Value Network Mapping (VNM): Visualization and Analysis of Multiple Flows in Value Stream Maps

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Abstract

A 'Value Stream' (VS) is "all the actions (both value-added and non-value-added) currently required to bring a product through the main flows essential to every product" (Rother & Shook, 1999, p. 3). The process of mapping the material and information flows of all components and subassemblies in a value stream that includes manufacturing, suppliers, and distribution to the customer is known as Value Stream Mapping (VSM). VSM has proved effective in identifying and eliminating waste in a facility with similar or identical product routings, such as in assembly facilities. Using VSM, many companies have changed their existing facility layouts, material handling, inventory control, purchasing and scheduling systems to reduce the total throughput times of parts and current levels of work-in-process (WIP) inventories.

However, the developers of VSM acknowledge that many value streams have multiple flows that merge. This would typically be the case in Make-To-Order jobshops that make products with complex BOM's, such as welded fabrications, furniture, stamping dies, etc. In order to map multiple flows in a value stream, Rother & Shook suggest to "draw such flows over one another. But do not try to draw every branch if there are too many. Choose the key components first, and get the others later if you need to" (Rother & Shook, 1999, p. 19). Instead of this "sampling" step in VSM, this paper introduces an alternative approach – Value Network Mapping (VNM) – that is able to map the complete network of flows in the value stream corresponding to a complex product BOM (Bill Of Material). Our approach integrates basic Industrial Engineering (IE) tools for material flow mapping, such as the Multi-Product Process Chart (M-PPC) and From-To Chart, with a software package for material flow analysis, PFAST (Production Flow Analysis and Simplification Toolkit). In particular, the software is effective for visualization and analysis of multiple flows in a value stream that has *products with dissimilar routings that share common resources*. Also, unlike standard VSM, the proposed approach helps to view a value stream at any and all levels of assembly in a product BOM. Lastly, this approach supports facility improvements to merge/streamline multiple flows in the facility, such as the creation of manufacturing cells and improvements in the current material handling methods. The development and benefits of this approach are demonstrated using results from a pilot study done in a local welding fabrication jobshop.

Outline of this Paper

First, the concept of Lean Thinking is introduced and reviewed. This is followed by an explanation of the basic concepts of Value Stream Mapping (VSM), with a listing of the advantages and disadvantages of VSM. Specifically, it is shown that the original VSM methodology breaks down in the case of "multiple flows in a value stream that merge" in the case of complex product BOMs. Next, the development of the proposed approach, Value Network Mapping (VNM), is explained in detail. Finally, the results from an industry project are analyzed and the potential benefits of the proposed approach are presented.

Introduction

Lean Thinking, a concept that is based on the Toyota Production System, extends continuous improvement efforts to reduce the costs of serving customer/s beyond the physical boundaries of a manufacturing

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facility, by including the suppliers, distributors and production system that support the manufacturing function (Figure 1). These improvements and cost reductions are achieved by eliminating the *muda* (wastes) associated with all activities performed to deliver an order to a customer. Wastes are defined as "all activities that consume resources (add costs to the product) but contribute zero value to the customer." According to Jim Womack and Dan Jones, there are five steps for implementing *Lean Thinking* in an enterprise: 1) Define Value from the perspective of the Customer, 2) Identify the Value Streams, 3) Achieve Flow in the facility, 4) Schedule production using Pull, and 5) Seek Perfection through Continuous Improvement. 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).

Basic Concepts of 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 (Figure 1). 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 VSM template. The (material) flow path of the product will be traced back from the final operation in its routing to the storage location for raw material. Relevant data for each operation, such as the current schedule (push, pull, and order dispatching rules in effect at any process ex. FIFO) and the amount of inventory in various queues, 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 wastes in a stream. This takt time is mostly used as an ideal production rate for each operation to achieve. Ideally, the cycle time for each operation should be less than or equal to 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 for a lean value stream (Rother & Shook, 1999, 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 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 which determines the production rate at which each processing stage in the manufacturing system should operate.

- Helps to unify several IE techniques for material 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* icons 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 time 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 VSM

- Fails to map multiple products that do not have identical material flow 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 (ex. takt time)[2] of the manufacturing system.

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

- Lacks the spatial structure of the facility layout, and how that impacts inter-operation material handling delays, the sequence in which batches enter the queue formed at each processing step in a stream, 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 (HVLV) manufacturing systems[3].

- Fails to consider the allocations and utilization of an important resource – factory floor space – 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 flows, large inter-operation travel distances, etc.

- Fails to handle complex product BOM's, branched and multi-level Operation Process Charts and Flow Diagrams that result in complex value streams.

- Fails to factor queuing delays, sequencing rules for multiple orders, capacity constraints, etc. in any map[4].

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[2] 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.

[3] 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.

[4] This could be easily and effectively done if computer simulation or a Finite Capacity Scheduling (FCS) software were used to develop and model the performance of the system represented by any map.

- Lacks the capability, due to the manual mapping method, for *rapid* development and evaluation of multiple "what if" analyses required to prioritize different alternatives for improving a Current State Map when time and/or budget constraints exist.

Industrial Application of VSM in a Fabrication Jobshop

C.O.W. Industries, Inc. (http://www.C.O.W.ind.com) is a fabrication jobshop specializing in the manufacture of precision metal products. The 75,000 sq. ft. facility contains fabrication, machining and welding equipment. The company produces a variety of products, ranging from large equipment cabinets to small turned parts. Process capabilities include punching, grinding, turning, milling, forming, and painting. A typical finished product consists of multiple unique components produced in the Press shop that are welded into a single unit. Hence, the material flow network for any welded product provided the opportunity to study value streams with multiple flow paths that merged into a single path after the welding step. The traditional VSM method was found inadequate for mapping such a flow network. hence, the proposed approach of Value Network Mapping (VNM) was developed, applied and tested for general use in similar manufacturing facilities.

Limitations of Value Stream Mapping

The product used for this study was an equipment cabinet, ED1M009-32, that was recommended by the client company. This particular product belonged to a family of similar products and accounted for a significant proportion of the annual production volume and sales of the company[5]. The cabinet consists of twenty-one components. Each component has a unique sequence of operations that require a large variety of processes.

The basis for development of a Current State Map for a value stream is the manufacturing routing that specifies the sequence of workcenters that must be visited in order for that product to be produced. However, when the authors began to draw the Current State Map for the above-mentioned multi-component fabricated product using the standard VSM method, the following difficulties were encountered:

- Given the large number of manufactured components, it was difficult to map each of their unique flow paths on a single 11 x 17 sheet of paper. To address this problem, Rother and Shook suggest that "(when) many value streams have multiple flows that merge ….. do not try to draw every branch if there are too many. Choose the key components first, and get the others later if we need to" (Rother & Shook, 1999, p. 19). However, no decision-making process is suggested to select a subset of key components to map. Also, if the components and sub-assemblies in the end-product are not completed and made available in appropriate "kits" as necessary, then the welding and subsequent assembly steps could not be executed.

