchased materials and components may be part of the task of the purchasing department or the task of a separate testing department.

two principles referred to earlier in this study[1]). According to one of these principles, a system of standards should consist of a foundation of basic standards relating to essentials and a superstructure of standards relating to details. The other principle is that a standard should leave the greatest possible freedom in the way its requirements are met. If these principles are applied to basic design, this must specify only those properties of a material that are essential to the basic function of the product, such as tensile strength, hardness, non-corrosiveness and permeability. Otherwise, the choice of a material should be left to service design (see below). The same rule applies to the specification of the processes by which the component parts are to be manufactured. In principle, basic design is independent of the nature of these processes, but in exceptional cases they must be specified because the desired performance cannot be obtained in any other way.

Service design concerns all features of the product that influence its use and maintenance in proper shape for correct performance in so far as these features are not covered by the basic design. Service design relates, for example, to the possibility of connecting or assembling the product with others; the resistivity of the product to outside influences, such as atmospheric conditions; the facility of cleaning and lubricating the product and of adjusting, repairing, and replacing its component parts; and the safety devices for protecting the operators and others against hazards involved in the use of the product.

The item "connectability" has great practical importance because it represents the principle of "flexible unification" to be observed in adopting basic or nominal dimensions and the tolerances thereon. Where a product must be assembled with others, connectability becomes part of its performance requirements. Examples are all elementary components of mechanical equipment such as bolts, nuts and screws; shafting keys; ball bearings; spark plugs; and firehose couplings; as well as all composite units or sub-assemblies whose connecting dimensions must be standardized to permit their ready assembly with other products, such as steam valves; electric motors; shaft couplings; clutches; and gear boxes.

The facility of cleaning and lubricating the product, and of adjusting, repairing, and replacing its component parts directly affects the maintenance standards. Consideration must be given such questions as to whether a part should be detachable to permit replacement when worn, and if so,

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[1]) Chapter II.

whether the fit with its mating part makes it possible to apply interchangeable manufacture or requires selective fitting and replacement of both mating parts at the same time [1]); and whether parts that may have to be replaced are readily accessible. Even the time element may be essential in making replacements. It has been suggested that the facility of removing a radio transmitter from an airplane should be specified as a performance requirement in such a form as: "The transmitter must be removable by one man in four minutes" [2]).

The choice of dimensions and materials specified with a view to service design depends on requirements of the product in actual use as determined by wear, atmospheric influences, corrosion, vibration, abrasion, rough handling by users, and so on.

Auxiliary detail design has for its object those features of a product that are not essential to its performance in regular service, yet valuable in some minor respect. Thus, from a technical standpoint the appearance of a product is an auxiliary detail, although the designer's æsthetic sense will cause him to give it due consideration. (However, from the standpoint of the sales department, appearance may be an essential factor calling for maintenance of strict standards). Other examples of auxiliary detail design are the arrangement of a screw eye on the cover of a pump or turbine casing to facilitate its transportation by means of a crane, and the arrangement of holes in a machine or apparatus solely intended for bolting it to the bottom of the box in which it is shipped. None of these details affects the essential performance of the product.

Production design has for its purpose the specification of the methods and means of manufacturing the product that are most effective from the combined technical and economic point of view. It translates the compliance with the requirements of the product as laid down in the functional design, into terms of shaping, dimensioning, finishing, treating, and assembling the product. This translation being based largely on the capacities of mechanical equipment into which the performance of work has been embodied in a standard form, production design is one of the developments most characteristic of the influence of standardization on modern mass production. Its correct solution may be just as important to

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[1]) Chapter IV, page 56.

[2]) Relation of Design to Airplane Maintenance, by John G. Lee (SAE Journal, Oct. 1, 1932). Discussion of this paper brought out the desirability of setting up standards for the "maintenance quality" of airplanes.

the financial results of the company's business as that of functional design because it may decide whether or not the manufacture of the product will yield a profit.

Sound production design represents the most favorable compromise between the requirements of the product; the possibilities of the manufacturing equipment, methods, processes, and materials; and manufacturing cost. In principle, the question whether a component part should be manufactured in the plant or purchased on the outside should also be determined by those in charge of production design. Purchase of component parts makes it necessary to consider whether a standard for these parts exists or whether one should be developed by the company.

The task of production design is to supply the manufacturing department with specific instructions for the manufacture of the product based on standard specifications for the following groups of items: (1) the materials of which the product is made; (2) the dimensions of the component parts, if necessary supplemented by manufacturing limits; and (3) the methods of work and the processes to be used for the rough-shaping, finish-shaping, treating, and assembling of the component parts [1]).

ORGANIZATION OF DESIGN

The several types of design interlock closely and it is therefore natural that in small organizations and in larger organizations where the product is of a simple kind, all subdivisions of design are taken care of by the same group of men. In larger concerns, however, and especially where the product is complicated, there will be a more or less distinct demarcation line between the groups in charge of functional and production design. Thus, these two functions as performed to meet the requirements of the telephone companies operating under the Bell Telephone System are assigned to the Bell Telephone Laboratories and the Western Electric Company, respectively. In reference to the standardization and manufacture of new apparatus in the Bell System it was stated that:

"the Bell Telephone Laboratories provide to the Western Electric Company standard specifications covering the description and performance of the apparatus, including manufacturing tests and inspections. It is the purpose of these specifications to give adequate information to the manufacturer regarding the device and regarding the performance requirements which it must meet when completed, but not to specify in

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[1]) "Treating" does not only include heat treatments of steel and other alloys, but also surface treatments, such as painting, varnishing and electro-plating.

detail the process of manufacture. This is done by the manufacturing organization itself, which standardizes for each type of apparatus the methods to be followed in its production . . . . When an order requiring engineering work by the Western Electric Company reaches one of its factories, the Equipment Engineering Department translates the telephone companies' requirements into manufacturing specifications and drawings utilizing standard equipment specifications and drawings on 80 to 90 per cent of all orders for central office equipment units, such as switchboards, desks, and the mechanical units for dial offices. This results in standardizing the information which goes to the Manufacturing, Installing, and Pricing Departments and minimizes the effort required to engineer, manufacture, test, install, and price the equipment" [1]).

Contrasting with the concentration of the different forms of design in a single organization, there are also cases where the increasing specialization in industry has extended into the field of design. Consulting engineers now undertake designing work on a contract basis. The letting of design contracts may be more economic than the permanent maintenance of an engineering staff for the same reason that it may not pay a firm to own certain machines because its volume of production is not large enough.

Similarly, specialists in the design and manufacture of tools, jigs and fixtures, dies and other equipment, undertake work of this kind on a contract basis. In the automobile industry, outside services to the production engineering department are now commonly used and other branches of industry may follow its example.

MANUFACTURING

The principle of leaving the greatest possible flexibility in standard requirements so as to permit the largest number of solutions to be used should also be applied to the manufacturing department. This should receive, in form of the production design, complete, specific, and practicable instructions as to what it is expected to do to manufacture the product, but it should be left free in the choice of the ways and means by which

1) The Fundamental Role of Standardization in the Operation of the Bell System, by H. S. OSBORNE (ASA Bulletin, Sept. 1931). To avoid misunderstanding, it should be mentioned that the term "equipment" designates here the equipment used by the telephone companies, which is the *product* manufactured by the Western Electric Company. Clear distinction is needed especially because this company also designs and builds part of its own manufacturing equipment.

these instructions are to be complied with in all cases where the result to be attained can be stated in specific terms. Thus, while the size of a cylindrical part can be definitely stated in terms of its manufacturing limits, no terms of measurement have as yet been found to express the "quality of surface", i. e. the combined effect of the size, shape and distribution of the minute unevennesses of a metal or other surface [1]). For the time being, surface quality can be specified only by indicating the method by which it is to be obtained (such as the number of grinding finishes and the type of grinding wheel to be used for each finish) or by reference to samples.

The standards most characteristic for the manufacturing department are "shop standards" relating to the production methods and the equipment and tools used for their application. While the production design may specify the desired result in minute detail, the manufacturing department must see to it that the proper tools and equipment are obtained and that they are maintained in good working condition. Standardization of tools and equipment is also indispensable for the development of standard data for the time and motion study department and thence, of data to be used by the planning and cost departments. These data affect again the standards on which the production design is based. This complete circle of influences shows how tightly the activities of all departments are interlocked and the consequent necessity of their coordination. It also shows the impossibility of getting a real grip on this problem of coordination without standards being set up.

One of the major problems in coordinating design and manufacturing is to find the correct balance between the accuracy required by the product and the possibility of maintaining this accuracy in the manufacturing department. Excessive demands on the shop equipment in respect to maintenance of accuracy are a frequent source of controversy between the engineering and the manufacturing departments. The designer soon tends to specify manufacturing limits closer than those strictly required for correct performance of the product.

