# Procedure for Scientific Value Stream Mapping

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## Foreword

Value Steam Mapping (VSM) is not a new technology. It was initially developed to support early uses of scientific management in supporting the time and motion studies of workers at the beginning of the 20th Century by engineers Frederick W. Taylor,[1] Frank and Lillian Gilbreth,[2] and Henry L. Gantt.[3] While Taylor concentrated on reducing time; the Gilbreth's focused on studying motion; and Gantt emphasized work breakdown structures and timing sequences in a Gantt chart. VSM was pragmatically applied at Toyota Motor Company in the late 1950s and early 1960s as the organization evolved its routing work of daily management into an efficient production system. When this was recognized and popularized by the MIT automotive industry study in the early 1990s in the book *The Machine that Changed the World* by Womack, Jones, and Roos,[4] the methods of Toyota came into full view of a wide variety of industries and the tools that accomplished these methods became targets for emulation by organizations seeking to make themselves better and also opportunities for consultants and academics to capitalize upon by wring books based upon a Western understanding of Japanese methods.[5,6,7,8]

While the Western interpretation of the Japanese concept of process mapping concentrates on how a graphical representation of processes can be achieved, this only represents the way a visualization of process activities is performed so workers can understand their flows in the daily management system. The production process contains both a visible element and an invisible element that collectively act to describe the total productive system. While the visible component may be mapped using symbols and icons, the invisible component must be mapped with data that describes the throughput. This is done in a simplified way for operators; however, engineers use process data to map the throughput and learn how to manage the flow.

The purpose of this process reflection is to describe a scientific approach to mapping the invisible flow of work as a way to increase throughput, balance work allocations, and eliminate waste. These are critical steps to the design of the production system which at Toyota is initiated as an engineering function that creates the system for "fine tuning" by operators in the workplace.

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1 Frederick W. Taylor (1911), *Principles of Scientific Management* (New York: Harper).

2 Frank B. Gilbreth (1911), *Motion Study* (New York: Van Nostrand); Frank B. Gilbreth (1912) *Primer of Scientific Management* (New York: Van Nostrand); Lillian M. Gilbreth (1914), *Psychology of Management: The Functions of Mind in Determining, Teaching< and Installing methods of Least Waste* (New York: Sturgis and Walton); Frank B. Gilbreth and Lilian M. Gilbreth (1916), *Fatigue Study: Elimination of Humanity's Greatest Unnecessary Waste* (New York: Sturgis and Walton): Frank B. Gilbreth and Lillian M. Gilbreth (1917), *Applied Motion Studies* (New York: Sturgis and Walton).

3 Henry L. Gantt (1919), *Organizing for Work* (New York: Harcourt, Brace, and Howe).

4 James P. Womack, Daniel T. Jones, and Daniel Roos (1991), *The Machine that Changed the World* (New York: Harper).

5 James P. Womack and Daniel T. Jones (1995), *Lean Thinking* (New York: Free Press)

6 Mike Rother and John Shook (1999), *Learning to See* (London: Lean Enterprise Institute).

7 Jeffrey K. Liker (2004), *The Toyota Way* (New York: McGraw-Hill).

8 Karen Martin and Mike Osterling (2013), *Value Stream Mapping* (New York: McGraw-Hill).

## Work Process Design

The early industrial engineers developed methods to breakdown work into its elemental components and to identify the time components of individual tasks so that the “one best way” to perform a job could be identified and its motions studied. This is the key concept behind VSM; however, more details are included in a comprehensive analysis including distance traveled, inventory levels, process operator ergonomics, and elements of waste. The objective of work process design is to increase work efficiency by eliminating waste in all of its forms. Thus, VSM is often coupled with waste identification and loss reduction activities. When Taiichi Ohno introduced his system of managing production at Toyota, he started with waste elimination as the critical point for organizing work into a productive system.[9]

The key methods used in work process design have not changed much since the time of the early IE’s: observing work, identifying waste in all of its forms, streamlining the work by eliminating this waste and the loss it creates, and standardizing on the one-best-way to perform the work. The purpose of a VSM is to provide a mechanism for understanding, documenting, and streamlining the flow of work so that the daily work process can be standardized and managed in a state of control. This represents gaining what W. Edwards Deming later called the “profound knowledge” of the work system.[10] Profound knowledge is necessarily statistical in nature as Walter A. Shewhart had demonstrated the ability of a statistical point of view to expose process knowledge and his process control charts became the voice of the process.[11]