- Given the large number of manufactured components, it was difficult to map each of their unique flow paths on a single 11 x 17 sheet of paper. Rother and Shook suggest that "(when) many value streams have multiple flows that merge, draw such flows over one another" (Rother & Shook, 1999, p. 19). However, in order "to draw one flow over another", one needs to identify which flow paths are identical, similar or non-identical. This task is non-trivial and cannot be done manually for any but the simplest of fabricated products. An additional drawback of this "aggregation" will arise when generating the timeline for compiling the production lead time for a fabricated product. The scheduling-related delays that occur when multiple activities in a complex product must

[5] In the case where a company does not a priori recommend a particular product for VSM, it would be necessary to select the product (or group of similar products). A new data analysis technique – PQRS Analysis – has been developed by the authors that simultaneously considers Quantity (or Volume), Routing (or Operation Sequence) Similarity and Revenue (or Sales) information for the products. Note that the Routing Similarity Analysis (or P-R Analysis) is equivalent to the Product-Process Matrix Clustering step.

access one or more common resources cannot be accounted for using a pencil-and-paper technique[6].

- In many multi-product manufacturing facilities, there is significant backtracking observed in the flow paths of several products. This occurs when the same process/workcenter is required for multiple non-consecutive operations in a manufacturing routing. In such situations, should the process box be duplicated in the map or should the material flow travel back to the previous machine? The current VSM methodology does not explain how to represent this case in the Current State Map.

- VSM does not incorporate the material handling information between any and every pair of consecutive process boxes, such as transfer batch size, frequency of product batch transfers between the two process locations, type/s of equipment used for material handling, travel distance and travel time. In practice, the material handling delays between consecutive process steps contribute a significant portion of the Non-Value Added time in the production lead time for a product. And, if the cycle time for material handling between any two process steps is not matched with the process cycle times, then it would be difficult to complete orders at a rate specified by the takt time. This mismatch between material handling rates and process cycle times results in inventory buffers being observed at each process box in a Current State Map.

Based on the above limitations of the standard VSM methodology described in Rother & Shook, the authors have developed an alternative method – Value Network Mapping (VNM) – that extends the current VSM methodology to handle fabricated products with complex BOMs. Specifically, the new approach (a) helps to identify and merge multiple flow paths in a value stream that are either identical or similar and (b) considers *all* in-house and outsourced parts that constitute the BOM and assembly structure of the product *instead of focusing on " the key components first"*.

Value Network Mapping (VNM): An Enhancement of Value Stream Mapping for Jobshops

Value Network Mapping (VNM) was developed to eliminate the limitations imposed on the traditional methodology when "many value streams have multiple flows that merge". A Current State Map for a single component (or assembled product) is built upon the manufacturing routing (or Assembly Operations Process Chart) for the component (or product). Hence, VNM utilizes algorithms for clustering of similar manufacturing routings and design of facility layouts to identify families of similar routings for which a single composite Current State Map could be developed. In addition, these algorithms utilize special data structures that capture the *complete* assembly structure of the product instead of extracting the key components only. Figure 2 presents a flowchart that gives a step-by-step explanation of the proposed VNM approach and compares it with the VSM approach. Results obtained from an industrial case study to evaluate this approach are also presented. The steps in the VNM approach are explained below

1. *Form a Product Family:* VSM defines a product family as "a group of products that pass through similar processing steps and over common equipment in your downstream processes " (Rother & Shook, 1999, p. 6). Since VSM is a manual diagramming method, the products that have been studied to date have few components in their BOMs and little or no differences in the manufacturing routings of the components contained in the BOMs. Products manufactured by a typical fabrication jobshop will exhibit the properties such as "multiple flows that merge", "flows that are identical or differ by at most one or two process steps" and "mulitple branches in the product BOMs. This is because, even within the family of welded cabinets produced by C.O.W. Industries, Inc., they were found to differ in (a) the components contained in their product BOMs and (b) the manufacturing routings of the components contained in their product BOMs. To form product families, VNM utilizes a combination of the following methods – Product - Process Matrix Clustering, Product - Component Matrix Clustering and PQRS Analysis – that have been computerized using the PFAST (Production Flow Analysis and Simplification Toolkit) package

[6] The interested reader is referred to the websites of state-of-the-art Finite Capacity Scheduling (FCS) packages such as www.preactor.com, www.asprova.com and www.rsbizware.com/rsb_solutions/scheduler/index.htm.

(Irani et al, 2000). Note that this step was not executed in this particular study since the client company had already determined the product to be mapped.

2. *Visualize the Flow:* Using a product BOM and the manufacturing routings of the components in the BOM, the Operations Process Chart for the product can be generated and transformed into a Multi-Product Process Chart (MPPC). When these charts are mapped onto the physical layout of the facility, the Flow Diagram for development of the detailed Value Network Map is generated. For our case study, Figure 3 shows the MPPC for all components and subassemblies in the cabinet. Figure 4 shows the Flow Diagram for this product. Note that the chaotic and congested material flows in the facility, due to the backtracking and crossing of different flow routes, would not have been identified using the simple VSM methodology.

3. *Collect data for the process boxes:* The Flow Process Chart (FPC) is a classic data collection tool used by Industrial Engineers to record all operation, storage, transport, delay and inspection steps in the flow path of a product. The VSM methodology has the unique feature that it records the information flows associated with the material flows in the same map. Hence, VNM utilizes the Enhanced FPC to attach material handling and scheduling-related information to the material flows mapped in the Flow Diagram (Figure 4). For our case study, Figure 5 shows the Enhanced FPC for one component contained in the BOM for the ED1M009-32 product.

4. *Merge similar routings:* This step in the VNM approach facilitates the placement of the process boxes on the 11x17 sheet of paper when developing the Current State Map without sacrificing the exact assembly structure of the complete product. The merging of similar routings helps to "draw similar flows over one another" but reduces the number of process boxes to be drawn on the paper. However, it is important not to lose the overall material flows contained in the Operations Process Chart for the product. This is achieved using the Modified Multi-Product Process Chart (MMPPC) derived from the MPPC. For our case study, Figure 6 shows the complete map of the product generated from Figure 3.

5. *Group Similar Routings into Component Families:* This step in the VNM approach helps to group components with similar manufacturing routings into families. Thereby, one could design multiple component manufacturing cells that would supply parts to the Welding department. This is done using the Machine-Part Matrix Clustering algorithms in PFAST (Irani et al, 2000). For our case study, Figure 7 shows the cluster analysis dendogram generated by PFAST that guided the grouping of components into different families.

