Value Stream Mapping from an Industrial Engineering Viewpoint

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Objectives

1. To give an overview of Lean Thinking as being a combination of Lean Supply Chain, Lean Manufacturing and Lean Distribution.
2. To explain the basic concepts of the Value Stream Mapping (VSM) tool for documenting and visualizing the complete order realization process used by a company to satisfy a typical customer.
3. To analyze the advantages and disadvantages of VSM.
4. To explain and enhance VSM by incorporation of complementary Industrial Engineering (IE) concepts and methods.
5. To compare the icons of VSM and those of various Industrial Engineering (IE) tools, such as: Flow Process Charting (FPC), Business & Office Process Charting (BOPC) and Process Analysis and Improvement (PA&I)
6. To develop a single set of icons for universal process decomposition and value assessment in service and manufacturing industries.

Introduction

Constraints placed on the Japanese car manufacturing industry after the World War II led Taiichi Ohno of Toyota Motor Corporation to pioneer a new type of production system – Toyota Production System (TPS) – that was "so different, and so much better than mass production" as to guarantee a new type of manufacturing system (http://www.lean.org/Lean/Community/Resources/thinkers2.cfm). Jim Womack and Dan Jones enhanced the original concepts of TPS into the framework of *Lean Thinking* that was first introduced in the US in the Fall of 1996. It extends continuous improvement efforts to reduce the costs of serving the customer/s beyond the physical boundaries of a manufacturing facility, by including the suppliers, distributors and production system that support the manufacturing function.

Lean enterprises organize their activities with less effort, space, inventory, defects, and product development time in comparison with traditional mass production systems. These improvements and cost reductions are achieved by eliminating the *muda* (wastes) associated with all the activities. Wastes are defined as "all activities that consume resources (add costs to the product) but contribute zero value to the customer".

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Five Steps for Implementation of Lean Thinking[2]

There are five steps for implementing *Lean Thinking* in an enterprise:

1. **Define Value from the perspective of the Customer**
   Precisely define value in terms of specific products with specific capabilities offered, at specific prices through a dialogue with a specific customer/s, and at a specific time (Womack & Jones, p.16). In other words, lean enterprise understands and focuses precisely on what the customer/s want to buy.

2. **Identify the Value Streams**
   Womack and Jones define the value stream as "the set of all the specific actions required to bring a specific product through the three critical management tasks of any business: …problem solving, …information management, …physical transformation" (Moore & Scheinkopf, p.17). Once the value stream has been identified, create a map of the Current State and the Future State of the value streams. The Value Stream Mapping (VSM) tool allows a visual representation of value streams to help identify and categorize the wastes in the Current State. This map is used to plan actions to eliminate the wastes and obtain the Future State.

3. **Flow**
   This step identifies and eliminates any *muda*-causing structures or activities in the product flow that increase the manufacturing lead-time. It encourages companies to look at the physical distance that separates all pairs of functional departments that are utilized during the order realization process to fulfill customer demand. The most dramatic reductions in total lead time will be achieved by a product-focused organization (focused factory).

4. **Pull**
   After the wastes in the system are reduced, a lean enterprise would use a strategy of *pulling* inventory through the system based on actual customer product demand, in contrast to the traditional approach of *pushing* inventory through the system. In a pull environment, the tendency of overproduction, which leads to increased inventory levels, can be controlled. In addition, letting the customers pull products as needed will eliminate the need for (unreliable) sales forecasts.

