The Process Map

Revised

Doug Sanders, Bill Ross and Jim Coleman

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Abstract

This paper describes the augmentation of Process Flowcharts and Cause and Effect Diagrams used in conjunction with other tools and techniques to facilitate and document process investigation and improvement. Using the Process Map to provide context to data acquired via Sampling and Designed Experiments.

Introduction

The pressure to continuously improve an organization's products and services requires management behavior and engineering decisions that reflect a knowledge of process and product performance as never before. Understanding and managing the causal relationship between process variables (factors or x's) and measures of product performance (Y's) is not only desirable; it is a competitive necessity.

Process study might then be defined as the acquisition of knowledge about process factors in order to be able to manipulate process outputs in a predictable fashion with minimum variation[1]. This work will necessarily include investigation of potential sources of variation present in a process in order to understand their impact on process outputs or product performance. Sampling (COV) and Design of Experiments (DOE) are powerful techniques to assist in rapidly acquiring this knowledge. Of course, process and engineering knowledge provide the basis for the use of these tools.

Tools used in process study include Cause and Effect (C/E) Diagrams and Flowcharts. The C/E Diagram provides assistance to the identification of potential sources of variation for investigation (possibly with control charts using various rational subgrouping plans). The flowchart is a graphical tool used to help illustrate how the steps in a process function together to deliver a product or service. Once created, a flowchart is an invaluable tool for communicating, training, assisting in the identification of value added and non-value added steps and analyzing of product processing issues. The Team Handbook discusses four commonly used flowcharts and the C/E Diagram[2].

Flowcharts facilitate process investigation, but typically do not provide insight into the mechanisms driving process levels and variability. On the other hand, the potential causal structure captured in the C/E Diagram is not tied to location in the process, nor is the current state of process knowledge depicted. Seldom is the full potential of the combination of Process Flowcharts and C/E Diagrams realized. Neither of these two

[1] The Analytic Examination Of Time Dependent Variance Components
[2] The Team Handbook, Peter R. Scholtes, Joiner Associates

tools indicate whether the potential sources of variation are currently being managed or if they can be managed at all. A further drawback lies in the fact they typically do not become living documents, updated as new knowledge is acquired concerning the causal structure of the process. The shortcomings of the C/E Diagram and process flowchart potentially inhibit the investigation and management of the causal structure.

The *Process Map* is a tool that displays current process knowledge and is a supplement to many of the traditional process investigation tools. It enhances the usual flowcharts with the type of knowledge captured in C/E Diagrams. The á priori construction of the Process Map can dramatically increase the effectiveness of statistical techniques by facilitating the critical thinking required to gain and utilize an understanding of the relationship between process factors and product outputs. As a working document, the Process Map is used to continually identify the factors that may or may not impact product performance.

Terminology

The intent of process study is to develop a deeper understanding of the transformation of process inputs (factors or x's) into process outputs (Y's), or in matrix notation, $\mathbf{Y} = f(\mathbf{x})$.

At each step in the process, the transformation of the process x's to product characteristics may be assessed by in-process outputs (y's). When the choice is made to monitor in-process outputs, it is usually to make sure any problems with the product are detected and corrected before substantial time and money have been invested. In reality, these in-process outputs are a function of the x's as well. In other words, $\mathbf{y} = f(\mathbf{x})$ and $\mathbf{Y} = g(\mathbf{y}) = f(\mathbf{x})$.

Further insight into these functions can be gained by gathering data to understand their relationships. Data may be gathered either by sampling (e.g., COV) or by manipulated sampling (e.g., DOE). When collecting data with a sampling plan, the Process Map is coded to provide context to the data analysis. Essentially the Map helps correlate the numerous x's with the response variables (Y's). Figure 1 depicts a Process Map of an injection molding process color coded to provide links between the x's and the Y's identified in a sampling plan.