6. *Draw the Current State Map:* When drawing the Current State Map, VSM suggests to "choose key components first, and get the others later if needed" (Rother & Shook, 1999, p. 19). However, this would not be recommended when mapping the flows for a welded structure that requires timely delivery of multiple kits, each consisting of several different parts. Using the VNM approach, this mapping of a large number of different flows could be done at two levels: At **Level 1**, we would map the flows of a complete product (or a family of products) using the MMPPCs and Enhanced FPCs generated from their BOMs. At **Level 2**, we would map the flows of components in any family using the MMPPCs, Enhanced FPCs and Cluster Analysis dendograms. Both levels of mapping essentially seek to combine/merge several flow paths in order to generate more compact Flow Diagrams without eliminating any components in a product's BOM. For our case study, Figure 8 shows a VNM at Level 1 for the ED1M009-32 product. Figure 9 shows the VNM at Level 2 for Component Family #1 in Figure 7. A unique feature of the VNMs shown in both figures is the material handling information – distance of travel and equipment used to move parts over that distance – associated with every flow between any pair of machines. Figure 10 presents an alternative representation for the VNM at Level 1 in Figure 8 – the Assembly Operations Process Chart – that shows the optimal flows of components, subassemblies and the final product without losing the assembly structure of the product.

Future Work

The current version of VNM lacks detailed analysis of the material handling systems and processes connecting different pairs of process boxes. Also, unlike the simpler maps produced using traditional VSM, the VNM needs to include information on lot sizing, job sequencing at each process and WIP buildup at each process due to queuing delays. A critical element of future VNMs needs to be the overall system throughput when multiple components and subassemblies require to use capacity-constrained resources at one or more process boxes.

Conclusion

This paper introduced a Value Network Mapping (VNM) approach that, unlike Value Stream Mapping (VSM), is able to map value streams that have multiple flows that merge. VNM utilizes a variety of material flow analysis and product grouping tools that can be executed using a software package called PFAST. Product grouping helps to merge flows whereby it becomes easier to visualize multiple flows in the value stream for a product that has a complex BOM, components with dissimilar routings and components whose routings share several process resources. In addition, VNM utilizes classical IE methods, such as Flow Process Charting and Systematic Handling Analysis, to show how facility layout and material handling make possible the design of "lean" value streams. Future work will focus on enhancing the VNMs to include WIP, cycle time, lot sizing and throughput information required to design the Future State Map.

Acknowledgment

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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.