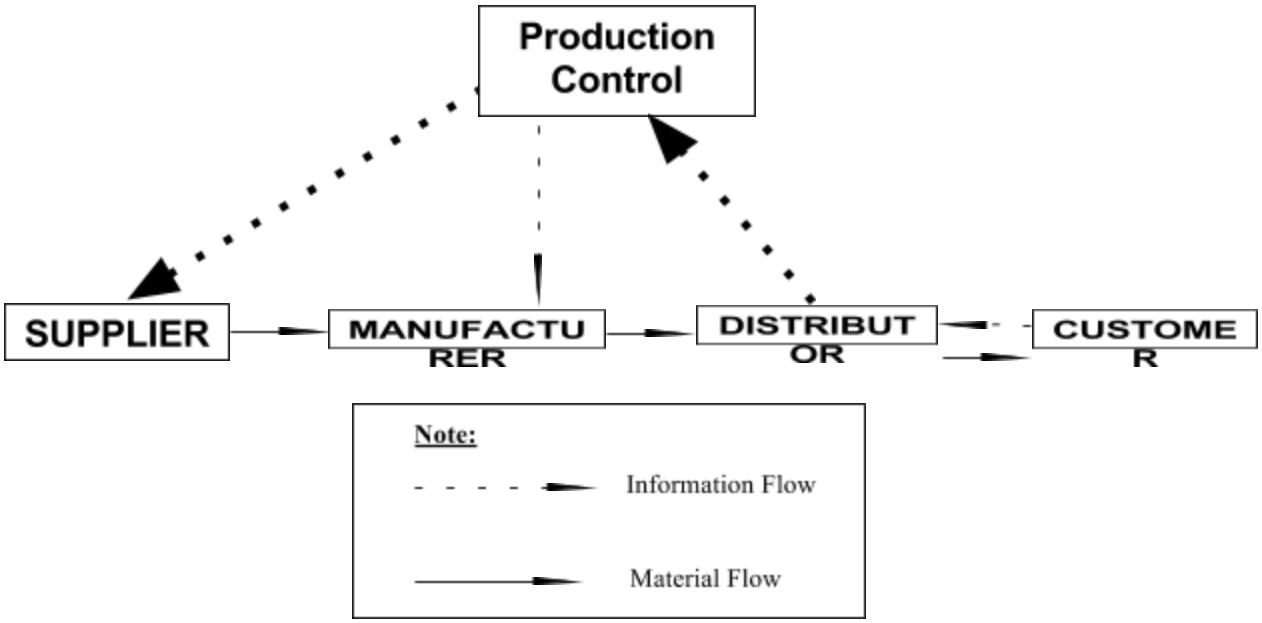
5. **Perfection**
   This concept reminds the lean enterprise to continuously improve the production system, and move its performance towards perfection. The entire process of lean implementation must be a never-ending process since, in practice, the process of reducing effort, time, space, mistakes, and costs can never be perfect. For example, for further lean transformations in a company that wishes to offer a

[2] http://www.lean.org/Lean/Community/Registered/Steps.cfm?

better product as per customer desires, it is necessary to go back to Step 1 in this 5-step process.

Value Stream Mapping (VSM)

Unlike traditional process mapping tools, VSM is a mapping tool that maps not only material flows but also information flows that signal and control the material flows. This visual representation facilitates the process of lean implementation by helping to identify the value-adding steps in a value stream and eliminating the non-value adding steps, or wastes (muda).



Using a VSM process requires development of maps: a Current State Map and a Future State Map. In the Current State Map, one would normally start by mapping a large-quantity and high-revenue product family. The material flow will then be mapped using appropriate icons in the rich VSM icon template. The product will be tracked from the final operation in its routing to the raw material storage. Relevant data for each operation, such as the current schedule (push, pull, order dispatching rules in effect at any process ex. FIFO) and the amount of inventory in queue, will be recorded. The information flow is also incorporated to provide demand information, which is an essential parameter for determining the "pacemaker" process in the production system. After both material and information flows have been mapped, a time-line is displayed at the bottom of the map showing the processing time for each operation and the transfer delays between operations.

The time-line is used to identify the value-adding steps, as well as wastes, in the current system. The comparison between the processing times and the takt time (calculated as Available Capacity/Customer Demand) is a preliminary measure of the value and waste.

This takt time is mostly used as an ideal time for each operation to achieve (ideally, the cycle time for each operation should be the takt time).

Based on the analysis of the Current State Map, one then develops a Future State Map by improving the value-adding steps and eliminating the non-value adding steps (waste). According to Rother & Shook, there are seven guidelines, adapted and modified based on the concepts of Lean Thinking, that can be followed when generating the Future State Map, or lean value stream (Rother & Shook, p.44-54):

1) Produce to takt time
2) Develop continuous flow
3) Use supermarkets to control production where continuous flow does not extend upstream
4) Schedule based on the pacemaker operation
5) Produce different products at a uniform rate (Level the production mix)
6) Level the production load on the pacemaker process (Level the production volume)
7) Develop the capability to make "every part every (EPE) <time period>"

Advantages Of Value Stream Mapping (VSM):

- ➢ Relates the manufacturing process to supply chains, distribution channels and information flows.

