

MULTI-LEVEL PROCESS MAPPING: A TOOL FOR CROSS-FUNCTIONAL QUALITY ANALYSIS

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Successful implementation of a quality improvement program requires a thorough understanding of a customer's desired product characteristics as well as a complete understanding of the process. Many statistical process control (SPC) implementation efforts fail because the connection between product and process variables is not made. Simple, single-level process flowcharts, while providing an overview of the process, are frequently inadequate as a tool for in-depth process analysis, particularly when input from more than one functional area is desired. At the other extreme, many techniques used by industrial engineers for process flowcharting require the use of complex notational conventions that often are too difficult for non-engineers to use effectively. In this article, a multi-level process mapping approach is presented as a tool that is simple enough to be used by a cross-functional quality analysis team to examine a process while providing sufficient detail to identify key process variables and serve as the foundation for developing improved standard operating procedures (SOP). The approach, which has been used successfully to analyze both manufacturing and service processes, is illustrated by a three-level process map developed by a team of workers at a paper manufacturing operation.

UNDERSTANDING BOTH THE PRODUCT AND THE PROCESS

The foundation for any quality improvement program is a thorough understanding of the customer's desired product characteristics. Many firms that implement SPC programs focus on the critical product variables as defined by the customer. Although necessary for quality improvement, a product focus alone is not sufficient. Problems frequently arise when the connection between product and process variables is not made, and insufficient attention is given to the process variables [1, 3]. To be successful, application of SPC requires that the *process* itself also must be targeted for analysis. The result of this analysis is a *process definition* that facilitates a clear and complete understanding of the process targeted for improvement.

This process definition can be used by management to develop the standard operating procedures which support consistency in operations.

In the context of an organization, a process is any combination of people, machines, materials, and methods that is aimed at manufacturing a product or performing a service. Although most managers are quick to assert their knowledge of the process they manage, in many cases they are inadequately prepared to define the process in sufficient detail to allow for substantial improvements. Process definition requires that the steps making up the process be fully delineated, and that all decisions that are made in the execution of the process be specified.

It is essential that all relevant functions are represented and process limits are defined. No one person or functional department has a complete understanding of the process, especially at the level of detail required to support process improvement. For example, equipment designers understand the basic engineering principles that underlie the process machinery. However, only workers involved in the direct operation and maintenance of the machinery are aware of the unique aspects of a given piece of equipment and its sensitivities to the day-to-day variations in raw materials and operating practices. Likewise, key information pertaining to specific customer requirements may be known only to sales representatives. The value of the team approach is that everyone ultimately has a more complete and consistent understanding of the process. Changes and improvements in the process will be made only after the process definition has been completed and analyzed in its entirety.

DEVELOPING MULTI-LEVEL PROCESS MAPS

A multi-level process map is a hierarchy of flowcharts and lists used to thoroughly define the process in increasingly finer levels of detail. The mapping process is descriptive, rather than normative, and the focus is on describing the process as it actually exists rather than how it is supposed to be. The upper levels of the process map are simple flowcharts that outline

key steps in the execution of the process, while in the lowest level, key performance measures and trouble modes are identified. Multi-level process maps are very similar to leveled data flow diagrams, a primary tool of structured analysis for information systems analysis [2]. However, instead of the pseudo code found at the lowest level of a leveled data flow diagram, the most detailed level of a multi-level process map contains a descriptive list of key variables relevant to that control point. This structure for the lowest-level process map is a key feature of this approach, providing a simple and understandable transition from documenting and describing the process to helping workers develop improved standard operating procedures.

The general approach in process mapping is to start with a broad overview of the process. The Level I map is a simple flowchart of the key steps in the process. Any flowcharting convention can be used, so long as chart formats are kept as simple as possible and any special charting conventions are clearly explained on the chart itself. For clarity and ease of comprehension, there should rarely be more than 15 blocks in a single flowchart, and crossing lines of flow should be avoided.

The blocks on the Level I map should be numbered sequentially using two-digit numerals spaced to allow for insertion of new blocks between existing blocks. The individual blocks of the Level I flowchart are called *control areas*. These control areas may each be expanded into further detail by developing Level II maps. Each Level II map is itself a simple flowchart consisting of blocks called *control points*. Control points are each assigned a four-digit number using the convention *xx.yy*, where the first two digits (*xx*) correspond to the associated control area of the Level I map, and the second two digits (*yy*) identify the specific control point. At Level III, each control point can be expanded into even greater detail through the use of variable lists rather than by flowcharts. The listed items, called *control elements*, represent the finest degree of detail in the process map. The numbering of any control element takes the form *xx.yy.zz*, where the *zz* portion identifies the specific listed item.