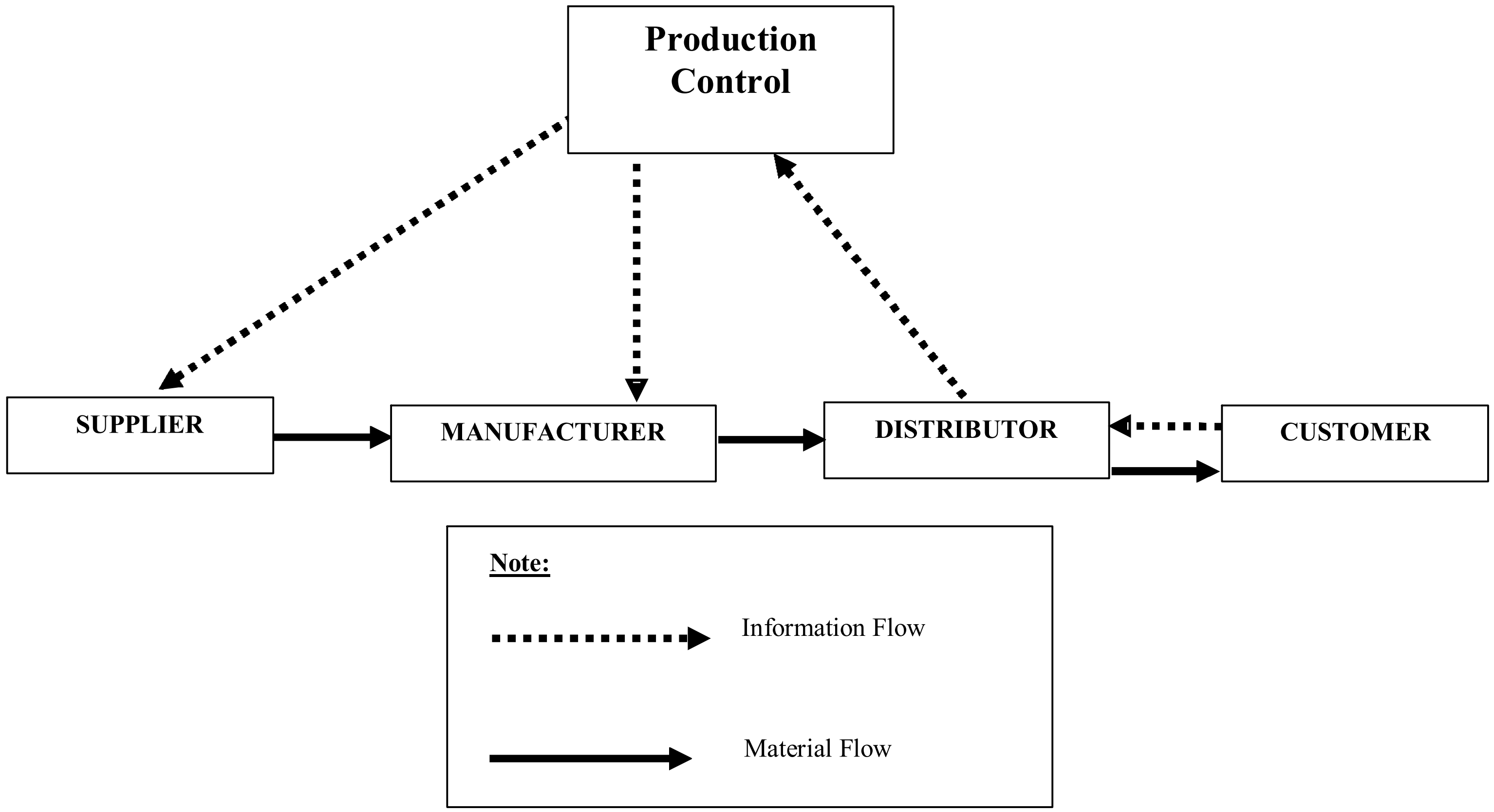

Figure 1 Material and Information Flows in a Supply Chain

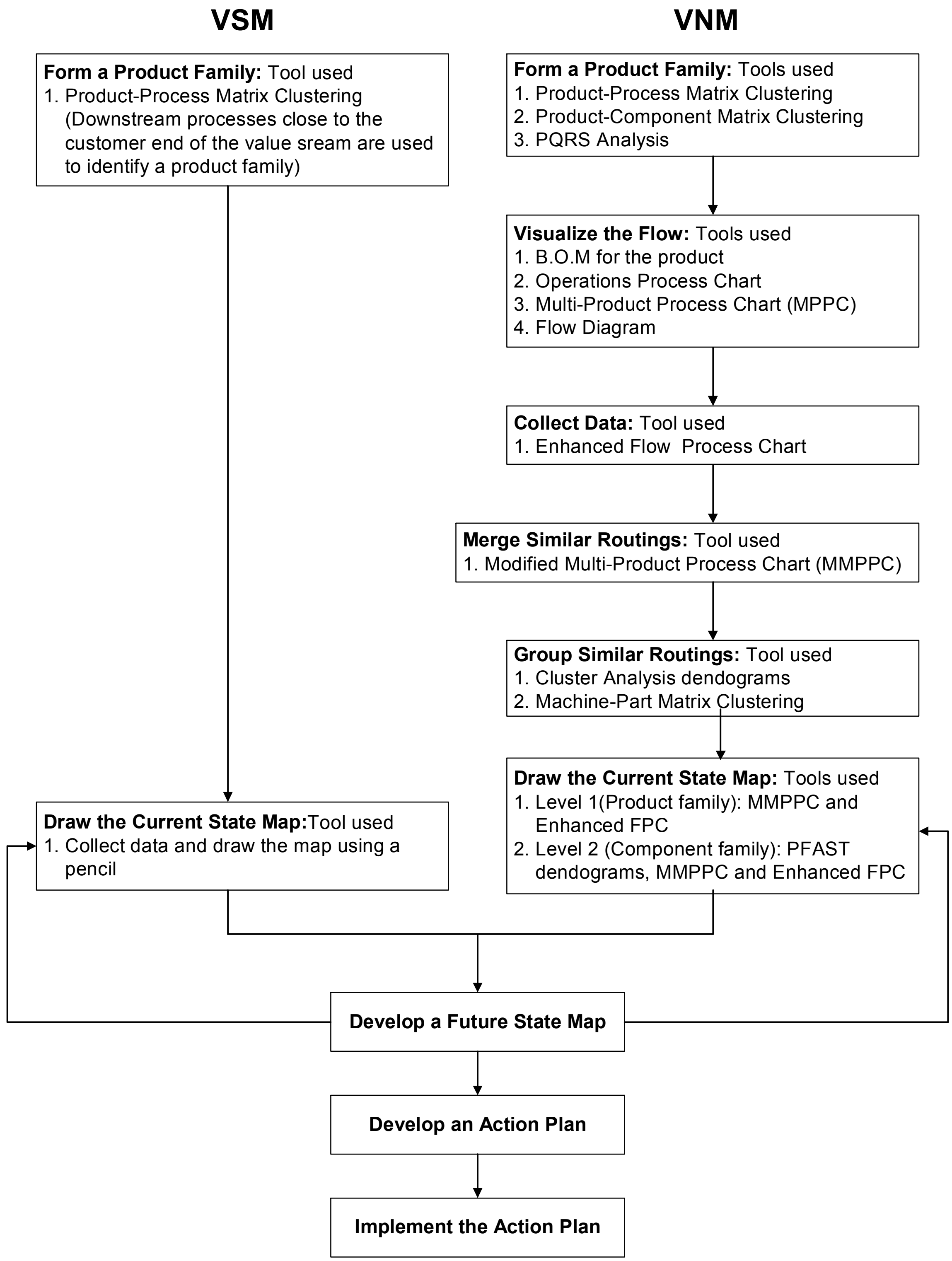

Figure 2 Comparison of Value Stream Mapping (VSM) and Value Network Mapping (VNM)