- ➢ Integrates material and information flows.

- ➢ Links Production Control and Scheduling (PCS) functions such as Production Planning and Demand Forecasting to Production Scheduling and Shopfloor Control using operating parameters for the manufacturing system ex. takt time (this is the production rate at which each processing stage in the manufacturing system should operate).

- ➢ Helps to unify several IE techniques for flow analysis, such as Production Flow Analysis (PFA), Business Process Reengineering (BPR), and Process Analysis and Improvement (PA&I) that, to date, have been taught and implemented *in isolation*.

- ➢ Provides important descriptive information for the *Operation* and *Storage* process elements that, to date has not been captured in standard Flow Process Charts used by IE's.

- ➢ Forms the basis for implementation of Lean Manufacturing by designing the production system based on the complete dock-to-dock flow for a product family.

- ➢ Provides a company with a "blueprint" for strategic planning to deploy the principles of Lean Thinking for their transformation into a Lean Enterprise.

Disadvantages of Value Stream Mapping (VSM):

- ➢ Fails to handle multiple products that do not have identical maps.

- ➢ Fails to relate *Transportation* and *Queuing* delays, and changes in transfer batch sizes due to poor plant layout and/or material handling, to operating parameters (ex. machine cycle times) and measures of performance of the manufacturing system (ex. takt time)[3].

- ➢ Lacks any worthwhile economic measure for "value" (ex. profit, throughput, operating costs, inventory expenses) which makes it similar to the Flow Process Charting technique used by IE's.

- ➢ Lacks the spatial structure of the facility layout layout, and how that impacts inter-operation material handling delays, the sequence in which batches enter machine queues, container sizes, trip frequencies between operations, etc.

- ➢ Tends to bias a factory designer to consider only continuous flow, assembly line layouts, kanban-based Pull scheduling, etc. that are suitable mainly for HIGH volume and LOW variety manufacturing systems[4].

- ➢ Fails to consider the allocations and utilization of an important resource – factory floorspace – for WIP storage, production support, material handling aisles, etc.

- ➢ Fails to show the impact on WIP, order throughput and operating expenses of in-efficient material flows in the facility ex. backtracking, criss-cross flows, non-sequential flow, large inter-operation travel distances, etc.

- ➢ Fails to handle complex BOM's that translate into branched and multi-level Operation Process Charts and Flow Diagrams for the products.

- ➢ Fails to factor queuing delays, multi-order sequencing rules, capacity constraints, etc. into a map[5].

- ➢ Lacks the capability, due to the manual process of creation, for *rapid* development and evaluation of multiple "what if" analyses required to prioritize different