"For instance, in a certain war contract, the government drawings carried a general note to the effect that all dimensions, unless otherwise noted, were to be made within $\pm$ 0.002 inch. A 2 inch fillet joining two surfaces and which had no other function, and which did not touch any

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[1]) In the United States this question is now being studied by a technical committee on Classification and Designation of Surface Qualities (B 46) organized in 1932 under the procedure of the American Standards Association (ASA).

other surface, was required by the government inspector to be made to exactly 2 $\pm$ 0.002 inch, although 2 $\pm$ $^1/_8$ inch would have made no difference in the strength or utility of the part. To meet the requirements of the inspector necessitated over 5 hours of machine time on each piece made and seriously hampered production." [1])

Such a procedure always increases manufacturing cost and the manufacturing department which naturally holds out for the largest possible tolerances, is often given an unnecessarily heavy, if not an impossible task. This applies particularly to plants that do not have standards for the regular inspection and maintenance of their manufacturing equipment. Excessive looseness of machine spindles in their bearings and other deficiencies of the production equipment may then make it impossible to maintain the close limits set by the designer even though this could have been done when the equipment was new, or still could be done if it were duly adjusted.

INSPECTION AND TESTING

The terms "inspection" and "testing" are sometimes used with the same, and sometimes with a different meaning. Inspection originally denoted a mere visual examination and is still used primarily to designate a simple examination of a quality, performance or condition. Testing denotes primarily the examination of a quality, performance or condition by submitting the object to certain actions or by letting it perform certain actions. Thus, an engine is *inspected* to determine whether its component parts are in sound condition, while it is *tested* by being operated.

In a manufacturing plant in the mechanical industry, three main kinds of inspection and testing may be distinguished, as follows:

(1) inspection and testing of materials and parts supplied from the outside on the basis of standard purchase specifications;

(2) inspection of semi-finished and finished components during the manufacturing process of the product and final inspection of the product after its assembly, based on the standard requirements (such as size, finish and appearance) embodied in the design;

(3) testing for performance of the completed product on the basis of the standard requirements laid down in the functional design.

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[1]) Production Control, by George D. Babcock (Management's Handbook, edition 1924, page 674).

Furthermore, inspection and testing require the adoption of standard units and methods of measurement, and in some cases measuring devices, such as limit gages.

The inspection of the component parts of a product during their travel through the manufacturing process must also be used to check the accuracy of the process itself. Rejection of product that should remain within definite control limits must be a reason to investigate why it exceeds these limits. Where partial control is applied, an abnormal increase in the percentage of rejected product should lead to such an investigation. Inspection data are valuable as an indication of assignable causes of variation in the quality of the product [1]).

RELATIONS OF STANDARDS DEPARTMENT

The departments or groups of departments with which the activities of a standards department must primarily be coordinated are the research department, the distribution group (consisting mainly of the merchandising, sales, and advertising departments) and the purchasing and planning departments. If the inspection and testing of materials and components purchased on the outside are performed by a special department (instead of by a subdivision of the purchasing department), this inspection or testing department — both designations are used in practice — must of course also be coordinated with the standards department.

RESEARCH DEPARTMENT

Close cooperation between the standards and research departments is a primary requirement. In the production group, design, manufacturing and inspection represent only three of the four essential functions comprised in all systematically conducted human activities, namely *planning, doing,* and *checking*. The fourth essential function which in doing work should precede the three just mentioned, is *fact-finding*. In a manufacturing concern this function is represented by research, supplemented by practical experience and sometimes in part by what is commonly called "development work".

When a standard cannot be set up because specific data are lacking or because it is impossible to express its requirements in terms of measurement, research must make an effort to supply the missing data. This task involves three main items, as follows:

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[1]) See Chapter IV, under Maintenance of Quality.

(1) the investigation of the characteristics of materials, methods, processes, and means essential for the product manufactured;

(2) the development of standard methods and units to measure these essential characteristics, or the development of a tentative basis of comparison if measurement is not yet possible;

(3) the correlation of the results of test measurements and the results obtained in actual practice.

Research must also keep track of the performance of the product in actual service to check the soundness of the existing standards and to detect possible reasons why they need revision. Even though the product gives satisfactory service, study of the results of practical experience by research methods may show the way toward improvement of the standards of design and manufacturing. Therefore, systematic collection of service data and their submission to the research department is one of the duties of the sales force. The research department may also be asked to ascertain whether unsatisfactory performance of the product is due to deficiencies in design, manufacturing, inspection, or testing, or to some cause that so far has escaped control. Investigations of this kind can be accomplished with success only if the research department proceeds on the basis of standards adopted by the other departments which furnish the necessary control limits.

DISTRIBUTION GROUP

The merchandising department plays a role in the distribution group similar to that of the engineering department in the production group. While the engineering department decides what the manufacturing department should make (formulating its decision in a design), the merchandising department determines what the sales department should sell, and consequently what the engineering department should design. This requires careful consideration of the problems faced by the production group in connection with the technical possibilities and the cost of manufacture. Hence, there must be close cooperation between the production and distribution groups, mainly through understanding between the engineering and merchandising departments, to arrive at standard specifications for the product which the distribution group considers as satisfactory to the customers and which the production group considers as a suitable basis for developing technical standards permitting economic manufacture. These product specifications should contain no more detail than is required by the sales problems, thus leaving the production group the greatest possible freedom in solving the technical ones. In general, the requirements should be formulated as much as possible in terms of performance specifications making reference to the following items:

(1) the performance of the product under normal conditions (the concept "normal" to be defined, i. e. standardized);

(2) the flexibility of performance, i. e. the actual performance of the product under conditions other than normal, and more particularly the standard limits between which it is expected to give satisfactory performance;

(3) the cost of performance, such as the power consumption of a machine;

(4) the cost of maintenance, such as cleaning, lubricating, and replacement of worn parts;

(5) the useful life of the product, or the actual operation time during which it should give satisfactory service;

(6) the appearance of the product, mainly from the viewpoint of sales possibilities;

(7) the cost of manufacturing the product determined in relation to a sale price.

The items listed under (1) to (4) inclusive can be determined with a fair degree of accuracy by the engineering department on the basis of recorded data, especially when conditions are standardized. In this case, the data can be readily assembled, like standardized physical components, into a solution answering a specific combination of requirements. It is then relatively simple to decide how the product should be made.

The decision regarding the useful life of the product may cause some difficulty. This useful life must not exceed the period of time after which the product becomes obsolete, but obsolescence is often difficult to predict. The question may become one of merchandising policy, artificial obsolescence being created to increase sales [1]). The production group is

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[1]) See, for example, Our Business Civilization, by JAMES TRUSLOW ADAMS.

interested in the period of useful life which the product should have, because this affects directly such questions as the choice of materials, fits, workmanship, and treatment of materials and components, and consequently also the cost of manufacture.

The appearance of the product is another item deserving careful consideration by the engineering and merchandising departments. While independent of technical performance, appearance may affect the cost of manufacture and be decisive in respect to the commercial success of the product. A large American company manufacturing electric equipment and devices found that electric flatirons with a black finish could not be sold even at a price considerably lower than that of flatirons of the same quality made with a nickel-plated finish.

The attitudes of the production and distribution groups, or more specifically the engineering and sales departments, toward the problem of setting standards for the product, are usually quite different. The fundamental contrast between the craftsman's and the merchant's way of looking at the product [1]) still exists under modern manufacturing conditions. Although the standards for the product are sometimes developed and maintained entirely in accordance with the ideas of the production group, the customer's wishes often determine what requirements the product should meet. These wishes may be contrary to the demands of sound design, but the production group will nevertheless have to count with them. A prominent automobile engineer recently made the following statement:

"Whenever the public decides that it would prefer a car higher than the present type of car, it certainly will get it. The engineer is suffering to-day because of the insistence from the sales department to make cars lower and lower . . . . As an engineer I would welcome any concerted demand from the public in that respect, for it is a tremendous job to hide the machinery between the floor and the road and have some road clearance, especially since we have the softer engine mountings and more rigid and difficult frame construction" [2]).

A smoothly functioning merchandising department should practically eliminate the traditional controversy between the engineering department and the sales department as to whether the latter should sell what the former chooses to design, or whether the engineering department should

[1]) Chapter I, pages 10 and 11.
[2]) H. M. Crane, in discussing his paper, How Versatile Engineering Meets Public Demand (SAE Journal, Jan. 1933).

design what the sales department says to be able to sell. Systematic investigation of the customer's wishes, known through regular reports from the sales staff, permits the merchandising department to set standards for the requirements of the product on a sound basis.