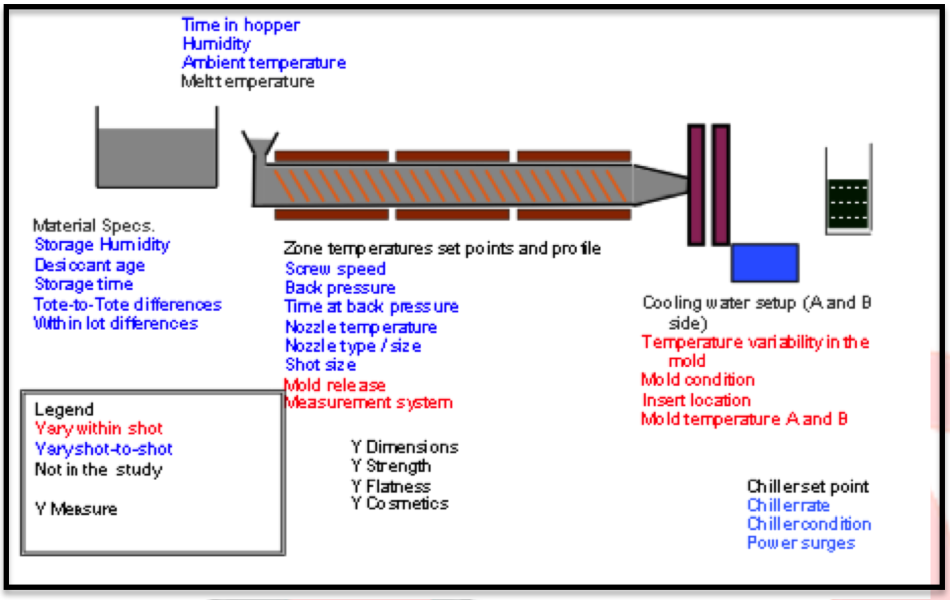

Figure 1: Injection Molding Process Map for Sampling

When collecting data via manipulated sampling, classifying the x's into one of two categories; controllable and noise factors is useful. These categories describe how the x's are currently (or predicted to be) managed. If one is willing to set an x at a certain value and maintained it within a particular range, it is considered controllable. Examples of controllable process factors include the following: feed and speed for a machining process, oven temperature and cure time in a gluing operation, gas pressure and purity in a plasma cleaning operation, the number of tellers working per shift at a bank, or the time a burger is allowed to remain under a heat lamp at a restaurant before disposal. In each instance, the process factor can be set and maintained around a desired value. A factor that cannot be, or is preferably not, set and maintained around a desired value due to cost, physical, or other constraints is considered noise. Examples of noise include the following: ambient temperature for a machining process, relative humidity in a gluing operation, the number and complexity of transactions per customer at a bank, or the time between purchase and consumption of a burger at a restaurant. In each instance, the factor is difficult or costly to control.

It should be noted a particular factor may be treated differently across processes. For instance, ambient temperature and humidity might initially be considered noise in a gluing operation, while these same x's are controllable factors for the production of semiconductors in a clean room environment. Of course, the decision to control a factor for a particular process might be reevaluated and could change as knowledge concerning the impact of variation in that factor on Y's is gained.

The classification of a process factor as either controllable or noise does not necessarily imply anything about the factor's impact on product characteristics (Y's). Typical variation in noise factors can have a substantial impact on the product's performance. Likewise, variability in a controllable process factor across certain levels may have little or no impact on the product's performance. Insight into the relationship between process factors and product performance; $\mathbf{Y} = f(\mathbf{x}) + \mathbf{N}$, can not be gained by simply categorizing the x's as controllable or noise. This relationship can only be understood through experimentation or prolonged observation using sampling. This categorization, however, does help to illustrate the current state of process management and can be used to enhance the design and analysis of studies utilizing DOE.

If process investigation (associated with appropriate data) reveals variation in a controllable factor or a noise variable has a significant impact on product performance, that factor is considered a critical x. Only through a combination of engineering and process knowledge, supplemented by process investigation (data collection and analysis) can these critical x's be discovered and confirmed.

Once a critical x is identified, steps must be taken to ensure it is managed to the point it will not cause undue variation in the product's performance. One way to manage such steps is to implement an engineering control. Until the product design or manufacturing process can be made robust to variation in these critical x's, control plans are used to manage the x's within a certain range so Y variability is minimized.