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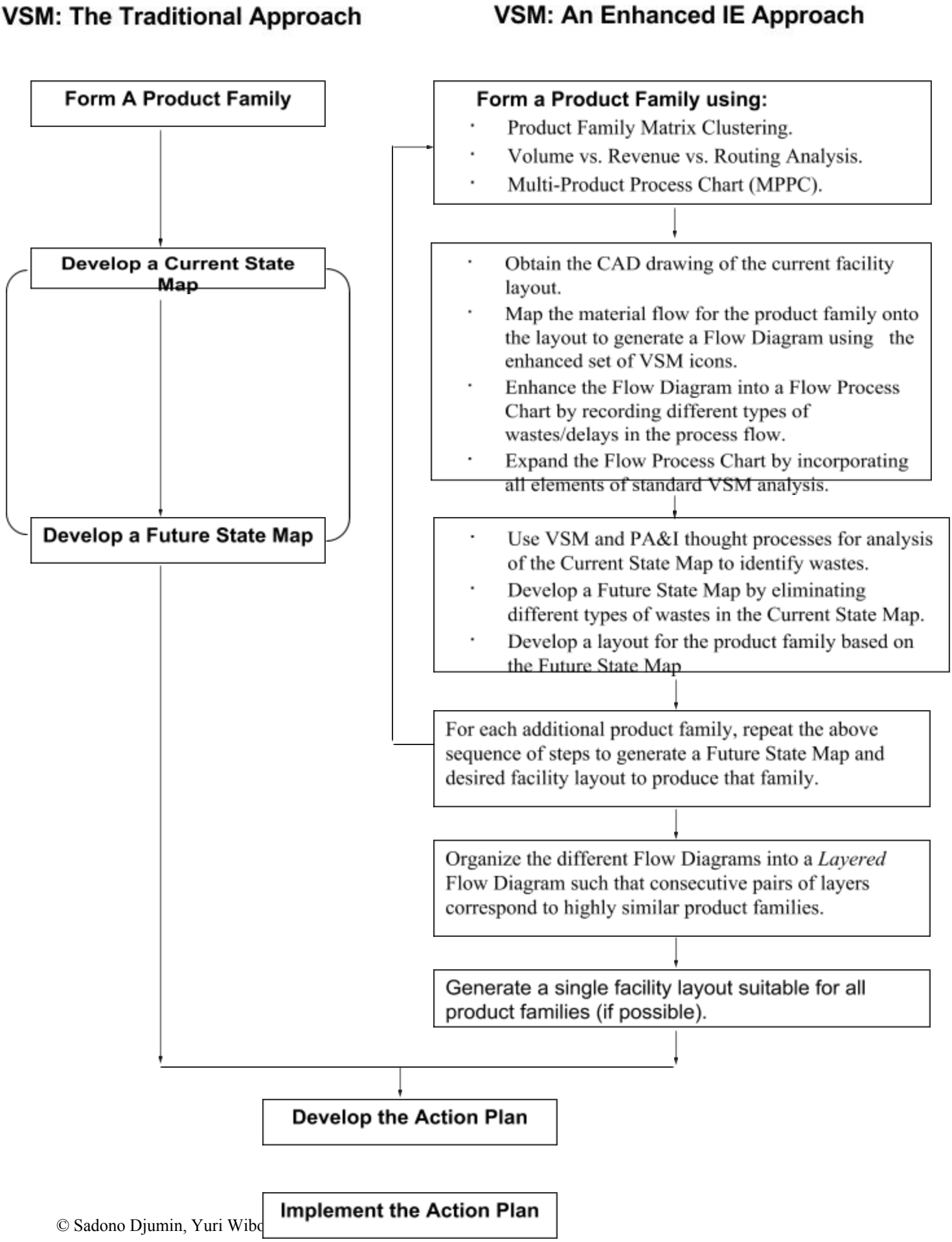
[3] Reasons for this could be (a) because the impact of a poor facility layout on order throughput, product quality and operating costs is assumed to be trivial or (b) superimposing all the information contained in a map onto a CAD drawing of the facility layout would reduce the readability of the map.

[4] These are design and operational strategies that are suited mainly for low-variety high-volume (LVHV) facilities, such as automotive OEM's and their Tier 1 or Tier 2 suppliers, and **not** high-variety low-volume (HVLV) facilities such as jobshops and Make-To-Order companies.

[5] This could be easily and effectively done if computer simulation were used to develop and model the performance of the system represented by any map.

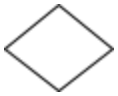
alternatives for improving a Current State Map when time and/or budget constraints exist.

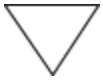


Proposal: An Integrated Set of Icons for Universal Process Mapping

In order to support universal process mapping, a set of icons that is rich in functionality and flexible in application must be developed. The icons contained in each of several IE tools – FPC, BOPC, PA&I – that are similar to VSM are tabulated in Appendices A, B, C, respectively. This study is based on the observation that, while the icons available in the IE tools are similar to those used for VSM, still the VSM icons capture a lot of process flow aspects that the IE tools ignored! Appendix D presents a table that compares the icons in various IE tools with those used for VSM.