Productive systems breakdown into processes, activities, and tasks which may be studied to identify the way they operate using measures of productivity and efficiency to identify drivers of waste. A scientific approach to VSM will decompose the system into its most detailed components of work, identify factors that create productive losses through leakage of materials or friction in flows and study these factors to discover their statistical nature and determine what can be done to improve the tasks definitions (e.g., improved knowledge of the standard work processes using both statistical analysis and observation of the human performance of work). Such a methodology is necessarily collaborative with the workers as the human component in a socio-technical system.[12]

## Understanding the Flows that Produce Value and Waste in Daily Work

What is important about the process of Value Stream Mapping? An effective VSM will disclose not only the process flow, sequence of activities, and identification of value-adding tasks; it will also describe an evidence-based workflow that enables better management and control of the work so that outcomes are produced reliably at the lowest cost of production (including systemic waste). Creating a scientific VSM concentrates on the data that discloses the pockets of waste and can be combined with the direct observation of worker movements to understand how the flow can be managed most efficiently. The “constructal law” states that when “system flow smoothly they are healthier.”[13] Thus, streamlining flow of work activities is an essential ingredient for healthier work processes.

The prerequisite to VSM is gaining process knowledge about the flow of work. Thus, “genichi genbutsu”

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[9] Taiichi Ohno (1988), *Workplace Management* (Cambridge, MA: Productivity Press).
[10] W. Edwards Deming (1992, 1994), *The New Economics* (Cambridge, MA: MIT Press).
[11] Walter A. Shewhart (1931), *The Economic Control of Quality of Manufactured Product* (New York: Van Nostrand).
[12] Gregory H. Watson (2018), *The Theory of Profound Knowledge; An Inquiry into Quality and Strategy* (Stillwater, OK: Oklahoma State University).
[13] Adrian Bejan and J. Peder Zane (2013), *Design in Nature* (New York: McGraw-Hill).

or "go and see for yourself" is a critical ingredient in mapping an existing process; however, to design a work process from scratch, this does not work. Thus, designers need to begin with the product and find a way to "put the pieces together" through a system of collaborative work activities. In Japanese, this is called "monozukuri" which "duplicates design into material form" and acts as an "art, science and craft of making things" or producing things of value for customers.[14] This definition may be further amplified:

- ***Art***: a product of conscious application of human creative imagination to express a conceptual idea through the technical proficiency in applying an artistic media. Art blends science and craft to make a holistic system.
- ***Science***: a systematic approach to build and organize a body of knowledge in the form of testable explanations and predictions about its particular object of study. Science provides a statistical basis for gaining profound knowledge.
- ***Craft***: a profession practiced by skilled laborers who gained the special knowledge by informal tinkering and trials to determine a best way of doing something to meet their own standard. Craft contributes the human activities that enable both the initial stage and final stage in all production systems.

Building an effective, efficient, and economical productive system requires the systematic design of the end-to-end using methods that create "evidence-based" insights into factors that will reduce the waste, stabilize throughput flow control, and minimize cost, defects, and cycle time. This value-producing work must also be designed so it is acceptable for workers by eliminating activities that are dirty, dangerous, or demeaning so workers can develop "pride" in their accomplishments.

Commencing the development of a VSM requires gaining knowledge of the process flows at a task level of activities. Science begins with observation – noticing what is done and how it is accomplished as well as the degree to which its performance works according to the designed work. When there is no work design, then applying a "common sense" approach by a skilled operator can be the starting point. This is why many high technology firms use experienced operators to build their products during R&D so their manufacturing process can be designed in parallel to the product itself. When there is no standard, you can document any sequence of activities as the initial standard and start improving it based on detailed observation of how it works to identify what can be improved. Then keep improving the process as long as new ideas are presented.

Thus, developing waste-free work processes requires eliminating the waste and enhancing the value by an evolutionary process of incremental improvement. The VSM makes this process more scientific by its provision of the data that establishes an evidence-based approach to value stream management.