The Level I process map indicates the overall scope of the process, and outlines the key subprocesses that are involved. When applied to a manufacturing process, the Level I map tracks the flow of material through a single-unit operation or production line. Applied to a service process, the Level I map depicts an ordered sequence of steps required to provide the service. In particular, the receipt, handling, storage, allocation, and preparation of materials (including in-

formation for administrative processes) are likely to be important steps in the process.

USING PROCESS MAPS TO ANALYZE A LABELING PROCESS

To illustrate an application of process mapping, consider the situation faced by the manager of a paper manufacturer. The number of mislabeled paper coils had reached the point where customers canceled orders. The plant had addressed the problem previously, but had not reached a viable solution. This failure was due in large part to many people involved in the manufacturing and shipping process having a lack of understanding of the process and ramifications of an incorrect label.

Developing a Level I (Macro) Process Map

To address this problem, the plant manager assembled a cross-functional team with representation from machine operations, production planning, shipping, and management. In an attempt to focus the attention of this team, an outside facilitator was employed. During the first meeting of the team, the members defined the parameters of the problem and developed a Level I (macro) process map of the labeling operation (Figure 1). The 11 blocks outline the flow of materials through the control areas of the process. As shown in Figure 1, the process begins with block [10], "coil ready," and through "complete paperwork (block [110])." In order for this approach to succeed, the Level I map must be completed as a group, with participation from all affected areas. At this early point in the analysis, simplicity and clarity are more important than detail, and the Level I map is constructed accordingly.

Developing a Level II (Micro) Process Map

After the Level I map was developed, each team member was charged with developing the Level II (micro) maps corresponding to his or her area of responsibility. Each Level II map is a flowchart describing the sequence of steps required to perform the subprocess represented by an individual block of the Level I map. It may not be necessary to develop a Level II flowchart for every block of the Level I map, particularly where a step is simple enough that further detail is not needed. Even among the Level II flowcharts there will likely be certain areas that are more complex than others. Priority and perspective are important at this point in the mapping process.

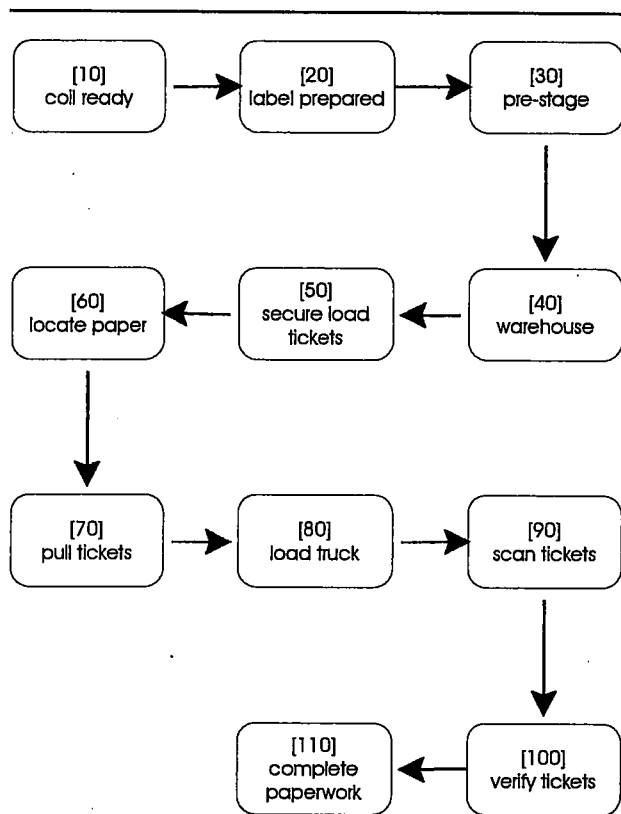


FIGURE 1: Level I process map for a paper coil labeling process

Upon completion of the Level II maps, the team convened to review the maps and modify them where necessary. An example of a Level II map for control area [20], label preparation, is shown in Figure 2. This map consists of a sequence of eight control points, beginning with "secure information [20.10]" and proceeding through "secure label on coil [20.80]."

A review of the records kept on mislabeled coils from the previous two months indicated which control points were most likely to be responsible for the majority of the mistakes. In order to focus on the key process variables that required attention, the team members were then assigned to complete a Level III process map for each of these areas.