The following table presents a potential integrated set of icons for universal process mapping by combining the capabilities of the different tools:

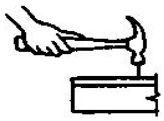
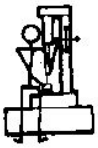
Integrated Icons	Definition
 **OPERATION**	● Occurs when an object (material, semi-finished, or finished product) is intentionally changed in any of its physical or chemical characteristics; is assembled or disassembled from another object; or is arranged for another operation, transportation, inspection, or storage. ● Occurs when information is given or received; when planning or calculating takes place. An operation symbol is also used to represent a person doing work.
  **INSPECTION**	**QUANTITY (VOLUME) INSPECTION** Occurs when a product is examined for identification or is verified for validation of quantity or amount. Measurement of amounts of materials, parts, or products for comparison with the specified amounts to judge whether a discrepancy exists. **QUALITY INSPECTION** Occurs when a product is examined for identification or is verified for quality of any of its characteristics. Testing and visual inspection of materials, parts, or products for comparison with quality standards to judge whether defective (substandard) products are being produced.
 	This icon represents the material movement or transfer from one process to the next ("push"). Push means that a

TRANSPORTATION	**PUSH arrow**	process keeps producing regardless of the actual needs of the downstream process.
	 **PULL arrow**	This icon is used when the product produced is "pulled" in a certain amount or quantity from the supplying process to the supplied process.
	 **CONWIP arrow**	This icon is referred to as CONWIP. It is used in the situation where the supplying process only produces when the buffer in front of a bottleneck process (or pacemaker), that holds work-in-progress (WIP) inventory, allows a space for new inventory to be added. If the WIP buffer is full, the supplying process must stop producing until the next (supplied to) process has used up some of the existing inventory. This will prevent the supplying process from overproducing.
 **STORAGE**	 **Raw Material and Finished Goods**	This icon represents the planned accumulation of inventory at the starting and ending points of the entire product flow that represent the storage of raw material and finished goods inventories, respectively.
	 **Safety Stock**	This icon represents "safety stock" that protects the system against sudden fluctuations in customer demands. It is intended as a temporary, not a permanent storage of stock; hence, there should be a management policy on when to use it.
 **DELAY**	 **WIP accumulation**	This icon represents the unscheduled accumulation of partially finished parts or products. The accumulation is called "unscheduled" when the parts do not have a definite schedule when to be produced next. While mapping, one needs to give a rough estimate on the amount of accumulation of this type of WIP.
	 **Operator Delay**	When mapping the flow of people, this will represent the delays experienced by the operator while processing the product ex. the time wasted while waiting for material to arrive.
INFORMATION FLOW		This is the icon generally used to represent flow of information.
		This icon represents *electronic* flow of information via electronic data interchange ex. telephone, fax, e-mails, etc.

APPENDIX A: FLOW PROCESS CHARTING (FPC) ICONS[6]

<table>
<tr><th>Basic Steps</th><th>Meaning of FPC Icons</th><th>Color Identification[7]</th></tr>
<tr><td rowspan="2">Operation</td><td rowspan="2">OPERATION

• Occurs when the physical or chemical characteristics of an object (material, semi-finished, or finished product) are intentionally changed; or, an object is assembled or disassembled from another object; or an object is arranged for another operation, transportation, inspection, or storage.
• Occurs when information is given or received or when planning or calculations take place.
• Represents the period of time when a person is doing work.

 
Drive nail
 
Mix
 
Drill hole</td><td>Forming, Machining, Treating, etc.

GREEN</td></tr>
<tr><td>Subassembly, Assembly, or Disassembly.

RED</td></tr>
<tr><td>Transportation</td><td>TRANSPORTATION

Occurs when an object is moved from one place to another, except when such movements are a part of the operation or are performed by the operator at the workstation during an operation or an inspection.

Comment: The direction of the arrow does not imply the direction of the actual transportation.

 
Move material by truck
 
Move material by conveyor
 
Move material by carrying (messenger)</td><td>Transportation (or material handling) activities

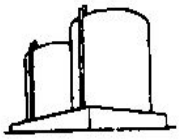
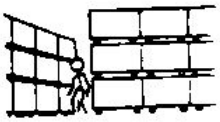
ORANGE
YELLOW</td></tr>
</table>

[6] Source: Niebel & Freivalds, p. 32

[7] The recommended colors are adapted from the International Materials Management Society's Standard Color Codes for use in layout planning and materials handling analyses. These colors are used to classify various areas in the plant. The colors of the different activity areas are particularly useful when attempting to consolidate similar functional activities within a plant, e.g. centralized support functions or centralized storage areas and to identify the extent of floorspace dedicated to non-value adding activities.