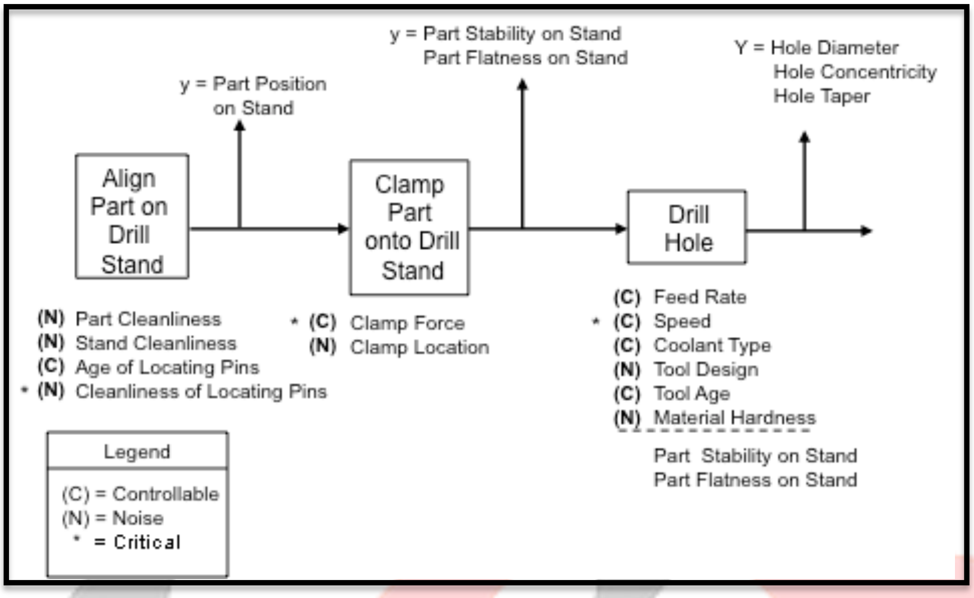

Figure 2: Drilling Process Map for DOE

To reiterate and expand, the intent of process study is to develop a deeper understanding of the transformation of process inputs and variables (x's) to process outputs (Y's). These factors may be studied via sampling or designed experimentation. Labeling and or highlighting the factors depends on the investigative tool used. If the investigative tool is sampling, the x's are typically color coded to match the sampling plan. If the investigative tool is a designed experiment, the factors are typically labeled controllable (C) or, if they are not managed (due to cost or other constraints), noise (N). When the impact of variation in process factors is empirically validated as influential in terms of variation in Y's (possibly through a series of DOE's), the process factor may be labeled critical. A simple example for a manual drilling process is shown in Figure 2.

Construction of the Process Map

It is worthwhile to point out the order of activities to create a Process Map is not important. The creating and use of a Process Map requires iteration. To construct a meaningful Process Map, careful consideration must be given to the scope of the process. What are the process boundaries and expected outcomes (Y's)? What are the target values for product characteristics? What is the penalty for deviation from these target values? How will management know if the process is performing in a manner that enhances the organization's competitive stance? Which Y's are truly important to the customer? What explanations are there about the variation in the Y's? While the answers to these questions are process dependent, consideration is required before beginning process investigation. The scope of the Process Map depends on the hypotheses about the answers to these questions.

Process Maps are hierarchical in nature. A macro Process Map describes the major activities (e.g. assembly of sub-assemblies) needed to complete and deliver a product or service to the external customer. It is possible and often necessary to divide a high-level map into detailed sub maps (e.g. assembly of components into a sub-component assembly). Detailed sub-maps may require further sub-division into specific operations or require expansion upstream in the product flow (e.g. work on the sub-component assembly process might lead to the component fabrication process). Frequently Process Maps cross various functional areas in an organization.

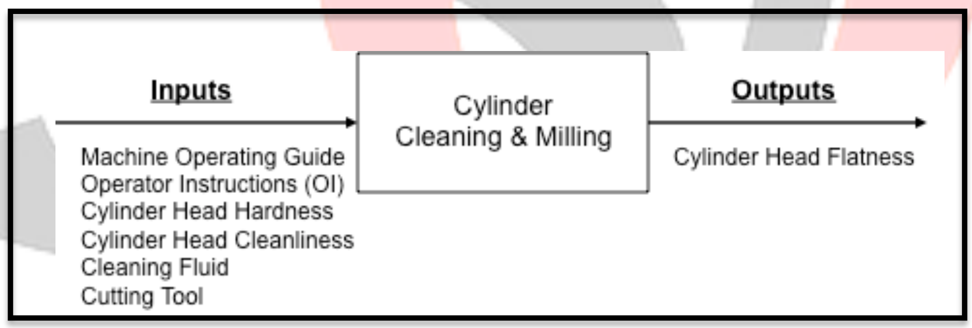

Figure 3 - Input/Output Diagram for a Machining Operation

After determining the scope and the level of the Process Map, the input factors (x's) to the process are identified. These x's are typically variables that initiate the process. Examples include raw material and raw material characteristics, a partially completed product (sub-assemblies and components), a work order or customer request, safety and government regulations, and tools. This information is captured and displayed in a simple graphical manner, as illustrated in Figure 3.

