fronted with a multitude of problems, such as exist in every trade and which have a general similarity one to another, it is inevitable that they should try to gather those problems into certain logical groups, and then search for some general laws or rules to guide them in their solution. As I have tried to point out, however, the underlying principles of the management of "initiative and incentive"—that is, the underlying philosophy of this management —necessarily leaves the solution of all of these problems in the hands of each individual workman, while the philosophy of scientific management places their solution in the hands of the management. The workman's whole time is each day taken in actually doing the work with his hands, so that, even if he had the necessary education and habits of generalizing in his thought, he lacks the time and the opportunity for developing these laws, because the study of even a simple law involving, say, time study requires the cooperation of two men, the one doing the work while the other times him with a stop watch. And even if the workman were to develop laws where before existed only rule-of-thumb knowledge, his personal interest would lead him almost inevitably to keep his discoveries secret so that he could, by means of this special knowledge, personally do more work than other men and so obtain higher wages.

Under scientific management, on the other hand, it becomes the duty and also the pleasure of those who are engaged in the management not only to develop laws to replace rule-of-thumb, but also to teach impartially all of the workmen who are under them the quickest ways of working. The useful results obtained from these laws are always so great that any company can well afford to pay for the time and the experiments needed to develop them. Thus, under scientific management, exact scientific knowledge and methods are everywhere, sooner or later, sure to replace rule-of-thumb, whereas under the old type of management working in accordance with scientific laws is an impossibility.

The development of the art or science of cutting metals is an apt illustration of this fact In the early eighties, about the time that I started to make the investigations above referred to to determine the proper movements to be made by machinists in putting their work into and removing it from machines and time required to do this work, I also obtained the permission of Mr. William Sellers, the president of the Midvale Steel Co., to make a series of experiments to determine what angles and shapes of tools were the best for cutting steel, and also to try to determine the proper cutting speed for steel. At the time that these experiments were started it was my belief that they would not last longer than six months, and, in fact, if it had been known that a longer period than this would be required, the permission to spend a considerable sum of money in making them would not have been forthcoming.

A 66-inch diameter vertical boring mill was the first machine used in making these experiments, and large locomotive tires, made out of hard steel of uniform quality, were day after day cut up into chips in gradually learning how to make, shape, and use the cutting tools so that they would do faster work. At the end of six months sufficient practical information had been obtained to far more than repay the cost of materials and wages which had been expended in experimenting. And yet the comparatively small number of experiments which had been made served principally to make it clear that the actual knowledge attained was but a small fraction of that which still remained to be developed and which was badly needed by us in our daily attempt to direct and help the machinists in their work.

Experiments in this field were carried on, with occasional interruptions, through a period of about 26 years, in the course of which 10 different experimental machines were especially fitted up to do this work. Between 30,000 and 50,000 experiments were carefully recorded, and many other experiments were made of which no record was kept. In studying these laws more than 800,000 pounds of steel and iron was cut up into chips with the experimental tools, and it is estimated that from $150,000 to $200,000 was spent in the investigation.

Work of this character is intensely interesting to anyone who has any love for scientific

research. It should be fully appreciated that the motive power which kept these experiments going through many years and which supplied the money and the opportunity for their accomplishment was not an abstract search after scientific knowledge, but was the very practical fact that we lacked the exact information which was needed every day in order to help our machinists to do their work in the best way and in the quickest time.

All of these experiments were made to enable us to answer correctly the two questions which face every machinist each time that he does a piece of work in a metal-cutting machine, such as a lathe, planer, drill press, or milling machine. These two questions are:

> In order to do the work in the quickest time, at what cutting speed shall I run my machine? and what feed shall I use?

These questions sound so simple that they would appear to call for merely the trained judgment of any good mechanic. In fact, however, after working 26 years, it has been found that the answer in every case involves the solution of an intricate mathematical problem, in which the effect of 12 independent variables must be determined.

Each of the 12 following variables has an important effect upon the answer. The figures which are given with each of the variables represent the effect of this element upon the cutting speed. For example, after the first variable (A) I quote:

> The proportion is as 1 in the case of semi-hardened steel or chilled iron to 100 in the case of a very soft low-carbon steel.

The meaning of this quotation is that soft steel can be cut one hundred times as fast as the hard steel or chilled iron. The ratios which are given, then, after each of these elements indicate the wide range of judgment which practically every machinist has been called upon to exercise in the past in determining the best speed at which to run his machine and the best feed to use.

(A) The quality of the metal which is to be cut, i. e. its hardness or other qualities which affect the cutting speed. The proportion is as 1 in the case of semi-hardened steel or chilled iron to 100 in the case of very soft, low-carbon steel.

(B) The chemical composition of the steel from which the tool is made, and the heat treatment of the tool. The proportion is as 1 in tools made from tempered carbon steel to 7 in the best highspeed tools.

(C) The thickness of the shaving, or the thickness of the spiral strip or band of metal which is to be removed by the tool. The proportion is as 1 with thickness of shaving three-sixteenths of an inch to 3½ with thickness of shaving one sixty-fourth of an inch.

(D) The shape or contour of the cutting edge of the tool. The proportion is as 1 in a thread tool to 6 in a broad-nosed cutting tool.

(E) Whether a copious stream of water or other cooling medium is used on the tool. The proportion is as 1 for tool running dry to 1.41 for tool cooled by a copious stream of water.

(F) The depth of the cut. The proportion is as 1 with one-half inch depth of cut to 1.36 with one-eighth inch depth of cut.

(G) The duration of the cut, i. e., the time which a tool must last under pressure of the shaving without being re-ground. The proportion is as 1 when tool is to be ground every one and one-half hours to 1.20 when tool is to be ground every 20 minutes.

(H) The lip and clearance angles of the tool. The proportion is as 1 with lip angle of 68° to 1.023 with lip angle of 61°.

(J) The elasticity of the work and of the tool on account of producing chatter. The proportion is as 1 with tool chattering to 1.15 with tool running smoothly.

(K) The diameter of the casting or forging which is being cut.

(L) The pressure of the chip or shaving upon the cutting surface of the tool.

(M) The pulling power and the speed and feed changes of the machine.

It may seem preposterous to many people that it should have required a period of 26 years to investigate the effect of these 12 variables upon the cutting speed of metals. To those, however, who have had personal experience as experimenters it will be appreciated that the great difficulty of the problem lies in