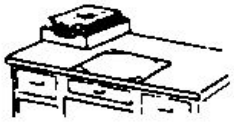
<table>
<tr>
<td rowspan="2">Retention</td>
<td>STORAGE

▪ Occurs when an object is kept and protected against unauthorized removal.
▪ Occurs when materials, parts, or products are accumulated as per a prior plan.

 
Raw material in bulk storage
 
Finished stock stacked on pallets
 
Protective filing of documents</td>
<td>Storage activities

ORANGE YELLOW</td>
</tr>
<tr>
<td>DELAY

▪ Occurs to an object when immediate performance of the next planned action is not immediately permitted.
▪ Occurs when materials, parts, or products are accumulated <u>without</u> a prior plan.

 
Wait for elevator
 
Material in truck or on floor at bench waiting to be processed
 
Papers waiting to be filed</td>
<td>Set down or hold activities

ORANGE YELLOW</td>
</tr>
<tr>
<td>Inspection</td>
<td>VOLUME INSPECTION

Occurs when a product is examined for identification purposes or for validation of quantity or amount against a pre-specified level to assess whether a discrepancy exists.</td>
<td>Inspect, test, check activities

BLUE</td>
</tr>
</table>

QUALITY INSPECTION

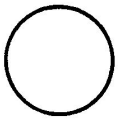
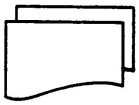
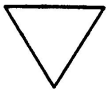
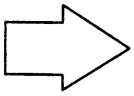
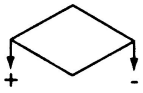
Occurs when a product is examined for identification or verification of an of its quality characteristics against pre-established quality standards to judge whether defective (substandard) products are being produced.

Examine material for quality or quantity

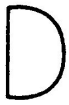
Read steam gauge on boiler

Examine printed form for information

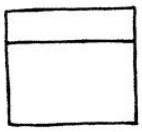
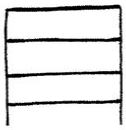
APPENDIX B: BUSINESS AND OFFICE PROCESS CHARTING (BOPC) ICONS[8]

BOPC Icons	Meaning
 **OPERATION**	Used when one performs some function such as matching or reviewing or filling an order, data input to a computer, etc.
 **FORM**	Used when one generates a form or a document. If more than one copy of the form is used, another page is shown behind the first page for each copy.
 **FILE**	Used when one files documents. A "T" could be placed inside the triangle to indicate a temporary file or a follow-up file and a "P" could be placed inside for a permanent file or completed file.
 **TRANSPORTATION**	Used when one physically moves objects other than paperwork ex. material, furniture, document carts, etc.
 **DECISION**	Used when one represents a Yes/No, Go/No Go decision at any point in the process flow where the direction of flow might change depending on the situation or system status.
 **APPROVAL**	Used when one requires management approval to execute a process step.
PAPERWORK FLOW	Used to show flow of information.
 **TELEPHONE**	Used to show flow of information by telephone or computer.
 **PROCESSING**	Used to show computer processing.

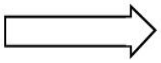
[8] Source: Meyers & Stephens, p. 332.

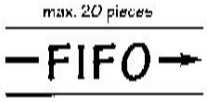
 **DELAY**	Indicates delay in a process, such as waiting for approval.

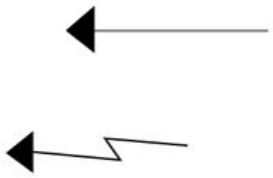
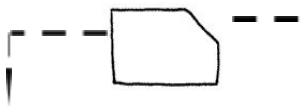
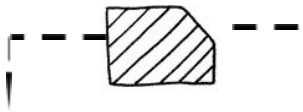
APPENDIX C: VALUE STREAM MAPPING (VSM) ICONS[9]