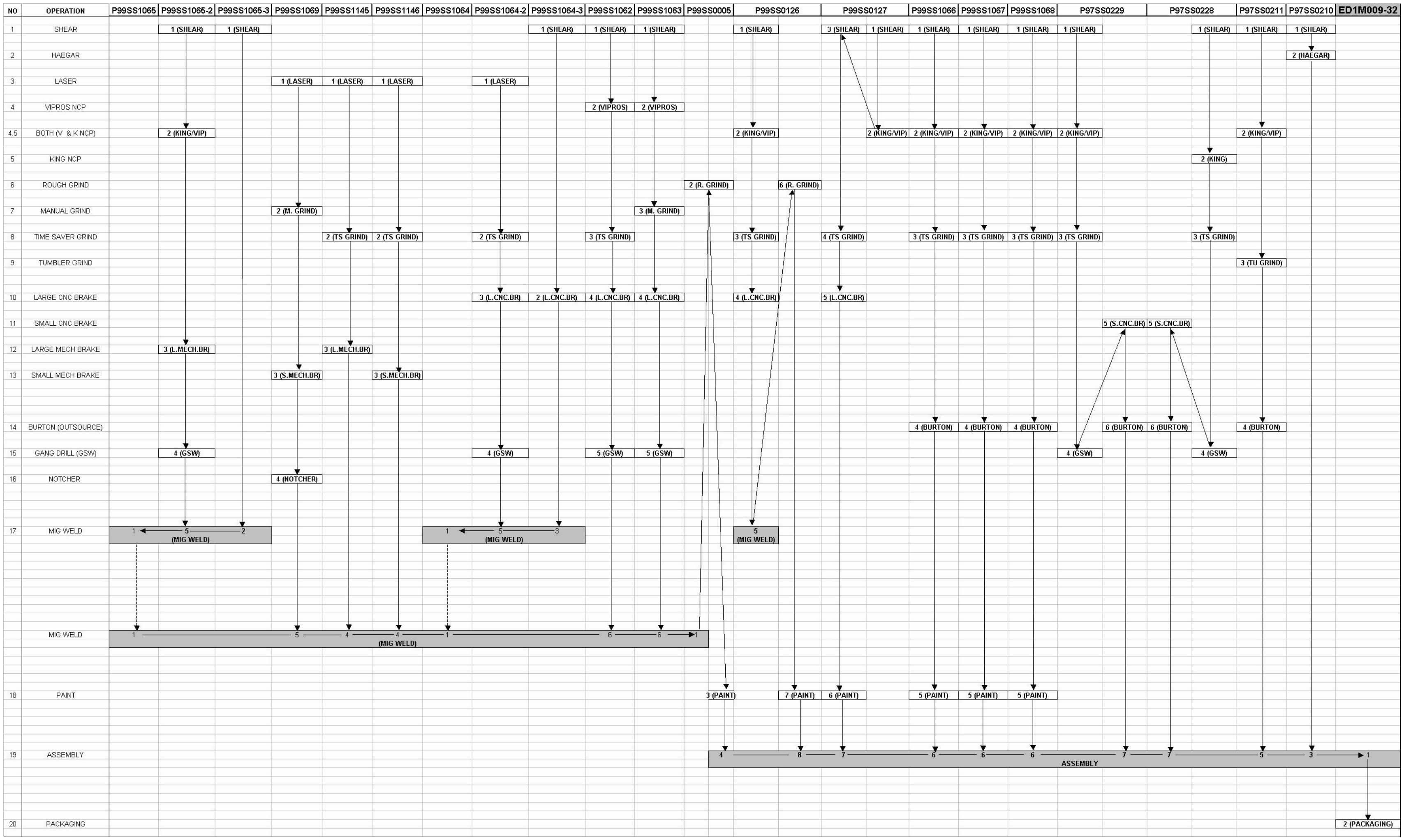

Figure 3 Multi-Product Process Chart (MPPC) for ED1M009-32

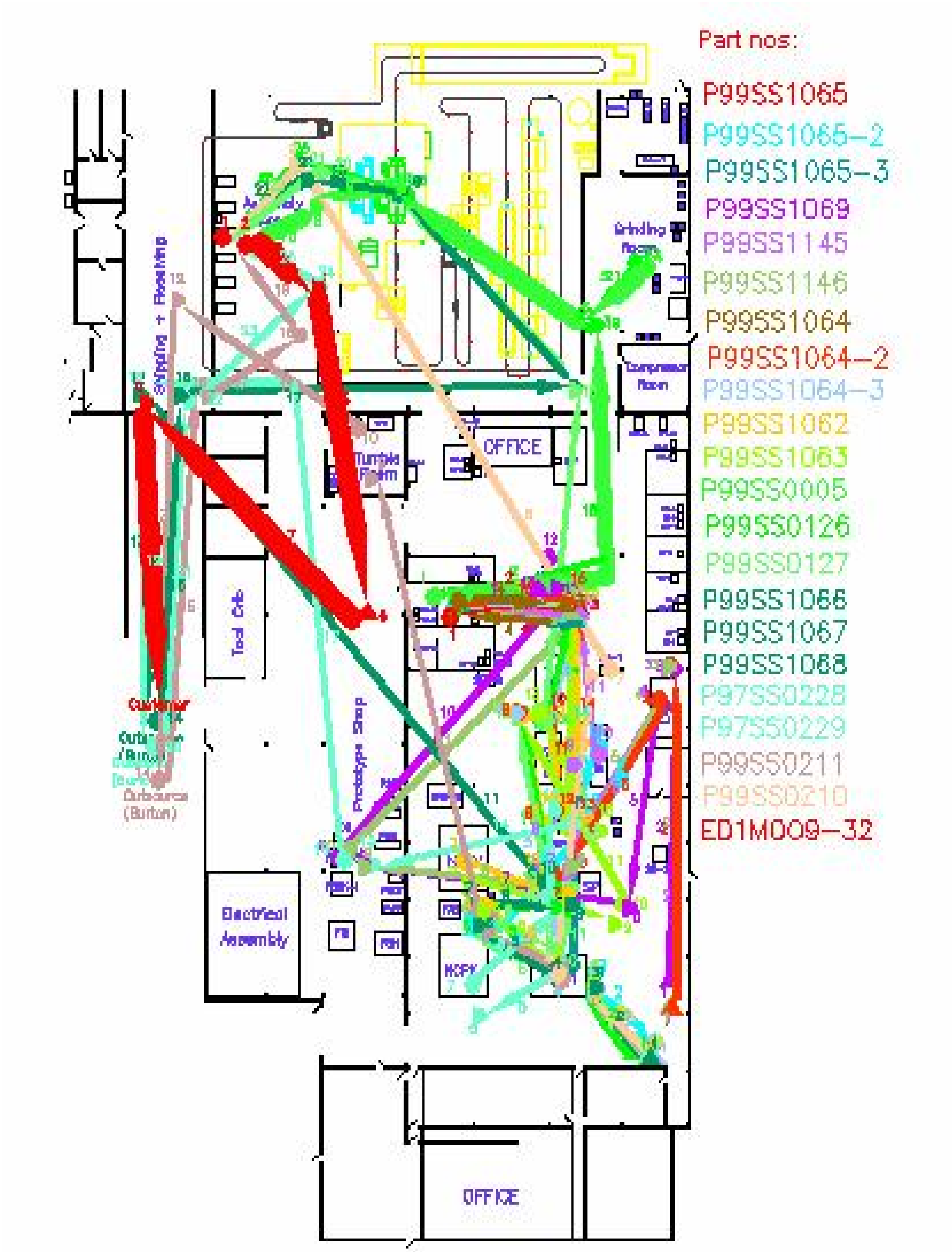

Figure 4 Flow Diagram for ED1M009-32

FLOW PROCESS CHART

Item Charted	ED1M009-32	Top Level	-
		Parent level	-

	Man	✓	Current State	Plant	C.O.W. INDUSTRIES
✓	Material		Proposed Future State (Alternative #)	Project	VSM
			Description of Alternative:	By	YURI WIBOWO, ZAHIRABBAS KHASWALA
				Date	24-May-01
				Sheet	1 of 4

Summary :

ORDER QUANTITY = 15 (average)

TOTAL PROCESSING TIME = 21.78 hrs (Set-up + Process + changeover)

TOTAL TRANSPORTATION TIME = 1.964 hrs

TOTAL INVENTORY TIME = 48 hrs

Summary

Icons	Description	Total
○	Operation	2
⬭	Handling	0
⇨	Transport	3
□	Inspection	0
D	Delay	2
▽	Storage	1

Item Charted	ED1M009-32	Sheet	2 of 4

Step Number	Work Center Number	Icons	Process Name	Specific Description of Actions	Data Box	Information Flow
1	1	● ⬭ ⇨ □ D ▽	ASSEMBLY	ASSEMBLE THE PARTS: **P99SS0126, P99SS0127, P99SS1066, P99SS1067, P99SS1068, P99SS0229, P99SS0211, P99SS0210, P99SS0005, P97SS0228**	JOB SET UP TIME: 0.8 hrs PROCESSING TIME: 2.2 hrs / part. Total: 5.5 hrs / 15 parts / 6 persons CHANGE OVER TIME: 0.0833 hr NO. OF OPERATORS: 6	FPC of P99SS0005 Update WCD by scanning barcode
2		● ⬭ ⇨ □ D ▽	PACKAGING		JOB SET UP TIME: 0.4 hrs PROCESSING TIME: 1 hrs / part. Total: 15 hrs/ 15 parts CHANGE OVER TIME: None NO. OF OPERATORS: 2 Assembly Operator	TRAVELER
3		○ ⬭ ➡ □ D ▽	TRANSPORT	**FROM** : ASSEMBLY TABLE **TO** : WIP LOCATION	TRANSPORT BATCH SIZE: 1 FREQUENCY: 15 EQUIPMENT: Manual Operated by: Assembly Operator TRAVEL DISTANCE: 35' TRAVEL TIME: [Load / Unload : 0.0167 hrs + travel : 0.0167 hrs]*15 = .5 hrs / 15 parts	
	Sub TOTAL	2 0 1 0 0 0				