Developing a Level III (Detail) Process Map

The Level III process map corresponding to a given control point consists of two parts: a brief *explanatory paragraph* that explains the details of the process at that control point, and several numbered *lists of variables* (the control elements) that enumerate the key quality

measures associated with that control point. The primary purpose of the explanatory paragraph is to explain why a procedure is specified in a certain way. (It is much more likely that people will conform to procedural guidelines if they understand the purpose of those guidelines.) Additional detail and clarification of any possible misconceptions also can be included in the paragraph. The lists that are most frequently included in Level III maps include: Materials (Process Inputs), Product (Process Outputs), Process (Control Variables), and Failure Modes. When appropriate, lists such as Safety, Environmental Concerns, and Regulatory Requirements can be included. A well-prepared Level III process map can serve as the skeleton of a standard operating procedure for the process at each control point; often, no further detail is needed.

It is recommended that specific ranges of two-digit codes be reserved for each category of lists on the process maps. For example, if the first four lists given above are included, the material characteristics might be indicated by a zz code between 01 and 25, product measures by codes 26–50, process variables by codes 51–75, and failure modes by codes 76–99. With this numbering system, each variable is uniquely catalogued. For example, the code 35.10.27 would represent control element 27 (a product characteristic), associated with control point 10 from control area 35. Rarely will more than 99 variables be required in any given Level III map, however, three-digit codes can be used if necessary.

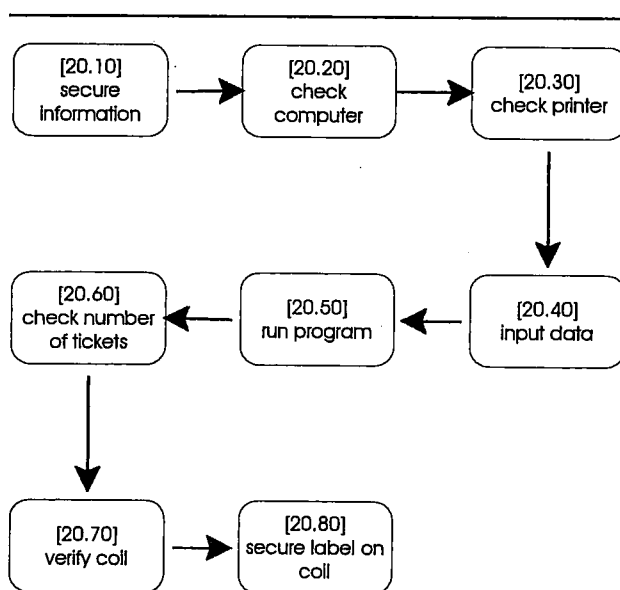


FIGURE 2: Level II process map for control area [20]—label preparation

An example of a Level III process map corresponding to control point [20.10] is presented in Table 1. For this map, the explanatory paragraph consists of a single sentence: "Coil number and identifying characteristics are collected from various locations and prepared for computer entry."

Following the explanatory paragraph is a *list of material (input) related variables*. The first step in developing this list is to indicate *precisely* what the material inputs to this process stage are, focusing only on those variables that are likely to have a significant impact on performance and quality. (Note that *material* generally refers to in-process product rather than the ultimate raw material.) It is important that the specific working definition of the material entering the control point be used, to prevent redundancy that will, in turn, lead to overly long Level III maps that are difficult to develop. Input from suppliers should be included if an evaluation of raw material requirements, specifications, and tolerances is required. Any limitations of measurability and controllability of the listed material variables should be noted on the process map, since they may represent areas of vulnerability of the process or areas of opportunity for future improvement. For this case, ten material characteristics were identified through a brainstorming session during a team meeting.

The next component of the Level III map often is the *list of product (output) variables*. In this context, the word *product* refers to the output of the specific control point being mapped. There should be a significant overlap between product variables at one control point and material variables at the following control point, because the output of one control point becomes the input to the next control point. Often, it is necessary to obtain information from the immediate "customer" (external or internal) for the product of the control point. Because finished product measures typically are of primary concern, a good starting point for developing the list of product variables is to determine the characteristics required by the end customer for the finished product and work backwards to establish cause-and-effect relationships between the product and material variables. The characteristics of measurability and controllability are critical, and product variables that either cannot be reliably measured or precisely controlled should be so indicated. For the Level III map illustrated here, no product variables were included since the product in this case is accurate information.