The salesman bent on satisfying the customer is naturally inclined to agree to a departure from the standards adopted by his company for its product if in this way he can secure an order on "specials". However, the manufacture of specials tends to disrupt the regular procedure of the production group — which consequently looks upon them with disfavor — and may actually result in a loss to the company caused by an increase in overhead which the salesman did not foresee. Therefore, just as in the production group the standards department should have the responsibility as well as the authority to decide whether or not a proposed exception to the use of standard materials or parts is permitted, just so the merchandising department should consider and rule on the acceptance or refusal of orders on specials. Thus, instead of becoming a matter of controversy between the sales and engineering departments, the question should be settled by the merchandising department on the merits of the case, and not through persuasion on the part of either group.

Replacement parts present a special aspect of the problem of maintenance standards. How long, from the viewpoint of service to the customer, should a company continue to keep in stock component parts for products made to obsolete standards that are still used by the customers? Keeping stock of spare parts for old products may become a heavy burden on the manufacturer. Due consideration should therefore be given to the setting of a limit for the period during which replacement parts shall remain available after revision or abolishment of the standards to which they are made.

PURCHASING DEPARTMENT

This department is closely connected with the production group because it supplies materials, tools, equipment and other necessities for the manufacture of the product.

Led by a feeling similar to that which often causes the designer to set limits closer than those required by the product, the manufacturing department may have a tendency to specify tools and equipment of a quality that is unnecessarily high. According to the principles of sound standardization work, the requirements of the manufacturing department should be stated as much as possible in form of performance specifications, it being the task of the purchasing department to supply the unit of performance at the lowest possible price, all other conditions being equal, such as reliability of the source of supply as to regularity and speed of delivery.

Standard purchase specifications for items concerning the production group should be set up through cooperation between the standards department as the representative of this group and the purchasing department, the research department giving such assistance as may be required. If the inspection and testing of purchased goods are carried out by a department specially equipped for this purpose, this should also be consulted.

PLANNING DEPARTMENT

The planning department has to "design" a schedule by which work is assigned to the several departments and, within these, to different production machines and workers. The data required for this schedule concern the capacity of the production equipment as to volume and quality of work; the times in which elementary operations should be completed; and so on. The quality of planning of work depends on the extent to which standards for these different items have been developed and recorded. Complete data permit the planning department to "assemble" them rapidly into a schedule of work or instruction sheets for detailed operations.

The planning department while not belonging directly to the production group as previously defined, is nevertheless closely related to it because of its interest in factors affecting production. A change in a tool may require the revision of a standard operation time on record with the planning department, as well as the revision of the standard specifications for the tool itself kept on record by the manufacturing department. Data on speeds and feeds of metal cutting operations are basic not only for the standards department, but also for the planning department.

SUMMARY

(1) A manufacturing concern in the mechanical industry should have as one of its coördinating agencies a standards department harmonizing the activities of the engineering, manufacturing and inspection departments with each other, as well as the activities of these departments as a group (production group) with other departments and groups in the

company, primarily the research, planning and purchasing departments, and the distribution group.

(2) The task of such a standards department also comprises the coordination of the respective activities within the company — design, manufacture and inspection — with similar activities undertaken on a larger scale, such as the standardization work carried out under the procedure of the national standardizing body.

(3) The standards department should give special attention to the harmonizing of the requirements for the accuracy of dimensioning (manufacturing limits) laid down in the design of the product, and the capacity of the manufacturing department to meet these requirements.

(4) The inspection and testing of materials and parts purchased on the outside, the inspection of semi-finished and finished components during the manufacturing process, and the final inspection and testing of the assembled product call for the adoption of standard units of measurement, methods of testing and measuring devices.

(5) Inspection and testing should be used not only as a means of separating acceptable from non-acceptable product, but also as a basis for studying the causes to which rejection of product is due.

(6) The research department should cooperate in the standardization work by investigating the essential nature of the requirements to be embodied in the standards; the possibilities of meeting these requirements by the use of physical objects, methods of work, and manufacturing processes; the development of methods for determining the requirements and possibilities in question; and the correlation of test results and performances under actual service conditions. If necessary, the research department should also assist in the interpretation of the practical experience obtained with the use of the product.

(7) Standard specifications for the product should be set up as a compromise between the market requirements, quality of performance or appearance of the product (or both), and cost of manufacturing. This compromise should be reached through cooperation between the production and distribution groups.

(8) Due attention should be given the question of expected obsolescence. Standard manufacturing limits need not be closer, and standard

qualities of materials and finish need not be higher than is required for enabling the product to give satisfactory service until such time as it will be discarded on account of obsolescence.

(9) The engineering and sales departments are likely to differ in viewpoint as to what the standard specifications for the product should be. The merchandising department should work out a compromise between these views based on facts obtained through market research. It should also decide to what extent orders on special or non-standard product will be accepted.

(10) The question as to how long a company should continue to keep in stock replacement parts for its customers after the standards for these parts have been revised, must be given due consideration.

(11) Standard purchase specifications, based as much as possible on performance requirements, should be developed through cooperation between the purchasing department and the department for which the supplies are intended. In so far as activities of the production group are concerned, the purchase specifications should be formulated by the standards department in consultation with the purchasing department and such other departments as may have an interest in the subject or possess special knowledge of it.

(12) The planning department in charge of the scheduling and routing of work and the establishment of standard detail instructions for the performance of work, and the standards department of the production group should work closely together because of their common interest in several types of standards affecting production.

CHAPTER VII

ORGANIZATION OF STANDARDIZATION WORK

In considering the organization of standardization work as a means of coordinating and integrating the activities of industrial groups and consequently of the industrial system as a whole, we shall start out from the individual company. While the internal details of standardization work carried out within the company are solely the latter's concern, this work should fit externally into the standardization scheme of the branch of industry to which the company belongs and into the more extensive scheme of national standardization. In some cases (for example, when a company exports to foreign countries), it may even be desirable or necessary for its standards to conform to certain recommendations for international uniformity established through cooperation between different national standardizing bodies [1]).

COMPANY STANDARDIZATION

Standardization within a company is generally most effective if the executive management has a clear conception of the fact that standardization increases the efficiency of the company's activities and that it is an indispensable function of sound business conduct. Standardization is sometimes used by a company to investigate its possibilities in an experimental way, because difficulties have been met by one or more of its departments through lack of coordination of their activities, either in their mutual relations or in their relations with outside organizations. The manufacturing department may suffer from lack of uniformity in the quality of materials or lack of interchangeability of component parts purchased on the outside. Or, the engineering or sales department may encounter difficulties through lack of standard nomenclature of the product. Under the pressure of such conditions the executive management may decide, for example on the insistence of the chief engineer, that standardization work should be undertaken in regard to a specific subject, i. e. on a limited scale. This may prove to be useful as an opening wedge for its introduction as a general function of the company. However,

[1]) See The Four Stages of Standardization, page 119.

the weakness of such a partial effort is that coordination of some, but not all of a number of closely interlocked activities, is in principle erroneous. Standardization promoted by one department and opposed by another (a not uncommon situation), will very probably fail to produce results that would be well attainable through a plan of standardization generally applied to the business of the company. Also, such a failure will impair the introduction of standardization into departments where it has not yet been used.

When standardization is applied for the first time, the question where it should be started can be answered only after the activities of the several departments have been thoroughly studied by the standards department and a general working plan based on a survey has been developed [1]). If it is possible to make rapid progress in a special line simultaneously with the development and execution of the general plan, this will greatly contribute to the success of the standardization work. In a company building textile machinery, the standardization of nuts alone gave a saving equal to 40 per cent of the appropriation of the standards department while the savings made during a period of seven months accrued to three times the annual cost of the work [2]). A large machine tool builder saved more than $ 10,000 per year only by standardizing the bolts and screws used in his machine [3]). However, standardization cannot always produce such striking results in the early stage of its application. It is more likely that the creation of harmony and rhythm in the operation of the activities will be gradual.

"The officials of one company have said that they spent quite a large sum of money in the years 1925, 1926 and 1927, and of course were continuing to spend good sums this year [1928]; but from the results that they had seen by the end of 1927, this expenditure would be returned to them in the year 1928 fourfold, based on the same production as they had in 1927. Now, as their production is larger in 1928 by at least 25 per cent, the dividends this year, figured on the expenditure of the three previous years, will be about 500 per cent. — This having been accomplished by a company that was generally accepted as having more than average efficiency, we are certain that similar activity reflected by other concerns would be at least equally productive and, in many cases, even

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[1]) See Working Plan of the Standards Department, page 115.
[2]) SM Bulletin, ASA (April 20, 1925).
[3]) Management's Handbook, edition 1924, page 513.

more productive because of the new basis of efficiency from which to calculate" [1]).

POSITION OF STANDARDS DEPARTMENT

The standards department must study its problems and make its recommendations without regard to the positions or personalities of those whose opinions or attitudes are involved. Therefore, it should be responsible only to the executive management and be immune from any influence on the formulation of its proposals regarding company standards. Any plan where standardization work involving the coordination of several departments is carried out by a staff reporting to the head of one of these departments, is defective because the standards department will probably become biased in its recommendations. Thus, if it reports to the chief engineer as the head of the staff of designers, the standards department may unknowingly become too rigid in the matter of manufacturing limits, while it may become too lenient in this respect when it reports to the production manager [2]). The necessary independence of the standards department also demands that the funds required for its work shall appear on the budget of the company as a separate item and not as part of the appropriations of another department.