Figure 5: Enhanced Flow Process Chart (FPC) for ED1M009-32

Item Charted ED1M009-32 — Sheet **3** of **4**

Step Number	Work Center Number	Icons	Process Name	Specific Description of Actions	Data Box	Information Flow
4		○ ⬭ ⇨ □ ◗ ▽	**DELAY** **(WIP)**		QUEUE TIME: 4 hrs (avg) WIP SIZE: 15 (avg) LOCATION: Opposite assembly on the table.	
5		○ ⬭ ➡ □ D ▽	**TRANSPORT**	**FROM** : WIP LOCATION **TO** : FINISHED GOODS STORAGE	TRANSPORT BATCH SIZE: 2 FREQUENCY: 8 EQUIPMENT: Handjack Operated by: Assembly operator TRAVEL DISTANCE: 116'. TRAVEL TIME: [Load / Unload : 0.05 hrs + travel : 0.0333 hrs] * 8 = 0.664 hrs	
6		○ ⬭ ⇨ □ D ▼	**STORAGE** **(FINISHED GOODS)**		QUEUE TIME: 5 days * 8 hrs shift = 40 hrs QUANTITY: 15 LOCATION: Finished goods storage (in the prototype room)	
	Sub TOTAL	0 | 0 | 1 | 0 | 1 | 1				

Item Charted ED1M009-32 — Sheet **4** of **4**

Step Number	Work Center Number	Icons	Process Name	Specific Description of Actions	Data Box	Information Flow
7		○ ⬭ ➡ □ D ▽	**TRANSPORT**	**FROM** : FINISHED GOODS STORAGE **TO** : WIP LOCATION (SHIPPING DOCK)	TRANSPORT BATCH SIZE: 2 FREQUENCY: 8 EQUIPMENT: Handjack Operated by: 1 persons from the shipping dept. TRAVEL DISTANCE: 144' 4". TRAVEL TIME: [Load / Unload : 0.0333 hrs + travel : 0.0666 hrs] * 8 = 0.8 hrs	
8		○ ⬭ ⇨ □ ◗ ▽	**DELAY** **(WIP)**		QUEUE TIME: 4 hrs (avg) WIP SIZE: 15 (avg) LOCATION: Shipping dock, on the floor	
	Sub TOTAL	0 | 0 | 1 | 0 | 1 | 0				

Figure 5: Enhanced Flow Process Chart (FPC) for ED1M009-32 (contd.)

4	6	5	8	10	11	2	3	9	7	1	12	13	14	15	16	17	18	19	20	21	22
P99SS1069	**P99SS1146**	**P99SS1145**	**P99SS1064-2**	**P99SS1062**	**P99SS1063**	**P99SS1065-2**	**P99SS1065-3**	**P99SS1064-3**	**P99SS1064**	**P99SS1065**	**P99SS0005**	**P99SS0126**	**P99SS0127**	**P99SS1066**	**P99SS1067**	**P99SS1068**	**P99SS0229**	**P99SS0228**	**P99SS0211**	**P99SS0210**	**ED1M009-32**
LASER	LASER	LASER	LASER	SHEAR	SHEAR	SHEAR	SHEAR	SHEAR				SHEAR	SHEAR	SHEAR	SHEAR	SHEAR	SHEAR	SHEAR	SHEAR	SHEAR	
MGRIND				VNCP	VNCP	VNCP		LCBRAKE				VNCP	VNCP	VNCP	VNCP	VNCP	VNCP	VNCP	VNCP	HAEGAR	
	TSGRIND	TSGRIND	TSGRIND	TSGRIND	MGRIND	KNCP						KNCP	KNCP	KNCP	KNCP	KNCP	KNCP	KNCP	KNCP		
SMBRAKE	SMBRAKE	LMBRAKE	LCBRAKE	LCBRAKE	LCBRAKE	LMBRAKE							SHEAR						TUMGRIND		
NOTCHER			GANG DRILL	GANG DRILL	GANG DRILL	GANG DRILL						TSGRIND	TSGRIND	TSGRIND	TSGRIND	TSGRIND	TSGRIND	TSGRIND			
												LCBRAKE	LCBRAKE				GANG DRILL	GANG DRILL			
MIG WELD	MIG WELD	MIG WELD	MIG WELD	MIG WELD	MIG WELD	MIG WELD	MIG WELD	MIG WELD	MIG WELD	MIG WELD	MIG WELD	MIG WELD					SCBRAKE	SCBRAKE			
											RGRIND	RGRIND		BURTON	BURTON	BURTON	BURTON	BURTON	BURTON		
									MIG WELD	MIG WELD	PAINT	PAINT	PAINT	PAINT	PAINT	PAINT					
											ASSEMBLY	ASSEMBLY	ASSEMBLY	ASSEMBLY	ASSEMBLY	ASSEMBLY	ASSEMBLY	ASSEMBLY	ASSEMBLY	ASSEMBLY	ASSEMBLY
																					INSPECTION

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Figure 6 Modified Multi-Product Process Chart (MMPPC) for ED1M009-32