## Procedure for Developing a Scientifically-Based VSM

So, how should a VSM be constructed? Once a process has been defined as a series of steps to create a specific outcome, then the checklist can be converted into a linear flow of activities. Why a linear flow? It is because a linear model is the simplest form for understanding how simple tasks can be replicated. By using a linear model workers can be taught the sequence of activities following the laws of simplicity:

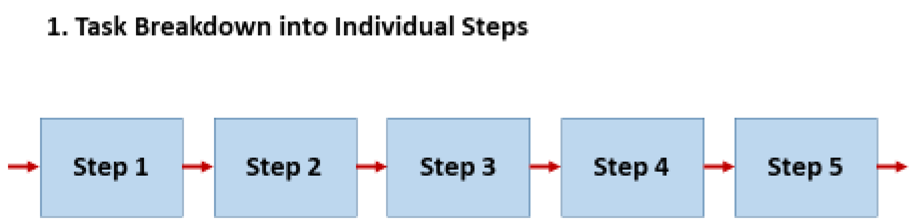
[14] Daniel Arturo Heller and Takahiro Fujimoto (2017), "Monozukuri Management," in *Japanese Management in Evolution*, Tsuotomu Nakaano (editor) (London: Routledge).

"Reduce: The simplest way to achieve is through thoughtful reduction."[15] Maeda defines simplicity as the elimination of the obvious [waste] and addition of the meaningful [value]." Obvious waste is what is visible when looking at the workplace; however, adding the meaningful creates true value and meaning is not obtained by observing it requires summarization and linkages which come from data analysis and a use of statistics to determine the most probable outcomes. A single observation is not statistical in the way it has been observed. Multiple observations are required to understand trends and to predict long-term performance. This enables prediction based on probabilities that have been established from the observations of past performance under known operating conditions (e.g., a structured work sequence that has been repeated often enough to gain confidence that a reliable understanding of its operational outcomes under established conditions of performance has been achieved.

Thus, we begin the VSM by creating the simplest map of the process: its linear flow of the "atomic" level at which operators perform their daily work. Systems models containing the intricacies and complexities of the system details and interactions.

Step 1: Map end-to-end work tasks as a linear flow of processes that identifies the boundary conditions of the process inputs (and their sources) and outputs (and their recipients). Measures of the incoming flow of demand (number of distinct ordering units required and the arrival rate of the orders) and the corresponding rate of incoming material flows and response performance from suppliers.

Figure 1: Linear Flow of the End-to-End Breakdown of Work Tasks into Individual Steps



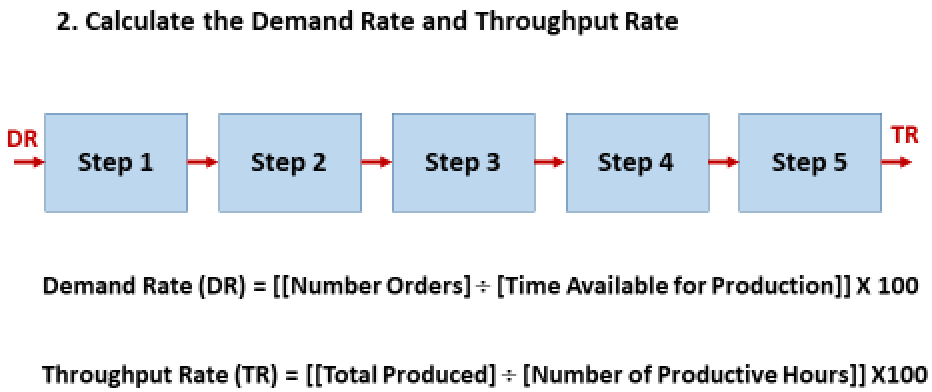

This decomposition of the process enables development of the simplest understanding of the basic work process so it can be studied in microscopic detail. It makes visible all of the actions, issues, and potential failure mechanisms that can occur and enables them to be managed by the person who is performing the task. If the resolution of the work is too broad or too shallow, then the process flow will not enable a detailed understanding of its contribution to the overall performance of the system. However, there is a caveat to applying this method: managing a single task, while necessary for developing maximum gains in the process flow, is not sufficient to assure system optimization. There is a risk of sub-optimizing one part of the system and not influencing the overall performance of the entire end-to-end throughput as another task is the bottleneck that constrains the entire flow. Thus, gaining a system-wide perspective is a necessary initial step so a VSM can be chosen for construction to achieve the best system-wide result.