Coordination of several departments makes it necessary for the standards department regularly to collect data about their activities. Its authority to do so should be definitely established and announced to all other departments even before the standards department begins its work. This announcement should come from the executive management with a statement of the latter's full support in order to avoid difficulties between the standards department and members of other departments who might show resentment when any matter pertaining to their work is investigated by "outsiders". The task of coordinating several departments is by its very nature a delicate one demanding much tact on the part of the standards department. Therefore, every effort should be made to avoid or remove any condition that might impair its relations with others. This is especially important during the initial stage of the work when the standards department has to make a survey of existing practice likely to bring to light certain deficiencies and wasteful conditions.

Another reason why the standards department should have an

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[1]) Progress in Industrial Management, report of Management Division, American Society of Mechanical Engineers (Mechanical Engineering, Jan. 1929).

[2]) See Chapter VI, under Manufacturing.

independent position is that it must be able to refuse the performance of tasks that fall outside the scope of its work or would require an objectionable deviation from its established program. Requests to this effect are sometimes made by departments desirous of having their conditions improved at the earliest possible date, once standardization has been undertaken.

Closely connected with the problems mentioned is that of collecting the data required for the coordination of the activities of the several departments. These data should be supplied to the standards department in a clear and concise form. In other words, it should not be necessary for the standards department to collect the data in the other departments. The idea of giving each of these an opportunity to submit the data as a contribution to the general plan of coordination is more conducive to the creation of a spirit of cooperation than an investigation "from the outside" which may be felt more or less as an inquisition. Furthermore, it may be more effective from a practical point of view to let each department compile its own data than to have this done by the standards department, especially when existing conditions are entirely unstandardized. Therefore, the standards department should, in principle, collect data in another department exclusively with special authorization given it by the executive management, either because the department whose data are concerned declares not to be able to supply these (or not in a form suitable for the purpose of the standards department), or because it refuses to supply the data. Whether or not such a situation will occur depends largely on the manner in which the executive management has prepared the organization for the introduction of standardization.

TECHNIQUE OF STANDARDIZATION WORK

Two different cases may be distinguished in the application of industrial standardization work. One is its application to a new problem which has not yet become influenced by any existing standards. The other is its application to a field where standards have already been established (for example, through traditional practice of long standing) and must be considered when new ones are developed.

The case where no standards (formal or informal) exist is an exceptional one. In our complicated modern industrial structure with its fargoing specialization, it is hardly possible to develop a new industrial standard without having to count with certain existing ones. Even the manufacture of an entirely new mechanical product will very likely involve the use of materials and components, and almost certainly the use of tools and equipment for which standards, or at least certain traditional practices, have already been established. Also, during the early phase of an industry, when the essential features of the product are still in a state of flux (so that a standard could be freely "designed"), the time is not yet ripe for standardization, while once the point has been reached where this can be undertaken successfully, a crystallization of certain essential features of the product has already occurred [1]). Almost any practical standardization problem will therefore be subject to certain limitations caused by technical or non-technical factors. Among the latter may be mentioned: economic factors (such as manufacturing cost and investment in existing drawings, patterns, tools and equipment), commercial factors (such as user demand and market advantages due to established practice), and human factors (such as traditional design and personal preferences of leading personalities in a particular group).

Where only few restrictions are imposed on the development of a standard for a mechanical device intended to answer a specific functional purpose, the course of procedure followed in establishing the standard will consist of two parts. One is the determination of the essential characteristics of the performance which the product is expected to give and the range of capacities which this performance should cover. The other part comprises the division of this range into subranges each of which is to be covered by a specific type or size of the device. Therefore, such a standardization program will consist of:

(1) the establishment of a series of standard performance ratings covering together the total range of performances required;

(2) the development of a series of standard designs each of which answers the requirements of a specific subrange of performance, the total number of different materials and component parts required for the manufacture of the several designs being kept as small as possible;

(3) the development of a series of standard methods and processes for manufacturing the product, the total number of different tools and operations being kept as small as possible.

The division of the performance range into subranges as mentioned under (1) should be made on the basis of geometric progression — the

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[1]) Chapter II, page 18.

subranges increasing by a constant percentage — unless there is a definite reason for deviating from this principle. Geometric progression has been made the basis of standard series of Preferred Numbers intended to serve as a guide to the designer and standardizer in specifying dimensions, ratings, capacities, etc., in all cases where no special requirements (technical or other) prohibit their application as impracticable [1]).

The standard designs of the products and the standard methods and processes required for their manufacture (including all materials, tools and equipment) mentioned under (2) and (3) may then be fitted exactly to the selected subranges of performance, just as the dimensions of the component parts of a machine built without any purchased parts or tools being used, may be freely chosen by the designer. In the case under discussion the standardizer, considered as a "designer" of standards, is not subject to any restriction dictated by existing standards, but he should pay special attention to opportunities for unifying standards through voluntary restriction of choice.

The procedure where the standardizer is bound only by the fundamental requirements of standardization technique cannot usually be followed when standardization is introduced into an existing industry. The possibility of setting a standard on the basis of purely technical considerations is more restricted as the industry is older. Traditional practice has often acquired such a weight through investment in manufacturing equipment and product in operation that immediate and complete "re-design" of the existing standards on a technically rational basis is impossible in practice. However, a gradual and smooth transition to a rational system of standards may be possible [2]).

SIMPLIFICATION AND RE-DESIGN

In principle, the application of standardization to existing products comprises two different techniques. One is simplification, or the weeding out of superfluous variety in types and sizes of the existing product. The other is the technical re-design of the remaining types and sizes to make

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[1]) See, for example, the French and German national standards for preferred numbers (séries de Renard; Normungszahlen) and Table Z 17-1927 recommended by the ASA to American industry for a trial in practice. The matter is now also under consideration by an ISA committee with a view to international unification. For interesting applications in engineering practice, see for example, Experiences and Suggestions Relating to the Preferred Numbers System, by R. E. HELLMUND (ASA Bulletin, Jan. 1931), and Die Getriebe für Normdrehzahlen, by R. GERMAR (Berlin, Julius Springer, 1932).

[2]) See Chapter IV, under Unification of Standards.

the new series of products cover most effectively the total range of performance requirements.

Simplification is sometimes the only technique applied, the basis of the weeding-out process being the sales records of the various types and sizes of product. The manufacture of products for which there is no or only little demand is then discontinued. This procedure is beneficial in so far as it permits the manufacturer to concentrate on a smaller number of different items and the distributor to reduce his stock. However, as no changes are made in the technical features of the products, simplification cannot harmonize the types and sizes whose manufacture is continued, nor can it utilize the opportunities for unification of materials and component parts of the various products. Simplification discards, but does not re-arrange what is conserved, and therefore cannot be used as a tool of coordination.

Technical re-design of a series of products, if it is logically to answer the total range of performance requirements, may have to be so drastic as to replace the series by one consisting of a smaller number of types and sizes differing individually from the existing ones. In such cases, mere simplification is bound to result in a solution which may be the most favorable one from the commercial point of view and perhaps the only one attainable for the time being, but remains a make-shift affair from the engineering standpoint. A striking example is the simplification of paper sizes in the United States [1]). This has led to the recommendation of a number of basic sheet sizes [2]) between which no logical relation exists either in linear dimensions or area. Thus, three of the recommended book paper sizes are 28 $\times$ 42 inches, 32 $\times$ 44 inches, and 35 $\times$ 45 inches. Contrasting herewith, the paper sizes as developed by PORSTMANN in Germany [3]) form a harmonious system in which all sheets of a specific series have the same shape; each sheet is half of the next larger one; and all sheets are derived from one basic sheet. This system has so far been adopted as a national standard system in thirteen countries to supplant all previously existing systems.

A typical example of re-design of a product of the mechanical industry

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[1]) Simplified Practice Recommendation No. 22, on Paper, published by the U.S. Department of Commerce in 1924 and revised in 1933.

[2]) The term "basic sizes" is used here to indicate the largest sheet sizes from which other sizes are obtained by subdivision.

[3]) Normformate, by W. PORSTMANN (published by Deutscher Normenausschuss). See also: A System of Standard Paper Sizes as Developed in Europe, by the writer (Industrial Standardization, July 1932).

for the purpose of setting up a national standard to replace various existing designs is the American Standard for Rotating Air Cylinders and Adapters (B5.5—1932) [1]. This new standard was developed to obtain interchangeability of different makes of air cylinders on spindles of machine tools without changing the adapter or draw rod.