Although *product* characteristics define the overall objectives of the manufacturing or service process, *process* variables provide the means by which the product objectives are realized. Control of the outgoing quality

TABLE 1: A Level III Process Map For Control Point [20.10]—Secure Information

Coil number and identifying characteristics are collected from various locations and prepared for computer entry.

Material (Input) Variables

20.10.05 part number
20.10.10 work order
20.10.15 net tons
20.10.20 shift
20.10.25 machine number
20.10.30 run number
20.10.35 reel number
20.10.40 log number
20.10.45 pallet weight
20.10.50 lineal feet

Process (Control) Variables

20.10.55 check legibility
20.10.60 check that each number is in range

Failure Modes

20.10.75 number in incorrect box
20.10.80 number out of range due to "boxing" number
20.10.85 machine recorder down, thus must estimate

of the *product* is achieved through control of the *process* parameters. The *list of process (control) variables* forms the next component of the Level III process map. When listing process parameters, **all** variables that may impact upon the quality of the outgoing product or the overall efficiency of production must be included, even those that are not presently controllable or measurable. In this illustration, the process variables include checking the legibility of the label and checking that each number is within a reasonable range (for example, a range of possible weights is known for each possible diameter of the coil—if the weight falls outside of this range, the entire label is suspect and must be checked and corrected).

The importance of a complete catalog of process variables cannot be overemphasized, particularly when the process maps are used to structure the gathering and classifying of information in order to adjust the process and obtain a more consistent, higher-quality product. For example, when developing a standard operating procedure, nominal process settings will be specified. There may be many combinations of these settings (for example, of temperature, pressure, load, or speed) that all yield acceptable results relative to a given product measure. Among these feasible combinations there may be certain ones that are economically advantageous. A detailed listing of process variables provides a good starting point for further studies aimed at identifying the optimal combinations of settings. Once an initial list of process variables has been

identified, it may be necessary to design and conduct experiments to quantify the relationships between selected process variables and corresponding product quality characteristics.

The next itemized list in the Level III process map identifies the things that can go wrong during normal operation of the process. This *list of failure modes* represents the assignable causes of variability that sporadically occur in the process. As with the other variable lists, care should be taken to keep focused on the failure modes at the control point that is currently under study. Input from line operating personnel is invaluable in developing an initial list of failure modes. The entries on the initial list can be validated through the use of a process log during process capability studies. Usually the Pareto principle will apply, and not everything that *can* go wrong actually *will* go wrong. The assignable causes of variability that occur most frequently in practice, once documented by data, can be eliminated once and for all through changes in the system. For the case illustrated here, three failure modes were identified: one or more numbers may not be in the correct box, a number may be out of range due to "boxing" the number (this is slang for transposing two or more digits of the number), and the machine recorder (like an odometer on a car) is not working, and thus the length of the roll must be estimated.

IMPROVING PERFORMANCE WITH PROCESS MAPS: THE FINAL STEP

A detailed, comprehensive process map serves several specific purposes. One application of Level III process maps is to provide a catalog of product quality measures that can be subjected to capability studies. Other applications include providing a basis for cause/effect analysis, the rudiments of SOP, a basis for developing process trouble-shooting guides, and the foundation for supplier quality activities. In addition, a well-developed process map can be a valuable training aid for both current and new employees. It ensures that everyone conceptualizes the process in the same (correct) way. In addition, the cross-disciplinary learning that occurs among team members dur-

ing the development of a process map can alone be worth the effort of the project.

Due to the learning that takes place during the development of the process map, the mapping procedure itself is evolutionary in nature. The process map need not be perfect in its initial form, because it will be subject to ongoing revision to correct inaccuracies, eliminate incompleteness, or reflect change.

For the coil labeling process described above, the process mapping approach resulted in an enhanced level of understanding of the process by all areas. After developing Level III maps for all control points, the team targeted several elements for improvement and recommended specific changes in operating procedures. With the support of the management team, the general work force was trained on the new procedures, and the frequency of mislabeling was dramatically reduced to only 2% of its earlier level.

In summary, multi-level process maps provide the structure required to bridge the gap between product observation and process analysis and thereby enable the successful implementation of SPC and total quality management. A set of process maps can describe a process in sufficiently fine detail to permit improvement in virtually every area. The mapping procedure facilitates the coordination of the efforts of all analysis team members from a wide range of functional areas. Moreover, the multi-level process mapping approach is applicable to all operational improvement efforts, including those focusing on service operations and administration functions, and can provide a useful starting point for benchmarking and reengineering initiatives. Whenever a better understanding of a process is required, time and effort invested in the process mapping procedure will be recaptured many times over.

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