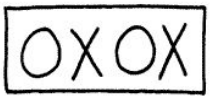
Material Icons	Meaning
 **FACTORY**	This icon represents: ● The supplier (placed in the upper right-hand portion of the map) which is the starting point of material flow. ● The customer/distributor (placed in the upper right-hand portion of the graph) which is the ending point of material flow.
 **MANUFACTURING PROCESS**	This icon indicates a process, operation, machine or department, through which material flows. Typically, to avoid unwieldy mapping of every single processing step, the process box is generally used to indicate one department inside which the material flow is continuous along a fixed path. In the case of an assembly process with several connected and sequential workstations, even if some WIP inventory accumulates between machines (or stations), the entire line would be shown as one process box on the door-to-door map. But, if there are distinctly separate processes, where one process is disconnected from the next process downstream, with inventory between them being transferred in batches, then each process must be assigned its own process box.
 **DATA BOX**	This icon is generally placed under other icons that have significant information/data that will be required for analyzing and observing the system being mapped. Typical information placed in a Data Box underneath FACTORY icons is the frequency of shipping during any shift, material handling information, transfer batch size, demand quantity per period, etc. Typical information in a Data Box underneath MANUFACTURING PROCESS icons: ● C/T (Cycle Time) — time (in seconds) that elapses between one part coming off the process to the next part coming off, ● C/O (Changeover Time) — time to switch from producing one product on the process to another ● Uptime— percentage time that the machine is available for processing ● EPE (a measure of production rate/s) — Acronym stands for "Every Part Every___".

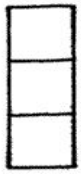
[9] Source: Rother & Shook, Appendix A

	• Number of operators — use OPERATOR icon inside process boxes • Number of product variations • Available Capacity • Scrap rate • Transfer batch size (based on process batch size and material transfer rate)
 **INVENTORY**	This icon represents the accumulation of inventory between two processes. While mapping the current state, the amount of inventory can be approximated by a quick count, and that amount is noted beneath the triangle. If there is more than one inventory accumulation between processes, draw this icon to represent the inventory in each location. This icon is also used to represent storage locations for raw materials and finished goods, since they represent the start and finish of the material flow for producing any product in a facility.
 **FINISHED GOODS TO CUSTOMER**	This icon represents the movement of raw materials from suppliers to the Receiving dock/s of the factory. Or, the movement of finished goods from the Shipping dock/s of the factory to the customer/s.
 **TRUCK**	This icon represents the type of transportation mode being used inside or outside the facility. The frequency of shipping is recorded inside the icon.
 **PUSH**	This icon represents the "pushing" of material from one process to the next process in a manufacturing routing. Push means that a process produces something regardless of the actual needs of the downstream process that will consume its outputs.
 **SUPERMARKET**	This icon represents an inventory "supermarket" (or buffer). Depending on the predictability of the customer demand, the material flow through the system might be continuous (one-piece flow). If the demand is fairly predictable, then the flow of the product could be continuous, thereby eliminating the need for a supermarket. However, when continuous flow (one-piece flow) fails in a system and the upstream process must operate in batch mode, then this icon should be located between two processes in order to (a) halt overproduction and (b) provide visual feedback on customer requirements. The storage capacity of the supermarket for various items in inventory will control the amount of product withdrawals from the supermarket, either to supplying or receiving processes.

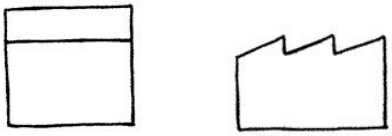
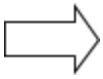
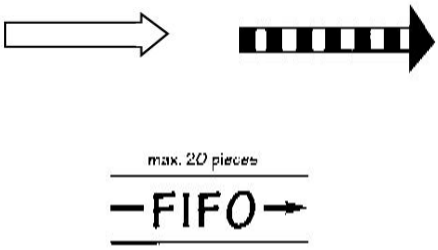
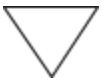
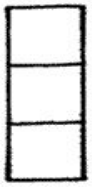
 **PULL WITHDRAWAL**	This icon indicates that a "pull" system of material flow control being used to connect a SUPERMARKET icon with the manufacturing process that supplies product into the supermarket.
 **FIRST IN FIRST OUT (FIFO)**	This icon is synonymous to CONWIP (constant work in process). It is used where the supplying process only produces when the FIFO storage lane has an empty space for new product additions. If the FIFO lane is full, then the supplying process must stop producing until the next process has used up some of the inventory stored in the lane. This will prevent the supplying process from overproducing. The maximum quantity in the FIFO lane should be recorded.