WORKING PLAN OF STANDARDS DEPARTMENT

The working plan of the standards department in charge of introducing standardization into a company where it has not yet been applied in a general way consists of three main parts, as follows:

(1) a survey of existing practice and conditions
This should generally cover the following items:

(*a*) the various types and sizes of products manufactured, and the performance requirements which these products are intended to meet;

(*b*) the materials and component parts used in the manufacture of the products, including methods of inspecting and testing these items, distinction to be made between manufactured and purchased components;

(*c*) the methods of work and processes used for the manufacture, inspection and testing of the products (components and assembled products), including tools and equipment;

(*d*) the standards used by the company, if any [2].

(2) a study of the results of the survey mentioned under (1)
This study has for its purpose to determine:

(*a*) whether the variety of products as to types and sizes can be reduced and if so, whether the market requirements should be covered by a simplified line of existing products or by a new line of re-designed products;

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[1] Developed by technical committee No. 11 of sectional committee B 5 on Small Tools and Machine Tool Elements, organized under ASA procedure.

[2] Even though standardization is not applied as a definite function of management in a company, this may use standards. They may become adopted through the personal care of a chief engineer, a production manager, or a purchasing agent who recognizes their importance.

(*b*) the need for applying standardization to the products of the company and to all factors involved in its manufacture, and the technical and economic possibilities of this application.

The solution of these problems usually requires consideration of a number of conflicting arguments brought forward by different departments. The engineering and manufacturing departments may be in favor of completely re-designing the line of existing products, but the merchandising department may be opposed to making any change with a view to the demands of the market. Or, the standards department may have to use considerable effort to convince the purchasing department, or even the engineering department, that standard specifications can and should be set up for items that have been dealt with so far by judgment. In such a case, the standards department will be in a much stronger position if it can point to the existence of a standard developed under the procedure of a responsible and neutral organization, especially the national standardizing body.

(3) formulation of proposals for company standards.

In building up a system of company standards, two questions should be given special attention. One is the subdivision of standards into a group comprising basic or primary standards, and other groups comprising more detailed standards of secondary importance, tertiary importance, etc. The other question is whether a standard on a specific subject has already been established by some other organization.

The two problems in question should be considered at the same time. The standards department may find, for example, that in addition to a national basic standard for a specific object, there exist several more detailed standards, all of which are based on the national standard, but more or less different from each other. Or, the national basic standard may have been supplemented by a trade association or technical society in a way deserving consideration by the company. For example, a series of extra-fine screw threads has been adopted by the Society of Automotive Engineers as an addition to the coarse and fine American (National) screw threads.

The general procedure of the standards department should be as follows. It will determine, basing on the nature of the products manufactured by the company, what standards are basic or primary, and what standards are of a lower order of importance. For each of these classes of standards, it will decide, after having studied the existing standards in the field, which ones should be adopted by the company. The order of preference to be followed in making this choice is: a national standard; a trade association or technical society standard; a standard adopted by one or more other companies; and a practice which has become informally, but generally adopted, perhaps without its origin being known.

Where the company's business is found to need standards and no existing ones are suitable for its purpose, they should be developed by the standards department which should also keep in mind the possibility of having the company change over without difficulty to a more widely adopted standard (trade association or national standard), if and when this becomes established.

WHERE TO START STANDARDIZATION

Although a complete answer to this question can be given only on the merits of each individual case, a general principle can be indicated which should be followed in carrying out a program of standardization work.

A manufacturing process is the gradual merging of a number of flows of activities each of which represents a series of causes and effects. Some of these flows originate within the company while others have their origin outside its sphere of activities and consequently enter this only after a certain stage of development has already been reached. Depending on which of these two conditions exists, it will be possible for company standardization to begin at the source of the flow, or it will be possible only to set up standard purchase specifications acting as a check on quality of condition or performance at the point where the flow enters the company's business. Thus, if it purchases parts with pipe thread connections, the kind of thread (including manufacturing limits) must be laid down in a purchase specification. However, if the company cuts the pipe thread on these parts in its own shop, purchase specifications must be established for the die-chasers as the "generators" of the threads. Again, if the company manufactures its own die-chasers by hobbing them from tool steel blanks, standards are also required for the bar stock of which these blanks are made, the hobs, and the method of hobbing the chasers. The three cases represent, in the order mentioned, an increasing degree of tracing back to its origin one of the lines of activities jointly leading to the manufacture of the final product. Such a tracing back, when carried out for different flows of activities, will reveal opportunities for the unification of standards used for controlling different flows. One company when introducing standardization, found that each of some thirty designers specified particular kinds of steel so that 160 varieties were used in the manufacture of its products. It also found that the heat treatment facilities were so imperfect that the results obtained with expensive alloy steels did not even equal those of ordinary chrome-nickel steels subjected to properly controlled heat treatment. Standardization led to the use of five instead of 160 varieties of steel (three for regular and two for special purposes) and heat treatment by electrically controlled furnaces [1]).

Under non-standard conditions, excessive variety of component parts often results from their repeated design by different men, no record being kept of what has already been designed and manufactured either for an earlier type of the same product or for a product belonging to another line of the same company. A manufacturer of special machinery found that more than 1100 different pins were being used in his plant for securing cams on shafts [2]). A machine tool builder carried in stock five cylindrical pins of the same size. Two were practically obsolete, two others were produced in small quantities, and only one was made in large lots on an automatic screw machine at a cost amounting to only one-fourth of those made in small quantities. The same firm used about 1000 varieties of mitre gears designed for driving two shafts at right angles at a 1 : 1 speed ratio [3]).

Designs may grow up side by side because the attention of the designer is focused entirely on the performance of the product, with disregard of the possibilities of tool unification. A survey made some years ago in a large American plant showed that the rectangular holes in the ends of the cast steel connecting rods of a series of machines of the same type (made in six sizes) were all different in size. Re-design undertaken in connection with a standardization program, made it possible to use the dimensions of the hole in the small end of a specific rod also for the hole in the large end of the rod two sizes smaller. Consequently, the twelve different holes adopted in the original design could be reduced to eight, and as each hole required the use of four broaches (a "rougher" and a "finisher" for each pair of opposite sides of a hole), the 48 different

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[1]) Engineering and Shop Standardization, by THOMAS R. JONES (American Management Association, Production Series, Pro. 100).

[2]) SM Bulletin, ASA (Sept. 1925).

[3]) SM Bulletin, ASA (March 2, 1926).

broaches originally needed could be reduced to 32. The price of the broaches was about $ 300 each and the change resulted, therefore, in a saving of between $ 4000 and $ 5000 in first cost alone.

Investigations of this kind occasionally bring up the question whether the product shall be re-designed so as to permit the use of tools made to standard dimensions (or dimensions generally adopted for the commercial product by its manufacturers) or whether it is preferable to keep the existing design and purchase special tools. In practice, the choice between these two possibilities usually must be made on the basis of manufacturing cost, due consideration being also given to such factors as interchangeability between new and old product. The use of standard tools (where special tools have been used so far) is often well worth the temporary trouble and extra cost which a change in design may involve. This matter deserves attention also from another point of view. When a new national standard has been established, it occurs that manufacturers and users are waiting for each other to put this standard into effect. The manufacturers who have old stock on hand and continue to get orders for it, decide to wait for orders on the new standard product before making a change. Consequently, many users of the old product who are willing to change to the new standard, are discouraged by the fact that the product made in accordance with it is not readily available and decide to order the old product again. The resulting deadlock may greatly retard the introduction of the new standard into practice. This can often be avoided if producers and users will agree on a time limit after which the old product is no longer to be manufactured or ordered except as a special.

THE FOUR STAGES OF STANDARDIZATION

Starting with the company as an industrial unit, standardization work may be carried out in four major phases, as follows:

(1) within the company;
(2) by a trade association or technical society;
(3) under the procedure of a national standardizing body;
(4) on an international scale.

An example of the functioning of a standards department in a company has already been given [1], as well as an outline of the basic principles to be observed in establishing such a department and organizing its work.

Independent of the difference in aspect of the standardization problems

[1] Chapter VI.

in each organization, a company requires standards whose observance is binding on the several departments in the performance of their tasks. This feature of compulsion which gives a company standard the character of a law, is generally absent in standardization work undertaken on a larger scale. A trade association may require its members to adhere to certain standards adopted by it, but such a requirement is an exception rather than a rule. Trade association standards most commonly, and technical society standards always, are recommendations which may be adopted or not.

In national standardization work carried out under the procedure of a central body established in a country by its industry [1]), a standard approved by such a body is also meant as a recommendation to be adopted voluntarily by industry and not as an instruction whose observance is compulsory. This standpoint has been adopted as a basic principle by the very large majority of national standardizing bodies now in existence. (An exception is the United Socialist Soviet Republics where the application of the national standards is compulsory).