Step 2: Calculate the incoming order rate (number of orders received divided by amount of production time that is scheduled to be available – this demand rate is called "takt time" as it indicates the product assembly duration required to match the incoming order rate (e.g., minutes per unit). This metric will define the effectiveness of the designed production process capability so a throughput production rate

[15] John Maeda (2012), *The Laws of Simplicity* (Cambridge, MA: MIT Press).

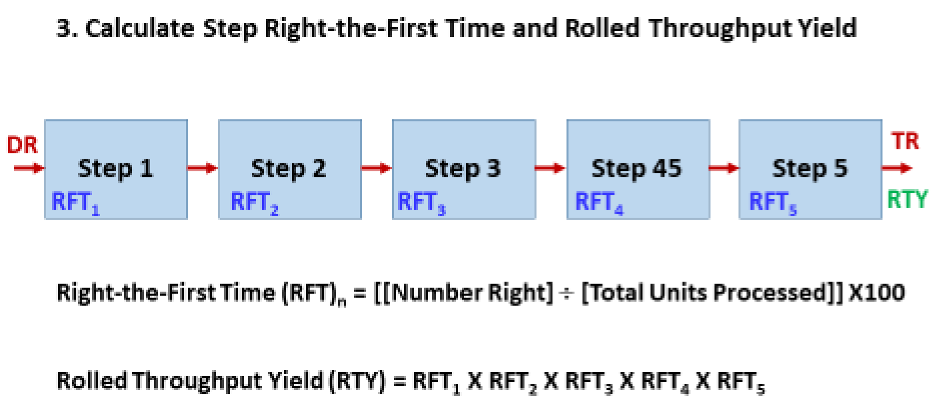
(e.g., units per hour) may be established which enables balancing the flow of work.

Figure 2: Adding Demand and Throughput Metrics to the Linear Flow



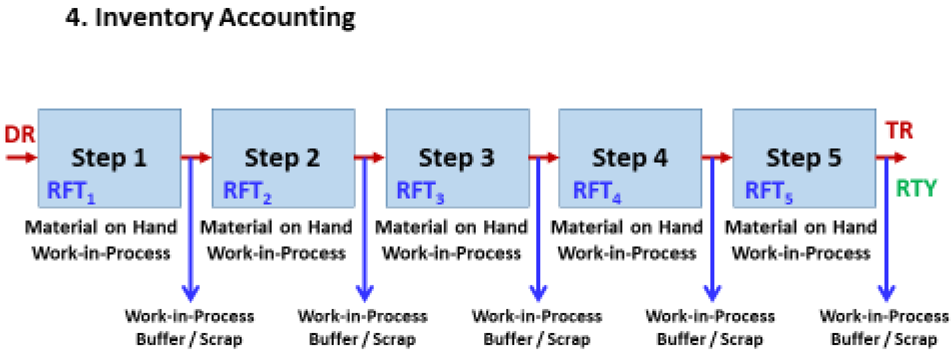

Step 3: Calculate the probability of "right-the-first-time" (RFT) for each step in the linear task flow. When these individual RFT ratios are multiplied they establish a probability for the capacity of a work sequence to produce a resultant outcome that is "right-the-first-time" for the end-to-end sequence. This quality outcome is referred to as "Rolled Throughput Yield" (RTY). RTY identifies how much of the productive output has been processed without any rework or "second touch" by operators (e.g., repair, retesting, or substituting components that do not assemble properly on the first attempt). This indicator provides a basis to understand the current maximum value that is produced; the percentage of work that follows "standard work" procedures; and identifies how much time is lost in production due to rework.