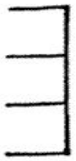
Information Icons	Meaning
 **INFORMATION FLOW**	These icons capture the information flows in any map. The icon representing the general flow of information icon is simply a straight arrow. The wiggle arrow represents the *electronic* flow of information via electronic data interchange (EDI), the Internet, Intranets, LANs (local area network), WANs (wide area network), etc. The latter icon is generally accompanied by a small box in the arrow, indicating the frequency of information/data interchange, the type of media used ex. fax, phone, etc. and the type of data exchanged.
 **PRODUCTION KANBAN**	This icon triggers production of a pre-defined number of parts. It is used as a signal for a supplying process to feed and provide parts to the next (consuming) process. It is also referred to as "one per container" kanban. It is a card or device that tells the supplying process the quantity and gives permission to do so.
 **WITHDRAWAL KANBAN**	This icon represents a "shopping list". It is a note card or device that instructs the material handler to get and transfer parts from a supermarket to the receiving process. The material handler (or operator) will go to the supermarket and withdraw the desired number of parts needed at the receiving process.
 **SIGNAL/TRIANGLE KANBAN**	This icon is used whenever the on-hand inventory levels in the supermarket between two processes drops to a trigger or minimum point. When a Triangle Kanban arrives at a supplying process, it signals a changeover and production of a predetermined batch size of the part noted on the Kanban. It is also referred as "one-per-batch" kanban. It signals when reordering is necessary. It is used when the supplying process must produce in batches because changeovers are required.

 **SEQUENCED –PULL BALL**	This icon represents a pull system that gives instruction to subassembly processes to produce a predetermined type and quantity of product, typically one unit, without using a supermarket.
 **LOAD LEVELING**	This icon is a tool to batch kanbans in order to level the production volume and mix over a period of time.

General Icons	Meaning
 **KAIZEN LIGHTENING BURST**	These icons are used to highlight improvement needs and plan kaizen workshops at specific processes that are critical to achieving the Future State Map of the value stream.
 **SAFETY STOCK**	This icon is used to represent an inventory "hedge" (or safety stock) against problems such as downtime, to protect the system against sudden fluctuations in customer orders or system failures. Notice that the icon is closed on all sides. It is intended as a temporary, not a permanent storage of stock; thus; there should be a clearly-stated management policy on when such inventory should be utilized by operators.
 **OPERATOR**	This icon represents an operator. It is usually placed in a MANUFACTURING PROCESS box to indicate the number of operators working at a particular workstation.

APPENDIX D: COMPARISON OF INDUSTRIAL ENGINEEERING TOOLS AND VSM ICONS

Industrial Engineering Icons	VSM Icons
 **Operation** This icon is more specific about any operations performed in a department or between two departments.	 In VSM, both icons represent operations, processes, or process departments.
 **Quality and Quantity Inspection**	In VSM, there is no specific icon for inspection.
 **Transportation** Does not describe the type of material flow occurring between operations/processes.	 Describes the type of material flow (Push, Pull, or CONWIP)
 **Storage** This icon represents a scheduled accumulation of materials, parts, and products. The type of inventory could be: ● Raw materials ● WIP ● Finished goods ● Safety stock	 This icon is used only to represent safety stock to safeguard against any fluctuations that might occur in the system. In VSM, this is distinguished from Work-In-Progress (WIP) that is viewed as "bad" inventory (and should be reduced), whereas safety stock is viewed as "good" inventory and should be kept under lock and key. Typically, this means getting permission from a high-level manager, who might want to study the

	need for using safety stock using a Root Cause Analysis and identify solutions before giving any permission to access this safety stock  This supermarket icon is very similar to the icon for safety stock. They are similar in that both represent partially finished parts (or products). The difference between them is that the SUPERMARKET icon is usually linked to the Pull system of scheduling using PRODUCTION or WITHDRAWAL kanbans.
 **Delay** This represents any unscheduled accumulation of materials, parts, and products in any process flow. Examples of such accumulation are: ● Work-In-Progress (WIP) ● Parts queued up before a machine ● Delay/ idle time of the operator	 This icon also represents WIP accumulation in VSM; however, it also records the amount of inventory accumulated. It is also used to represent storage locations for raw material/s and finished good/s.

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"What is the Theory of Constraints, and How does it compare to Lean Thinking?" http://www.lean.org/Lean/Community/Resources/thinkers2.cfm.