The special value of national standards does not lie solely in the fact that they result from coordination on a wider scale than standards developed by a trade association or technical society. Essential is also the fact that they are established through cooperation of the main groups interested in the subject of each standard under conditions guaranteeing their balanced representation. In the case of a manufactured product, these groups are the manufacturers, distributors, and users.

The main function of a national standardizing body is the coordination of standardization activities that otherwise might lead to duplication of effort and, what is worse, to the setting up of conflicting standards for the same subject. Therefore, the central body must be strictly judicial in its decisions. This is essential for its prestige with industry which must be certain that problems submitted to the national body will be dealt with in a manner fair to all parties and that a national standard will be established only on the basis of a consensus of the major groups concerned with the subject.

The need for a national standardizing body coordinating the

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[1]) A national standardizing body has so far been established in Australia, Austria, Belgium, Canada, China, Czechoslovakia, Denmark, Finland, France, Germany, Great Britain, Holland, Hungary, Italy, Japan, New Zealand, Norway, Poland, Roumania, Sweden, Switzerland, United Socialist Soviet Republics, and United States of America.

industrial groups in a country became particularly obvious during the World war and shortly after it. With a single exception the twenty-three bodies of this kind now in existence were founded since the beginning of the war. [1])

National unification of industrial standards in the several countries led to efforts to eliminate discrepancies between national standards relating to the same subject. In the mechanical field, for example, it was found that Whitworth (coarse) screw threads being widely used not only in Great Britain, but also on the European Continent, the British and Continental standards for these threads should be unified. Similarly, dimensional standards for ball bearings (nominal dimensions and tolerances thereon) used in numerous products of the mechanical and other industries were found to call for international unification to secure general interchangeability. This unification has already been achieved for the most commonly used types of radial ball bearings.

Unofficial conferences between secretaries of national standardizing bodies [2]) led to an international conference in New York in 1926 where the basis was laid for the International Standards Association (ISA), a federation of national standardizing bodies. Its purpose is the systematic exchange of information on standardization work accomplished or in course of development in the different countries affiliated with it, and the promotion of uniformity between national standards set up in different countries if such uniformity appears to be desirable and practicable.

SUMMARY

(1) Standardization, if it is to yield the greatest benefits, must be applied to the activities of a company in a general way, and not with the sole purpose of improving deficiencies in some of the company's operations. However, its successful application to special problems will help to introduce it as a general policy.

(2) The standards department of a company should be independent of other departments and should report exclusively to the executive management. This should give the standards department full and open support and enable it to collect without difficulty the data regarding activities of the other departments for whose coordination it is responsible.

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[1]) The British Standards Institution was founded in 1901.
[2]) In London (1921) and Zürich (1923).

(3) When no standards or existing traditional practice have as yet exerted any considerable influence on the manufacture of a product, a system of standards may be "designed" in a way similar to that in which a machine is built to answer its performance requirements. However, such cases are exceptional because the standardization department will usually have to give consideration to existing standards, just as the designer of a machine is bound to specify certain materials and components available in the market.

(4) Standardization of a line of existing products comprises simplification, or elimination of needless variety of types and sizes, and re-design of the types and sizes conserved, on the basis of technical considerations. Simplification alone does not permit to harmonize these types and sizes and therefore cannot serve as a tool of coordination.

(5) If practicable with a view to economy of operation and the demands of the market, standardization of existing products should include their re-design in such a way as to cover most effectively the total range of performance requirements and to permit the highest degree of unification of all factors affecting the manufacture of the products, such as materials, component parts, tools, methods of work and manufacturing processes.

(6) The recommendations of the standards department should be based on the results of a survey of existing practices and conditions. These should be studied to decide where standardization should be applied to the company's activities and whether it should consist of simplification alone or simplification combined with re-design of the remaining types and sizes.

(7) The question whether existing standards can be used should be considered in close connection with that of subdividing the standards needed by the company into basic or primary standards, secondary standards, tertiary standards, etc.

(8) The standards department should keep in constant touch with standardization work relative to subjects of interest to the company performed by other organizations. In making proposals for company standards, it should try to use, if at all possible, existing standards in the following order of preference: national standards; trade association or technical society standards; and standards used by other companies.

(9) The chain of causes and effects in the various flows of activities composing the manufacture of the product must be traced back to the point where each flow enters the sphere of activities of the company. Consequently, the properties of all objects supplied from the outside must be controlled by purchase specifications and where objects manufactured by the company are concerned, standardization of tools must be considered first in so far as these are the generators of the dimensions of the objects.

(10) The tracing back of each flow of activities will not only show the logical sequence in which standardization should be undertaken in a particular line, but also the possibilities for unification of items belonging to different lines.

(11) The introduction of a new national standard into actual practice may sometimes be expedited if the different parties having an interest in it agree on a definite date on which the object of the new standard shall become available or go into effect.

(12) The integration of standardization work within and between industries has led to the establishment of national industrial bodies acting as central coordinating agencies for standardization work in their respective countries. A federation of such bodies has been founded to promote the international unification of national standards wherever this appears to be desirable and practicable.

CHAPTER VIII

SOME FURTHER ASPECTS OF STANDARDIZATION

Basing on an analysis of the essential functions of standardization made in the earlier chapters of this study, certain principles and methods were developed to serve as a guide in the practical application of standardization, especially in the mechanical industry. In so doing, the attention was focused primarily on the use of standardization as an engineering technique, such questions as arise, for example, in connection with its economic and social aspects being touched upon only in so far as they concern directly this particular matter. A brief review will now be given of some further aspects of standardization which are of interest in connection with the previous discussions, such as its advantages to producer and consumer, its influence on their mutual relations, its significance as a social function, etc.

ADVANTAGES OF STANDARDIZATION

In considering the effects of standardization, distinction must be made between its use by the producer as a means of increasing the efficiency of his own business activities and the function of standardization as a social force. However, these functions are not incompatible, as is clearly shown in practice by the establishment of national industrial standards through cooperation of producers, distributors, and consumers.

The economic advantages of standardization to the producer may be briefly summarized here, for the sake of completeness of the general picture [1]. Standardization of the means of production and the manufactured product yields the benefits inherent to mass production — the possibility of supplying a large volume of goods of sound quality at low cost. Through concentration on a restricted variety of products, standardization leads to reduction of capital tied up in stocks and inventories. Better coordination of activities (in its perfect form resulting in continuous flow production) increases the turnover of capital invested in raw materials, and semi-finished and finished products. Standardization simplifies the stockroom and reduces the necessary storage space.

[1] For a more comprehensive treatment, see for example the report on Industrial Standardization published by the National Industrial Conference Board (New York, 1929).

Standardized equipment means saving of labor, and therefore less labor per unit of output. Maintenance standards for production equipment and safety codes decrease breakdowns and accidents, and consequently also labor turnover. Where producers and users are able to agree on the standardization of a product, business will be subject to less fluctuations and this again will favorably influence stabilization of employment. Standardized design, involving thorough coordination of the requirements of the product and the means of production, reduces waste and salvage cost. Standardized conditions in a plant permit to make a better use of standard cost accounting systems for reducing arbitrary allocation of costs to different departments or operations. The use of such cost systems also may serve to detect technical deficiencies and their economic waste, and thus lead indirectly to improvements in the technical standards.

Both domestic and foreign trade are favorably affected by standardization. All other conditions being equal, the decrease in cost price made possible through standardization of the means of production (particularly, but not exclusively, in mass production) leads to an increase in sales volume [1]). Interchangeability of parts, in the first place a basic requirement for mass production, is also a matter of great practical importance to the consumer from the viewpoint of service in maintenance and repair, and therefore a distinct commercial asset to the product. In foreign trade, a special advantage of adhering to definite standards of quality lies in the speed and clarity with which business transactions can be carried out and the confidence which is created between geographically widely distant groups [2]).

The individual manufacturer, or in a cooperative way the trade association, may profitably use in advertising and distributing goods, the advantages which accrue to the consumer on account of their standardization. Concentration on a smaller variety of products permits to lay more stress in advertising campaigns on the characteristics of each item, while the containers of a standardized product (packages, cans, boxes, etc.) can be closely adapted to it and given advertising value by the very uniformity of their appearance. Moreover, the distribution of

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[1]) This applies more particularly as the demand for the product is more elastic because it is able to force from the competitive market other goods answering similar requirements, or because the price reduction brings the goods definitely within the reach of new groups of consumers belonging to lower brackets of income.

[2]) Even the technically non-informed consumer will have confidence in the practical value of standards set up by properly balanced committees of experts, such as those organized under the auspices of the national standardizing body (see also page 120).

goods in standard containers may save considerable cost of handling. Standardization of products coupled with certification as to their compliance with definite standards [1]) will facilitate the making of loans, for example to farmers on warehouse receipts.

STANDARDIZATION IN AGRICULTURE

Although this subject falls outside the scope of the present study, a few words may be said about it on account of certain features which agricultural and industrial standardization have in common.