Figure 3: Adding the RFT and RTY Measures to the Flow of the End-to-End Breakdown of Work Tasks



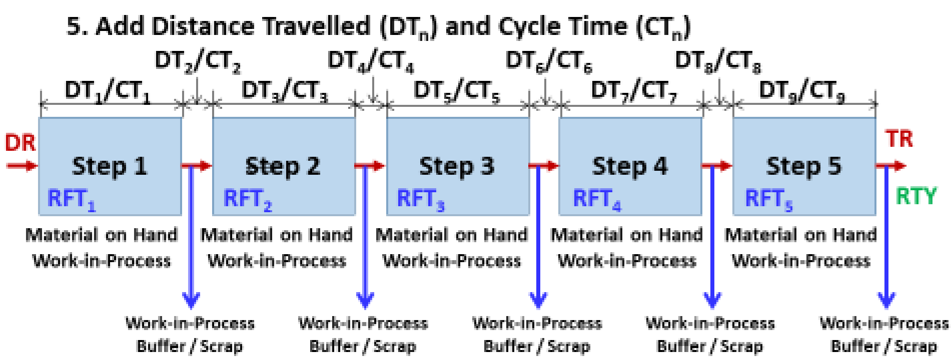

Step 4: Within each step (an activity box) and between the steps (a flow arrow) identify the amount of work-in-progress (WIP) in terms of units of production (not using monetary value or days of inventory) to describe the location of parts inventory and semi-produced throughput so the material flow can be balanced with the throughput rate of the workflow that aligns to the incoming order rate. This analysis describes the "kanban" structure for material flow in the line. It also indicates how well the buffers are being managed between the flow and where scrap is being created in the process tasks. The bottleneck in the process can be identified from a quality perspective as that step that has the lowest RFT level and also produces the most scrap.

Figure 4: Add the Raw Material Inventory and Work in Process Inventory to the Flow Chart




Step 5: Calculate the "distance traveled" by a production unit through this process by tracing its "one-piece flow" from start (initiation of the production order) to finish (completed unit of production that is ready for shipment to fulfill that order). Keep track of the total production time for the entire flow which includes the time spent in each step as well as the time between each step (e.g., the waiting or queueing time). This will indicate transportation and motion inefficiencies where time is being wasting time and accumulated as unproductive working time. Evaluate the distance traveled flow using a “spaghetti” type diagram where an operator walks the flow using a pedometer to establish the longer flows and using a tape measure for determining the distance traveled for the shorter flows. Use a stopwatch to check the cycle time of each step or (if available) bar code scans. It is important that all time from end-to-end in the system are counted. When performing this analysis an assessment of the value-adding contribution should be made (e.g., is the time value-adding (VA), non-value-adding (NVA), or required time (RT)?). To understand the amount of variation in these flows it is necessary to conduct this one-piece-flow analysis for several cycles to gain sufficient statistical understanding of the process performance.

Figure 5: Adding the Distance Traveled and Production Time Measures to the Flow Chart




Step 6: Trace the production process using a “one-piece-flow” analysis for a minimum of 30 units of the final product through the linear flow of the above steps and record time spent in each production step (as well as the intermediate waiting steps or transportation (movement), and the inventory levels as the process operates. Analyze this data using a one-way ANOVA where each step in the linear flow is used to define rational sub-groups and box plots are produced for each analysis of time and inventory variables to determine variation in performance of process activities as well as to demonstrate the line balance. All this data can be analyzed using a statistical point of view.