A flowchart depicting all of the process steps, including inspection and rework, is constructed next. It can be helpful to create an initial map of the process in the as-is condition. This requires interrogation of the process over various sampling intervals, including multiple operators, multiple shifts, and changing noise conditions. Each formal or informal inspection yields in-process outputs (y's) by which the process may be monitored. Keep in mind, data on these factors is often not recorded or may not even be measured. Frequently y's must be identified with engineering knowledge rather than processing experience.

The Process Flowchart - illustrating all of the steps in the process, the process outputs (Y's), and the in-process outputs (y's) - is now prepared for the addition of process factors (x's). **All** process factors should be identified. The Process Map should not filter x's, but rather should assist in the identification and documentation of all x's.

Categorizing the x's as controllable or noise may help us to understand how the factors are currently being managed. This illustrates the current state of process belief; that is, how variation in the process factors translates into variation in the process outputs. Early versions of the Process Map will typically be based on scientific theory, engineering knowledge, and operator experience. Through process investigation and the application of statistical techniques including DOE, this list of all process factors can be filtered so critical process factors are identified. The variation in these critical factors has a significant impact on product characteristics, Y's, or on in-process outputs, y's, that in turn effect the Y's. For example, the number of tellers working during a shift at a bank, x, may have a significant impact on the time a customer is required to wait in line prior to service, y, which in turn may have a dramatic impact on the customer's satisfaction with the banks service, Y.

An Illustrative Example

Through process investigation, a manufacturer of compressors has learned that the flatness of the cylinder head is critical to product performance. An experiment was designed to determine which process factors, or x's, have a critical effect on flatness.

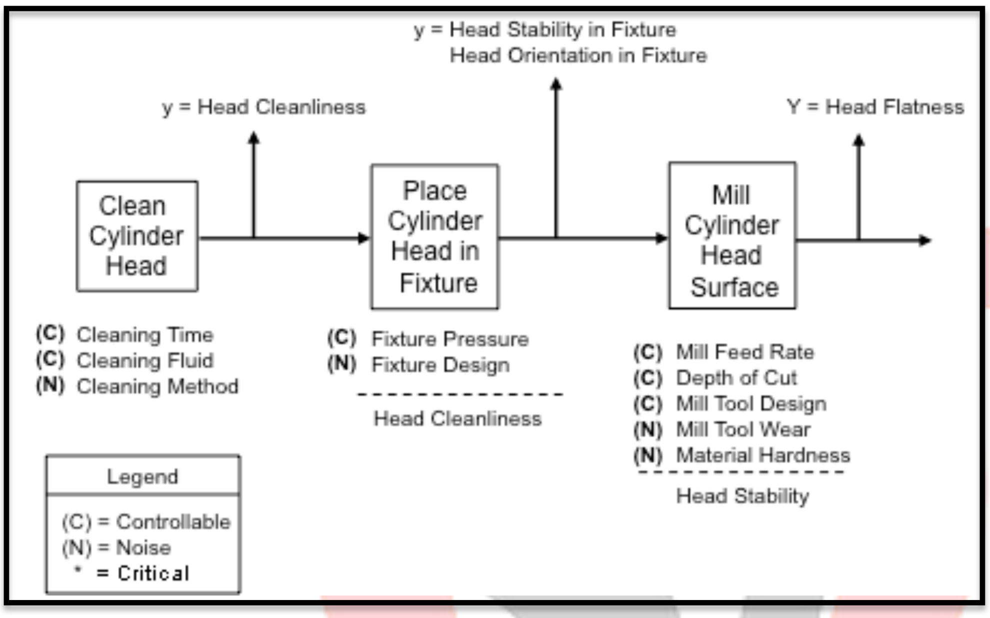

Figure 4: Compressor Cylinder Head Initial Process Map (Before Experimentation)