Standardization as a systematically applied technique developed in the agricultural field much later than in the industrial. Man had already begun to manufacture when he started to sow and reap. Furthermore, agriculture has long been a production process to the outcome of which man could contribute very little, the results depending almost exclusively on climatic conditions and the fluctuating influences of the weather. Measures to control the development of the product (at least in part), such as the use of greenhouses and improvement of the soil by fertilizers, are relatively old and may be compared to similar efforts made by industry to control the quality of manufactured product. However, until recently most of the standardization work in agriculture consisted merely of the selection from existing types. Agricultural standards, such as those for cotton, grain, meats, eggs, and other commodities, have now been set up on the basis of scientific research [2]) and some of these standards have even become the basis for international agreement, such as those for cotton. Grading, an important matter in agricultural standardization, has in some cases developed to the point where mechanization has become possible.

CERTIFICATION

Standards supply the consumer with a basis of comparison for different kinds of qualities of the product. However, the question as to whether goods comply with the standards set for them, arises in each individual case where a business transaction takes place. The statement of the producer that such a compliance exists is often accepted by the consumer on the strength of the supplier's known integrity. In other cases, however, and particularly where ultimate consumer goods are concerned, the need

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1) See this Chapter, under Certification.

2) For example, by the U.S. Department of Agriculture.

arises for some kind of certificate given either by the producer or by an organization keeping a regular check on the quality of the goods, such as a testing laboratory.

Some national standardizing bodies (for example, the German and the British), trade associations (such as the American Petroleum Institute and the American Gas Association), and technical societies (such as the American Society of Mechanical Engineers and the Society of Automotive Engineers) have standard symbols which may be used on products made in accordance with the standards approved by these organizations.

The U.S. Department of Commerce has developed a Certification Plan according to which manufacturers will be invited to state that they are willing to certify, when requested to do so, that their products comply with certain selected standard specifications used as a basis for purchases made by the U.S. Government.

The certification idea is not new. Trade brands used by the Gilds had a definite value as certificates in so far as they were backed by the standards of the Gilds for the materials, workmanship, style and performance of their products. With the disappearance of the Gilds, the value of most trade brands degenerated and many are now used solely for advertising purposes, frequently with the avowed intention of "lifting the goods out of competition", which is diametrically opposed to the purpose of standard specifications [1]). The growing interest in standardization activities of trade associations — which at least in the U.S. now exert the dominating influence in this work — may ultimately lead to the re-instatement of the regular use of the trade mark as a recognized certification symbol based on general industry standards or national standards.

A certification plan, if it is to work out effectively, requires a policing force to check regularly whether those certifying to the quality of their products live up to their pledge. This side of the problem involves many considerations of a legal nature which are not easy to solve, whence the national standardizing bodies established in several countries by the national industry, have not yet put into effect any scheme including such a policing body [2]).

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[1]) In principle, the adoption of standards for the types and qualities of goods is necessary, if a regular market, permitting comparison of prices in different localities and at different times, is to be established.

[2]) In the U.S.S.R. where standardization is carried out under the control of the state and compliance with the standards is compulsory, the task of policing evidently also devolves upon the state.

MARKETING AND ADVERTISING

These two functions are too often based exclusively on the use of brands or trade names without the manufacturer giving any information about the essential merits of his products. Standards give the consumer a basis of comparison for the quality-price ratio. This fact, if properly brought to the attention of the consumer, will help to enlarge the market, benefiting not only the individual manufacturer, but the entire industry [1]).

An industry may suffer damage and even get into disrepute, by the actions of manufacturers making low-grade goods. One of the most effective remedies of such a situation is the setting up of sound general industry standards as these increase the public's confidence. In extreme cases where legal action becomes necessary against an "outlaw" manufacturer, either by his own industry or by a consumer, the existence of standards will greatly facilitate the procedure.

RESISTANCE TO STANDARDIZATION

Fundamental reasons why standardization is appreciated less by the executive in charge of the commercial end of the business than by the technical man have been discussed in an earlier chapter [2]). A few additional causes of resistance to standardization rooting in the competitive nature of our business system will be briefly discussed.

The producer is primarily interested in standardization from the viewpoint of what it can do to promote his own business. He may be convinced that standards have their merits in this respect, but also believe that their application on a wider scale (standardization for the entire industry or the still more extensive national standardization) does not work to his advantage. For example, he may hold that the unification of the product tends to decrease the individual character of each particular make of the product, thus weakening its competitive force. Or, he may consider rigorous standardization of his own product as an excellent means for creating a quasi-monopoly whose merits would be lost, at least in part, by standardization on a more extensive scale [3]). This attitude reminds

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[1]) Certain considerations of the producer that may cause him to favor standardization in his own business, but not as a policy for his industry as a whole, will be discussed later.

[2]) Chapter I, page 6 ff.

[3]) Also, a manufacturer favoring standardization of raw materials and semi-finished products purchased by him, may be opposed to standardization of the product which he manufactures. Thus, the difference between the consumer and the producer standpoints may sometimes be observed in a single individual or firm.

of efforts made by manufacturers in an earlier period to compel the buyer of a product to order repair or replacement parts from the original manufacturer [1]. It is now recognized that such measures impair, rather than promote the interests of the manufacturer because the failure readily to obtain new parts not only irritates the user, but also may cause him considerable loss, thus working to discredit the product. If a manufacturer is unwilling to cooperate in a general standardization program securing, among other things, interchangeability of parts independent of their make, his only alternative is to provide extensive servicing facilities for his customers. Such a complete service can be given, generally speaking, only by companies of relatively large size whose products are sold in a wide market. The normal solution, available also to the company of medium or small size, is to join in the establishment of general industry standards or, if inter-industry relations call for them, national standards. Proof of the growing recognition that ultimately the social function of standardization works out also to the benefit of the individual manufacturer is given, for example, by those companies which relinquish their patent rights to make possible the approval of their products as national standards [2].

Manufacturers as a group sometimes fear that once a national standard for their product has been set up in cooperation with the users, these may block the revision of the standard even though the manufacturers believe the time for it has come on account of technical progress. This standpoint does not appear to be sound. A national standard is set up by agreement between the several interested groups because all of them expect to benefit by the effects of its stabilizing influence, one of which is the prevention of changes in essential features of the product (such as those controlling its interchangeability) made solely for commercial reasons and impairing the user's, and therefore indirectly also the producer's interests. However, if a change appears to present advantages important enough to the user to outweigh the temporary difficulties which it will cause him, the user will not oppose that change but even may demand that it be made. Therefore, if progress has advanced to the point where it is possible to give the user the same or a better product at a lower price, or a better product for the same price, this will necessarily

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[1] For example, by using special screw threads to create non-interchangeability with products made by others.

[2] In some countries, the fact that an object is patented bars it from approval by the national standardizing body.

lead to revision of the standard, else it will be abandoned in actual practice. If progress is not sufficient to bring this about, the demand for the original article will continue and the manufacturer will reap further dividends from the capital invested in the existing standard [1]).

STANDARDIZATION AND INDIVIDUALITY

Objections to standardization on the ground that it hampers or even kills individuality are strongest in those cases where standards concern most directly the human element. Whenever questions of taste are at stake, for example in respect to clothing, furniture or interior decoration, many will decry any step toward standardization as an effort to take joy out of life. Nevertheless, nomenclature and sizes of garments and shoes, quality of materials measured in terms of thread count, fiber content, sunfastness, etc., and other features of interest to ultimate consumers have been standardized for their benefit without raising any protest on their part, ample margin being left for variation required by individual taste.

A good deal of resistance has also been met by efforts to standardize the accomplishment of work through adoption of standard times in which operations should be completed and standard methods of performing operations. It has been claimed that the "one best way" to do work imposes such a restriction on the individuality of the worker as to be incompatible with his dignity as a human being. Much of this criticism has been aimed (and rightly) at cases where the principles and methods developed by pioneers like Taylor and Gilbreth were applied, or rather mis-applied, by those having only a superficial knowledge of the subject, with the result that workers were unduly driven by the tasks set for them, or continuously irritated by the dulness of a monotony that could have been avoided [2]). Also, the principles and methods in question have been fought, in this case wrongly, because labor resented entering upon a scheme of actually measuring the accomplishment of work. The reasons back of this kind of opposition are often the same

[1]) Where quality of goods is concerned, nothing prevents the manufacturer from making his product to a standard higher than the one generally adopted, and to use this "super-standard" quality, for example, as a claim for a trade-marked product.