Figure 6a: Add Summary Data for VA, NVA, and RT to the One-Piece Flow

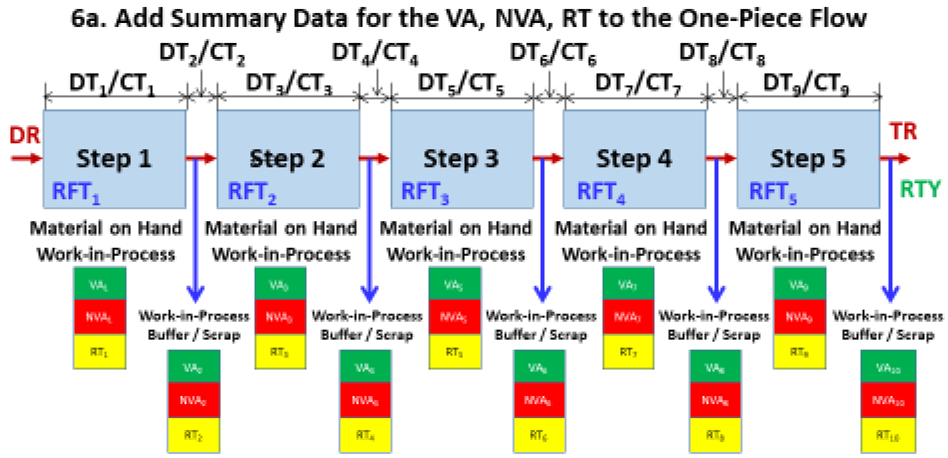
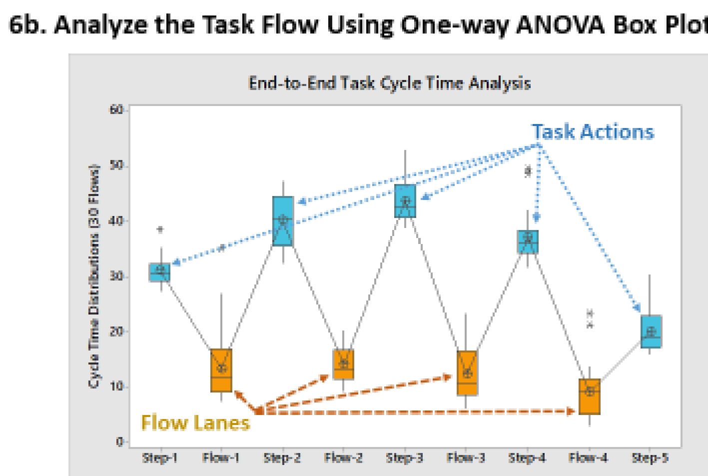



Figure 6b: Plot the End-to-End Performance of Step and Flow Cycle Times as Box Plots




Flow lanes represent the time between the process tasks as this represents mostly waiting time and travel time these activities would be labeled as either NVA or RT – and thus subject to reduction to their minimal level of duration. The task actions may combine all three types of activities (VA, NVA, and RT) in their composition and thus need to be analyzed to identify unnecessary actions and waste.

Step 7: Evaluate the process flows using the following four analyses:

(1) Individuals charts for time on task showing each step as a stage in the control chart (also the timing for flows between these steps);

(2) Process capability for each step (for the specification value compare actual time to "value-adding" component of work (which will represents the "ideal performance") as the upper limit of the "specification" and zero as lower limit);

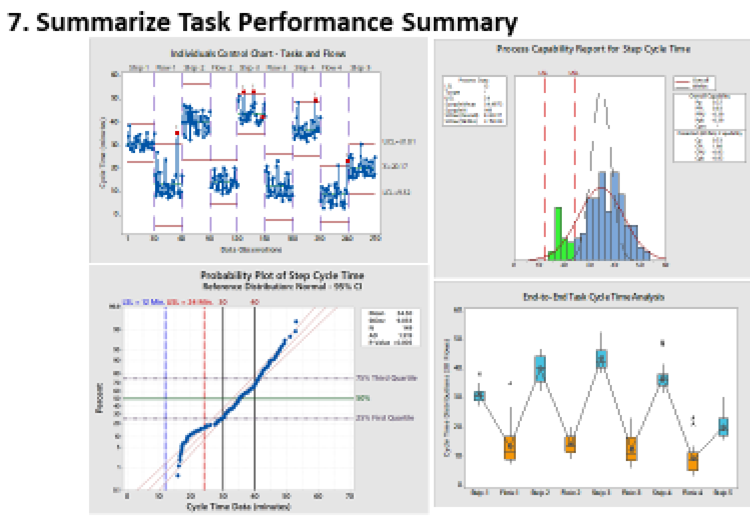
(3) Probability plots of the same cycle time variables to understand flow distributions in these runs;

(4) One-way ANOVA of the cycle times for steps and flows can be inserted in the fourth panel of the 4-Up Chart: this analysis may be supplemented using other analyses for classifying the issues, failures, or concerns noted;

(5) Finally, evaluate the count of accumulated issues that create lost productivity using Pareto analysis of those issues (e.g., levels of failures by type) as identified in data collection [optional step].

Determine where weaknesses exist in this process that create productivity or quality losses and identify opportunities to make improvements.