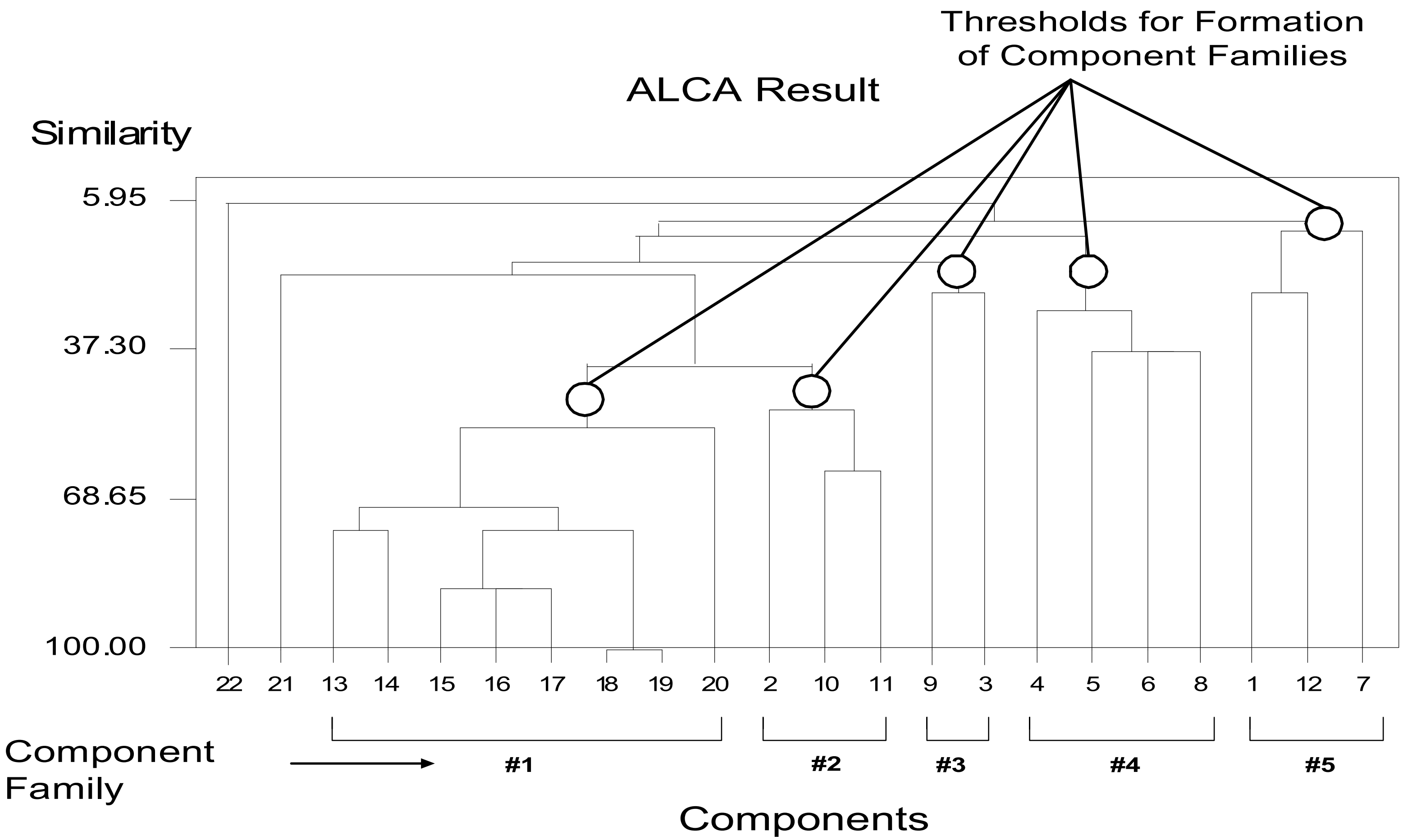

Figure 7 Thresholds for Component Family Formation to generate Level 2 VNMs

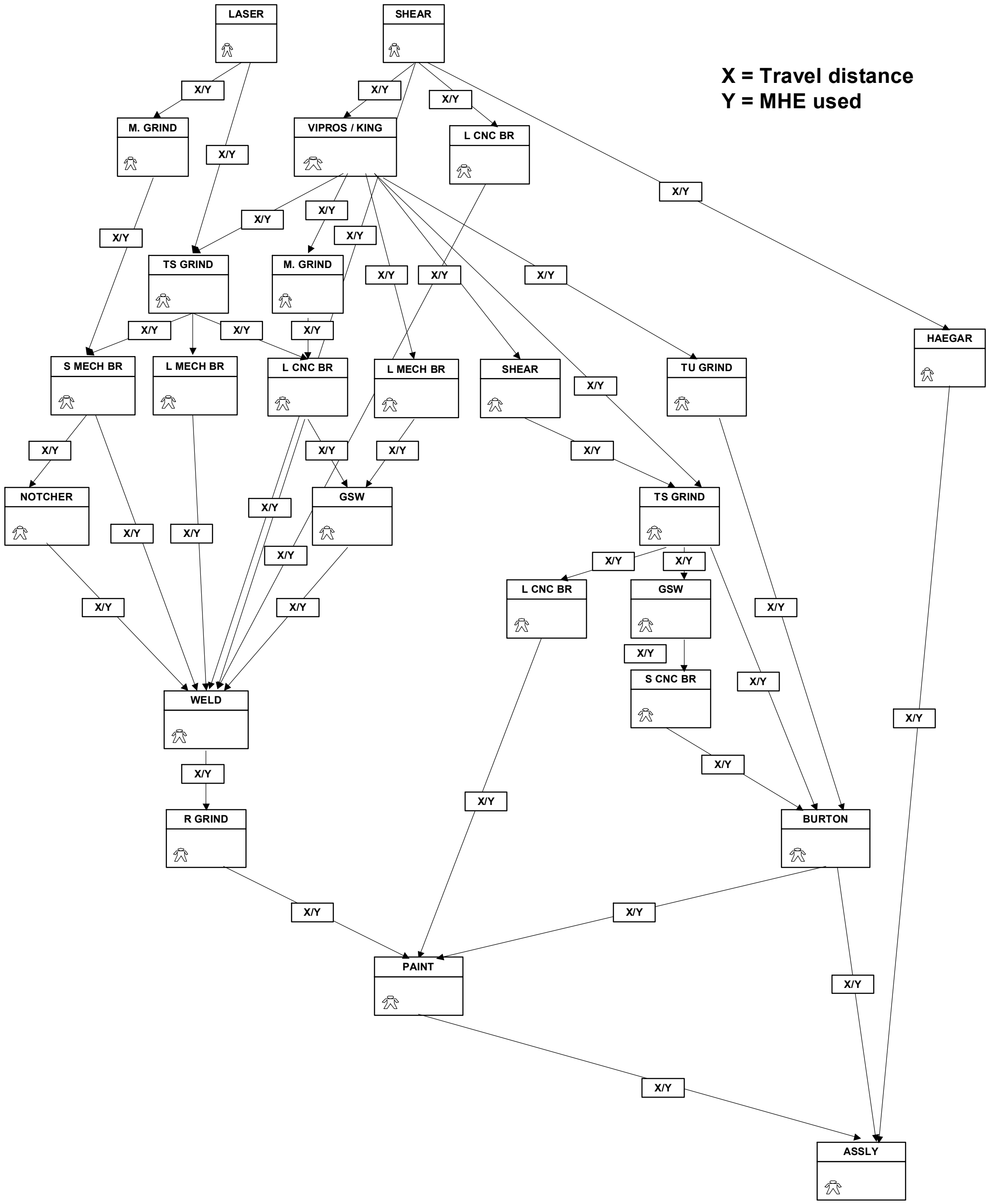

Figure 8 VNM at Level 1 for ED1M009-32