[2]) Some types of workers like the monotony of highly repetitive work because the automaticity with which they can perform their task permits them to think of other matters most of the time. A change in the task may even be strongly resented by this kind of worker.

as those making a producer look with disfavor on standards placing the quality of his goods on a basis of measurement or comparison. However, in recent years, enlightened leaders of the labor movement have taken a more favorable attitude toward standardization in this field. It is now coming to be realized that the "one best way" to do work is meant to constitute a basic or nominal standard level [1]) on which the widest possible tolerance must be given to allow for the individual variations in the worker's physical make-up, his rhythm of doing work, etc., so that the standard method may be adjusted to his personal disposition without its effectiveness being impaired [2]).

The knowledge of the factors entering into the performance of work by human beings, such as the influence of fatigue, interest in the work, etc., is still very restricted. For this reason alone (i. e. even if we disregard the intricate nature of the human being as a factor in doing work), the tolerances to be given on values specified in standards of this class must of necessity be larger than those adopted in a kind of work where more is known about cause and effect, and conditions are therefore better controllable, such as in the manufacture of precision parts. Also, standards of work accomplishment must be based on a definite formulation of the task; the conditions under which this is to be performed and the means and methods by which this is done; and the type of worker most suitable for the task. This logically calls for selection of workers on the basis of standard tests giving an indication of their natural disposition and acquired skill or knowledge, a class of standardization work assigned to the science of psychotechnics.

The delicacy of problems involved in the establishment of standards of accomplishment is, therefore, to be traced back largely to the high degree of flexibility which these standards must possess and yet be definite enough to serve their purpose. Any change in conditions affecting the worker or his surroundings must be given careful consideration in setting up the standards and a close watch should be kept as to whether revision is necessary. Thus, in psychotechnical work, the correlation of the results of the tests used for examining applicants for jobs and the results obtained later on with the same workers in actual shop practice, requires constant checking.

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[1]) See Chapter IV, under Revised Conception of a Standard.

[2]) This is comparable to the teaching of playing a musical instrument. The method taught may be varied more or less in its application by the individual pupils and yet be distinctly recognizable as the basic form in each case.

INTEGRATION OF STANDARDIZATION WORK

Isolated applications of standardization have occurred in earlier centuries on a sometimes quite extensive scale. The need for coordination in military operations led to early uniformity in weapons and war equipment. Standardization of ships and their rigging to make them behave in the same way under given weather conditions so as to keep together as a fleet, is said to have existed in the old republic of Venice which also saw to it that "service stations" of interchangeable spare parts were kept in stock in foreign ports visited by these ships. The Gilds had standards not only for their products, but also for the training of their artisans and the relations between the different classes of their membership. During the 19th century, individual applications of standardization increased in consequence of the requirements of mass production. Examples are to be found in the manufacture of rails and other steel sections, pipe, and wire. However, standardization performed on a wider scale by entire industries and as a national function, did not develop until after it had received a tremendous impetus for strict coordination of industrial production from the requirements of the World war. Moreover, the pressure of economic conditions in most countries after the war favored efforts toward large-scale rationalization as a means of national economy, a movement which also benefited standardization.

From a technique applied by relatively few individual concerns for the purpose of increasing the efficiency of their own operations, standardization thus came to be considered as a social function calling for the establishment of national clearing houses to avoid duplication of effort and the setting up of conflicting standards. Even though on many occasions standardization is hampered or barred by egotistic considerations where its application would be possible, there is an increasing amount of evidence to show that the national standardization movements are constantly growing. This is largely due to the fact that industrial groups are coming to realize that their interests are so tightly interlocked on account of the fargoing specialization of our modern production system, that the maximum benefit of standardization work can come only from cooperation of all groups under the auspices of a central, neutral coordinating body.

SUMMARY

(1) Standardization will not only benefit the production end of an industrial organization, but may also profitably be applied to the

commercial functions of the business, such as marketing and advertising.

(2) By its very nature, agriculture is generally more difficult to standardize than industrial production processes. Yet, scientific research had led to the successful establishment of standards in the agricultural field.

(3) The consumer often needs proof that goods actually comply with the standards to which they are claimed to be made. A certification plan can furnish such a proof. However, to be reliable, it should include a policing agency — a problem involving several legal aspects.

(4) More extensive standardization in an entire industry, or on a national scale, may be opposed by the producer on several grounds, even though he is convinced of the merits of standardization applied to his own business.

(5) Standardization has been successfully applied to the essential quality features of goods whose attractiveness to the consumer lies primarily in the individuality and variation of their appearance.

(6) The establishment of standards for the accomplishment of work presents particular difficulties on account of the very intricate nature of the factors involved.

(7) Standard tests for selecting workers are the logical complement of standards for jobs and tasks. A continuous checking of the results obtained with workers in actual practice against the results of the tests by which they were accepted, is a primary requirement.

(8) With the growth of industry during the 19th century, standardization has been applied by private concerns to make possible the use of mass production methods. It has now come to be recognized as a social function which will yield its greatest benefit to all if used for the coordination of entire industries in regard to their internal, as well as their mutual relations. This can be achieved best by industry itself, under the auspices of a central national standardizing body.

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STELLINGEN

I

The fact that an object (product, method or process) is patented should not be a reason for the national standardizing body in the country concerned to refuse, as a matter of principle, to approve that object as a national standard.

II

The listing in a national standard of items marked "not recommended" or "to be avoided" is not desirable, as such a practice is inconsistent with the basic purpose of setting up a standard.

III

In general there is no danger that the establishment of a national standard specifying a quality for a product which is lower than the quality of similar product available in the market will result in the decrease in quality of this better-than-standard product to the standard level.

IV

The establishment of national industrial standard specifications by a body other than the central standardizing body representing the national industry — even though such specifications be published under the name of simplified practice recommendations or commercial standards — is incompatible with the essential purpose of national unification of industrial standardization work.

V

In cases where variety in existing practice calls for the setting up of a national standard, while at the same time a new and improved practice is becoming more widely adopted, it may be desirable to set up two standards. However, if the groups concerned agree that the new standard is decidedly superior and that the standard for the old practice is set up merely on account of its being widely used, a time limit should be agreed on after which the standard for the old practice will be abandoned.

VI

There is no reason for embodying in a national standard for fits between cylindrical parts, a constant maximum hole system in addition to the basic hole and basic shaft systems.

VII

The basic size of a part should be defined as the low limit of a hole and the high limit of a shaft. The American Tentative Standard B4a-1925 which defines the basic size as "the exact theoretical size from which all limiting variations are made" is indefinite in this respect.

VIII

The designation of standard fits between cylindrical parts by names which indicate a certain facility or difficulty of assembling the parts to give the required fit (such as "push fit", "tight fit", etc.) is not desirable. Designation by letter symbols or numerical symbols is to be preferred.

IX

The use of the nominal size of the mating parts as the low limit of the basic holes and the high limit of the basic shafts should not be abandoned for the sake of keeping the permissible variations in the size of the gages within the tolerances on the workpiece. Such an arrangement makes it more difficult for the designer to visualize the fits because his attention is focused on the extreme gage sizes instead of on the (nominally) extreme sizes of the workpiece, and also because the nominal size line functions no longer as a natural reference line for the entire system of fits.

X

The clause contained, for example, in the French and Belgian laws on companies with limited liability, according to which each director is obliged to be the holder of a certain number of non-negociable shares has no value as a guarantee of good management and may block the selection of the best man available at a certain time.

XI

One of the main tasks of the engineering college is to teach the student the scientific principles of doing the work in which he is being trained, rather than to supply him with the widest possible knowledge of detailed means and methods. For example, more attention should be paid in engineering courses to the fundamentals of standardization instead of occasional reference being made to standards existing in the field of the student's work.

XII

Gilbreth held that if a specific operation is performed by different workers in the same time, the most expert worker is the one whose method contains the fewest therbligs [1]), and furthermore, that if the number of therbligs is also the same for the different workers, the most expert one is he whose method shows the largest number of simultaneous beginnings and endings of motions performed by different organs, such as the two hands. A possible explanation is that the skill of a worker depends largely on his natural ability to combine unconsciously the production of the nervous impulses required for the beginning or ending of motions.

XIII

The design by engineering students of simple machine components or units, such as shaft couplings, should be supplemented by the practical testing of their performance by the students.

XIV

In determining the minimum and maximum permissible clearances of an exacting fit it may be necessary, with a view to the requirements of good lubrication, to select values different from those laid down in a general standard giving the limiting clearances for the range of diameters within which the nominal diameter of the parts in question lies.

XV

The physical means of safeguarding the operator of a machine tool and other workers should preferably form an integral part of the design instead of being a separate device attached to the machine tool. In many cases, this principle can be followed in practice only if the safety rules for the machine tool concerned are the same in all states or countries where it is used.

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1) A therblig is an elementary subdivision of an operation, according to the Gilbreth theory of doing work.

XVI

The development of a simple and inexpensive method and apparatus for determining the size and shape of the microscopic deviations of the surface of a machine part from its ideal shape would be highly valuable for the knowledge of the problem of wear of moving parts as well as for the detection of minute cracks influencing their strength under repeated stress.