The experimenter, focusing on the milling operation, generated a design to examine the effect of mill feed rate, depth of cut and tool design on flatness. By constructing the initial Process Map shown in Figure 4, the experimenter learned several important things prior to running the design. First, the experimenter learned each piece is rigorously cleaned prior to milling. The criticality of this cleaning operation was unknown. Additionally, the experimenter learned each of the three operators had developed his/her own fixture for holding the part during milling. While the design of the fixture may have a critical impact on the flatness of the part, nothing was in place to control which fixture was used. For this reason, fixture design was considered noise. Lastly, the experimenter learned of two other noise factors that may impact flatness.

The allowable amount of tool wear and the hardness of the cylinder head were not currently being controlled.

Information from the Process Map led to an experiment designed to investigate the following factors: Cleaning Time, Cleaning Fluid, Fixture Pressure, Mill Feed Rate, Depth of Cut, and Tool Design. While the hardness of the material, the amount of tool wear, and the design of the clamping fixture were not normally controlled, the experimenter could control these factors for the duration of the study and decided to include them in the design. The results for the 16 run design are easily interpreted using the effect chart illustrated in Figure 5.

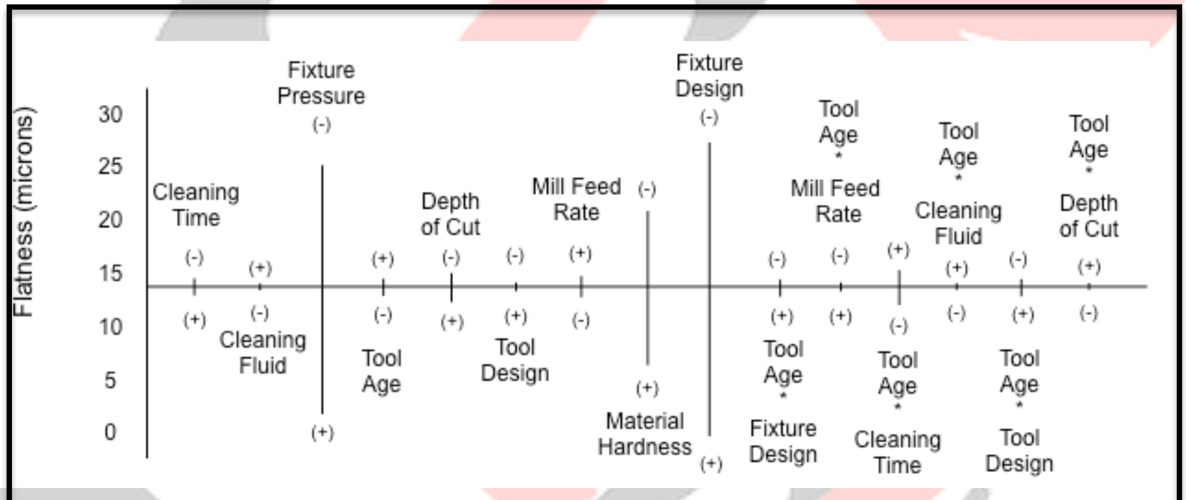

Figure 5: Effects Plot from Machining DOE

On the effects plot in Figure 5, the magnitude of each factor and interaction relative to the average flatness in the experiment is shown. Note only 6 of the two-way interactions are illustrated on the chart because of the resulting confounding for this particular design. For example, the interaction between tool age and depth of cut (Tool Age*Depth of Cut) is confounded with the interaction between Material Harness and Fixture Design (Material Hardness*Fixture Design). Because the effect of these two interactions will be identical, only one of the two is illustrated. As with all fractional factorial experimental designs, the confounding must be carefully considered prior to selecting the design and when interpreting experimental results.