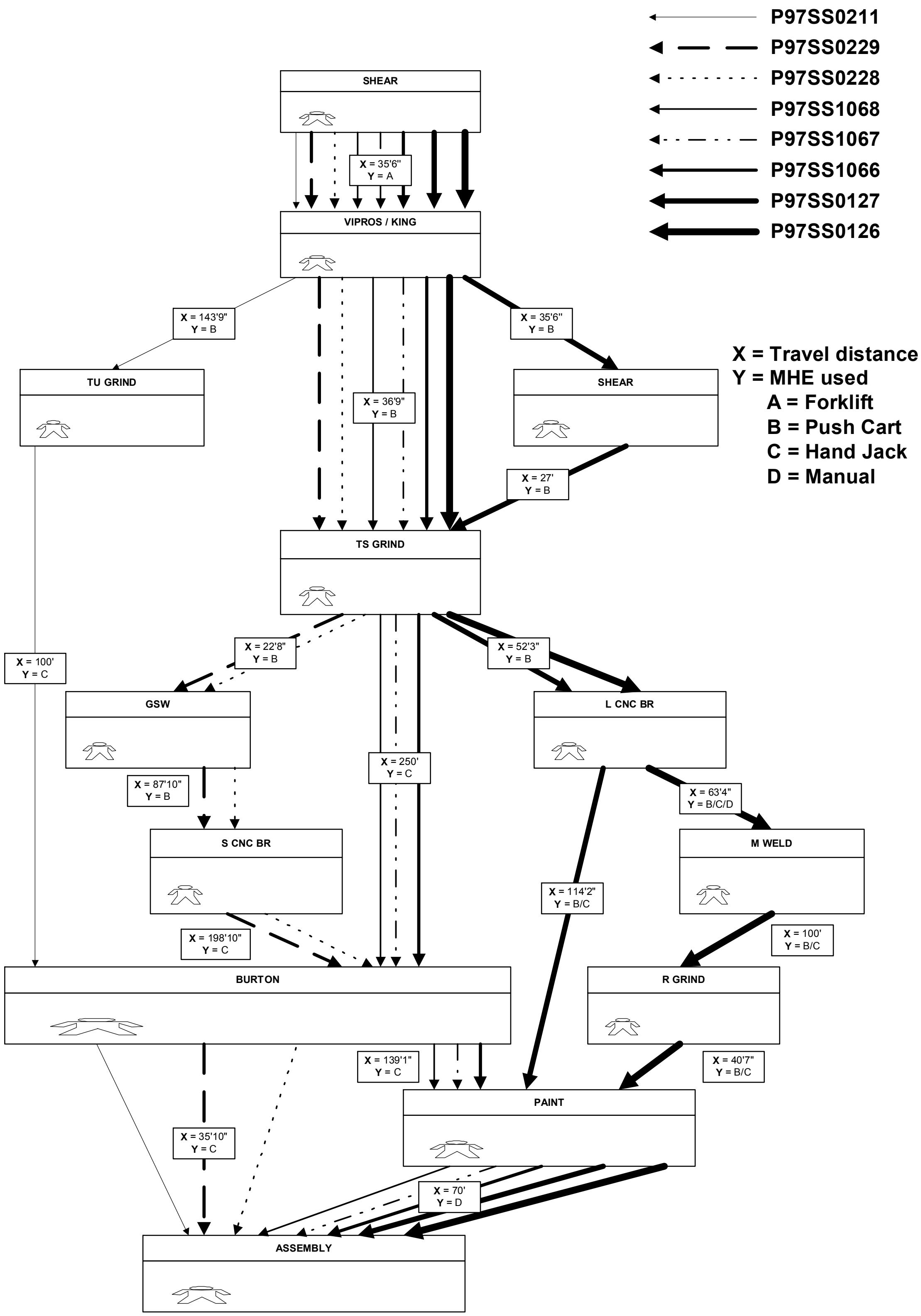

Figure 9 VNM at Level 2 for Component Family #1 for ED1M009-32

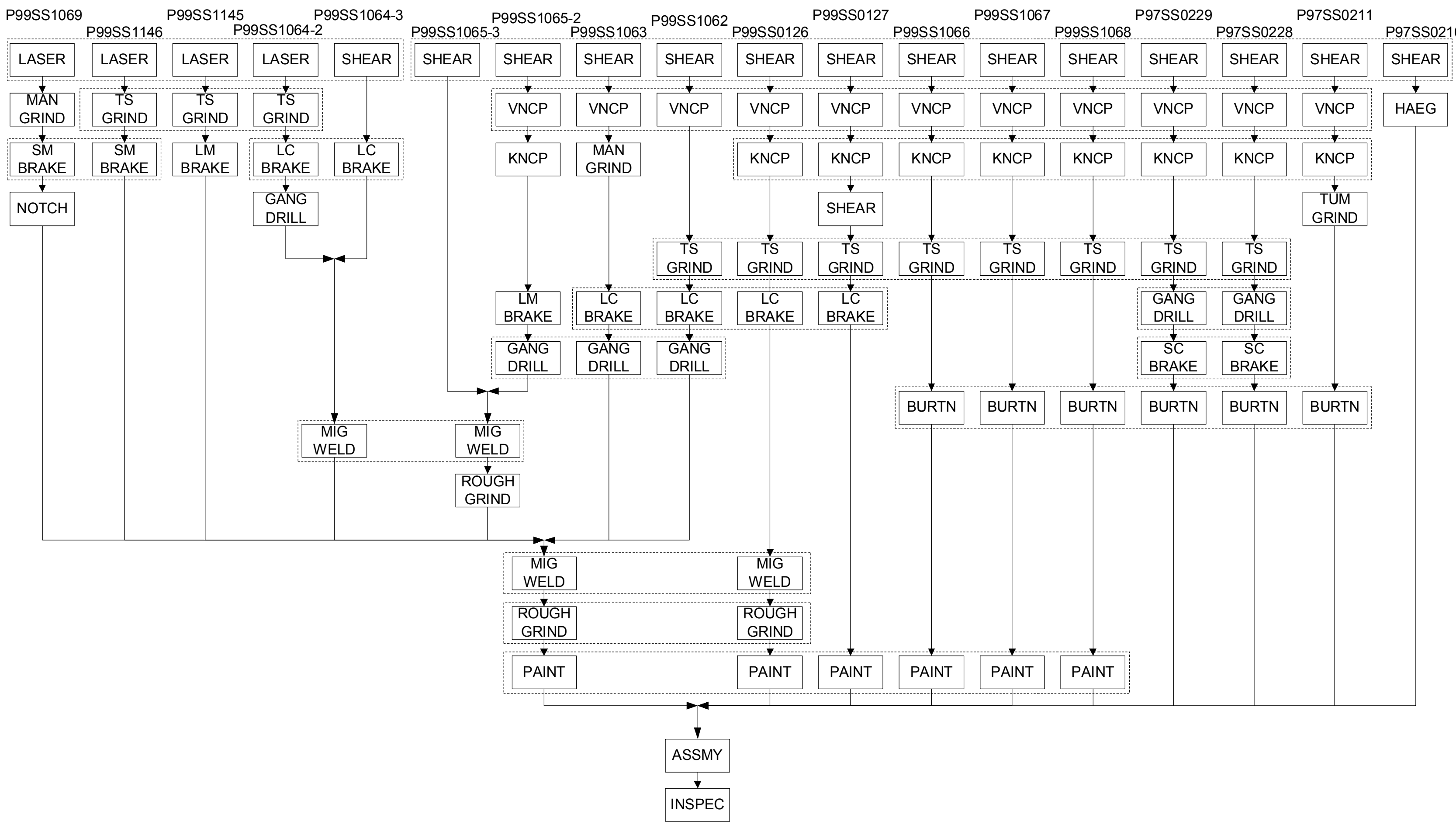

Figure 10 Assembly Operation Process Chart for VNM at Level 1 for ED1M009-32