Figure 7: Graph these Analyses in a Summary Plot using a Motorola 4-Up Chart



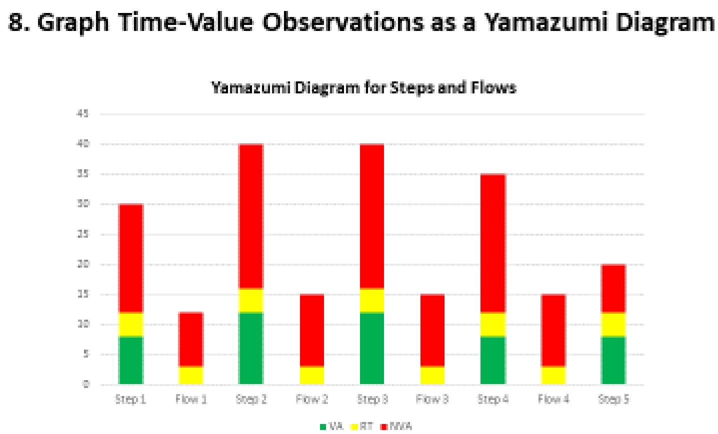

The Individuals Chart in the first panel of the 4-Up Chart shows the total cycle time for both the "step" functions and the "flow functions" of this task. A process capability study in the second panel indicates that the five "step functions" lack uniformity of flow and that they take longer than the targeted band of performance. The probability plot in the bottom lower panel indicates that data in the $50^{th}$ percentile of the "step function" distribution is operating between 30 and 40 minutes of cycle time rather than the 12 to 24 minute desired cycle time. The final panel shows that both "step functions" and "flow functions" need to be reduced in cycle time and balanced for performance. This provides the baseline perspective to make improvements for this end-to-end task.

Determining what to reduce and where to reduce requires a subsequent drill-down into both each "step function" and "flow function" in the process. This can be accomplished by analyzing the characteristics of the work that is performed in more specific detail by category of value: VA, NVA, and RT.

Step 8: For this data set review the information collected within each step to identify the magnitude of time dedicated to Non-Value-Added Tasks (waste that should be eliminated); Required Tasks (necessary work that needs to be minimized), and Value-Added Tasks (required work that satisfies the customer's requirement for the deliverable outcome and should be optimized). The same analysis should be done in the case of each of the "Flow Functions"

Plot this information as a Yamazumi Diagram (a stacked bar chart illustrating all three waste categories) in each bar of the "step-and-flow" functions.

Figure 8: Graph Time-Value Observations as a Yamazumi Diagram




This procedure will tell you: (1) how much time is wasted which enables you to discover (2) where the flow is not regular and (3) where waste is occurring. It does **NOT** describe what the specific nature of the waste. That is the initial process improvement step - conduct a deep dive to determine real sources of cycle time waste and answer the question: why do we spend this much time to do this work?

## Reflective Questions:

Consider a task that you wish to analyze using a scientific approach to understand the process flow and how to improve the way it performs in terms of cycle time efficiency, transaction cost, inventory levels, quality of the activity, and collaboration among the workers. Ask yourself the following set of questions before you begin this VSM process:

1. How would the customer of this task define its purpose, measure its outcomes, and communicate to the workers about performance issues that may arise.
2. What is the value contribution of this process? How does it produce value? When considering how it operates as an end-to-end sequence, what can go wrong, what would indicate that such things have gone wrong, and what countermeasures have been designed to put into place immediately upon a detection of the issue's triggering signal?
3. How does the process address customer requirements? How is this performance measured? What is the design of the process with respect to its material and information flows?
4. Using a Fishbone diagram or Mind Map, identify all of the various components of the task according to the 7-M categories of process functionality (manpower, machine, measurement, method, money, materials, and Mother Nature). Ask yourself, how can each of these go wrong and where in the set of operator tasks can these events occur?
5. Identify all of the people involved in this task from the source of materials consumed or applied, to the decision makers who provide information. What is the social architecture of the people who are related to this work and what are their responsibilities relative to its performance (perhaps a RACI type of matrix can help demonstrate the division of labor and responsibilities)?

Once this preliminary knowledge has been gained it is time to develop your value stream using the steps identified above!