For this particular experiment, the average flatness was 14.8 microns. The magnitude and direction of the effect for any given factor or interaction can be calculated by examining the difference between the average flatness at the high level of the factor and the average flatness at the low level of the factor. For example, consider the effect of fixture pressure. In this experiment, the two levels of fixture pressure were 100 PSI (-) and 200 PSI (+). The average flatness when the fixture pressure was held at the (+) level was 4.6 microns. When the fixture pressure was held at the (-) level, however, the average flatness was 25.0 microns. Hence, changing fixture pressure from 100 PSI to 200 PSI reduced the average cylinder head flatness by 20.4 microns (4.6–25.0=-20.4). Because the cylinder head is responsible for sealing off the chamber it is desirable to set up the process so flatness is minimized. Thus for right now, fixture pressure should be set to 200 PSI, and further experimentation should be performed on this and other important factors to determine optimal settings. The other factors and interactions can be analyzed in a similar manner. The effect plot can also be used to compare the relative importance of the factors in the experiment. Note that the difference between the average flatness at each level of a given factor or interaction is represented by the length of the vertical line drawn between the two levels.

As can be seen from Figure 5, the experimenter learned several valuable things that would not have shown up in the initial design. Cleaning time and cleaning fluid seem to have little impact on the flatness of the part, as illustrated by the relatively short lines.

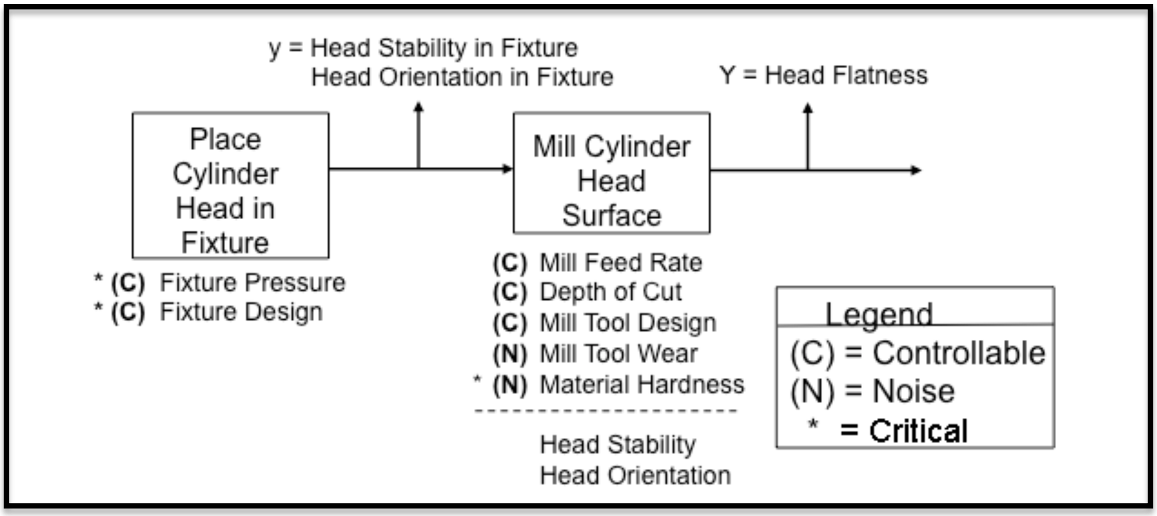

Figure 6: Compressor Cylinder Head Process Map (After Experimentation)

Further experimentation revealed the parts did not have to be cleaned at all. This step in the process was eliminated, reducing the cycle time and labor required to fabricate the part. The results also indicated the factors included in the initial design, across typical levels, have little to do with the flatness of the part. The important factors were those added to the experiment after constructing the Process Map. As can be seen from Figure 5, critical process factors included the design of the holding fixture, the fixture pressure and the hardness of the incoming cylinder heads. Through further experimentation, the optimal fixture design and pressure were determined and are currently being controlled. However, the process owner is uncertain how to control the hardness of the incoming cylinder heads. While this factor is critical, it is still considered noise because it is not currently being controlled. Note the Process Map has been updated to reflect the new level of process understanding (see Fig. 6). Critical process factors have been identified, and the current state of factor control is shown.

Conclusion

Graphically combining the knowledge typically depicted on a flowchart with that from a Cause and Effect Diagram, the Process Map overcomes the weaknesses of the two tools used independently. Additionally, the Process Map provides a clear understanding of the current state of process knowledge. As knowledge is gained through prolonged observation using sampling or through a series of experiments, the Process Map is updated to highlight critical process factors. Through this living document, the current state of process knowledge is readily available to all interested parties, greatly enhancing classical process improvement techniques including sampling and DOE. By using this tool to understand and manage the causal relationship between process factors and product performance, any process can be continuously improved to ensure success in today's competitive environment.

References

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