

Chapter 23

Implementation of JobshopLean in a Forge Shop

In this chapter, we describe a project to introduce JobshopLean in a custom forge shop by implementing a Modular Layout that was designed using PFA (Production Flow Analysis). The strategy for designing a flexible layout for this forge shop was to (1) group as many machines required to produce a part family that could be re-located into Layout Modules¹, (2) locate these modules in close proximity to the monuments, and (3) coordinate workflows between the layout modules using visual triggers, such as designated WIP locations and roving forklift operators who had daily production schedules issued to them.

About Ulven Forging

Ulven Forging was founded in 1971. The company began with open die forging, then gradually added closed die hammer forging, press forging and upset forging. Today it is one of the most versatile forge shops in the US. The forging operation is one of six companies in the Ulven Group. The other companies include a steel foundry, a CNC machining facility, and three companies with proprietary product lines for construction and related industries. The CNC division offers both lathe and mill CNC and manual machining services.

Ulven uses *open die forging* to produce larger-size products, as well as prototypes and short-run quantities. *Closed die hammers* are used to produce longer runs of forgings ranging in weight from ½ lb. to 100 lb. Ulven's *closed die forging* business first exceeded its open die volume in 1996. *Press forging* is used for medium- to high-volume runs and is set up with automatic bar feed systems and induction heating. *Upset forging* is used for both low- to high-volume runs. Parts are forged in a horizontal position where the work piece is gripped between two grooved dies and deformed by a heading die that exerts force to the end of the stock. Examples of upset forgings include axles, rod ends, eye bolts and shafts.

Being a military/government contractor, this custom forge shop had a critical need to be flexible and respond to significant product mix changes without any increase in lead times. A poorly-designed facility layout and high variety of parts resulted in complex material flow control in the shop. This was the primary reason for high manufacturing lead times for delivery of mission-critical parts to defense customers. Some equipment in this forge shop, such as hammers, had significant foundations that made it economically infeasible to relocate them which made them “monuments”. However, the support equipment, such as induction heating and flash trimming, were somewhat more mobile, as were other support operations such as material storage, tool and die storage/repair,

¹ A Layout Module is a small group of machines that could be operated by a single associate, or at least a smaller number of associates than the number of machines. A module is an incomplete cell because all the machines required for the cell could not be moved and co-located into a cell.

material cutting (shear and saw), shot blasting and magnetic particle inspection. Their CNC machine shop was at a separate location.

Data Collection and Preliminary Machine-Part Matrix Analysis

The sample data provided by the company consisted of 530 products and 57 pieces of equipment. To do the PFA analyses, the P-Q-R-\$ (P=Product, Q=Quantity, R=Routing, \$=Sales) information for each product and the attributes for each piece of equipment were collected, as shown in Tables 1(a)-(g) and Tables 2(a)-(b) respectively. Next, the traditional Machine-Part Matrix Clustering (aka Product-Process Matrix Analysis) method was used to find the part families and their corresponding machine groups that are the basis for forming cells. The optimized 0-1 matrix (Figure 1) with “1”s colored to make them visible indicated considerable overlap in the machine requirements of the different part families. This is typical of jobshops and other Make-To-Order manufacturing facilities that make a large variety of products in low-to-medium quantities. Based on this analysis, it was felt necessary to do P-Q Analysis and P-Q-\$ Analysis to segment the product mix. Product Mix Segmentation helped to select a subset of parts from the original population of 530 for more detailed analysis.

Table 1(a) P-Q-R-\$ Information for each Product

Product No.	6-Month Quantity	Sell Price	6-Month Total \$	Product Routings															
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
80-D70865-004				17	21	22	26	29	27	48									
80-A138-1000				17	3	7	12	4	58	55									
80-A138-1001				17	3	7	12	4	53	55									
80-U104-1009				17	3	7	12	4	53	55									
80-U104-1010				17	3	7	12	4	53	55									
80-2303611				17	16	11	10	29	4	55									
80-37B				17	3	7	12	4	55										
80-37C				17	3	7	12	29	28	4	55								
80-A117-1002				17	2	55													
80-A117-1003				17	2	55													
80-A117-1004				17	2	55													
80-A117-1005				17	2	55													
80-A139-1000				17	16	11	10	15	29	53	4	55							
80-13334X				17	39	40	21	22	53	29	4	55							
80-SC300-0417-00				1	16	53	55												
80-B131-1000				17	3	7	12	4	53	55									
80-B131-1005				17	3	7	12	4	53	55									
80-B00909				1	15	54	55												
80-B00910				1	15	54	55												
80-B137-1000				17	39	40	21	22	53	26	29	4	48						
80-B107-1004				17	21	22	48												
80-A37353				17	6	2	11	10	29	54	55								
80-C27416-1				17	6	2	11	10	29	54	55								
80-C27416-2				17	6	2	11	10	29	54	55								
80-C46806-1				17	6	2	11	10	29	54	55								
80-C55581				17	6	2	11	10	29	54	55								
80-C558-1				17	6	2	11	10	29	54	55								
80-D8097				17	6	2	11	10	29	54	55								
80-B113-1001				17	56	57	54												
80-B136-1000				17	3	7	12	4	53	55									
80-200130996N				17	3	7	12	53	55										
80-2016685993				17	39	40	21	24	55										
80-201685993N				17	39	40	21	24	55										
80-202990010N				17	16	11	10	55											
80-204760151N				17	3	7	12	53	55										
80-C153-1000				17	39	40	26	4	55										
80-C150-1000				17	39	40	29	28	53	55									
80-C150-1001				17	3	7	12	4	53	55									
80-C150-1002				17	3	7	12	4	53	55									
80-11SIL				17	21	22	53	26	29	28	48								
80-126600030000				17	39	40	29	53	55										
80-C106-1002				17	39	40	29	28	55										
80-C07E1002-3				17	16	11	10	15	29	28	4	55							
80-100FH				17	21	22	26	53	29	28	48								
80-125FH				17	21	22	26	53	29	28	48								
80-175FH				17	42	41	26	53	29	28	48								
80-C115-1000				17	21	22	26	53	29	28	48								
80-MC860				17	6	2	7	12	42	33	41	57	54	55					
80-MC860AG				17	6	2	7	12	42	33	41	57	54	55					
80-C116-1006				17	43	35	48												
80-C151-1000				17	3	7	12	4	53	55									
80-C151-1001				17	3	7	12	4	53	55									
80-D122-1000				17	39	40	53	57	54	55									
80-D122-1001				17	39	40	53	57	54	55									
80-C0122-P				17	32	31	53	29	28	27	48								
80-D118-ULC0122				17	39	40	21	22	53	29	28	27	48						
80-16-108				17	16	11	10	4	55										
80-E126-1000				17	39	40	29	53	27	48									
80-4003111				1	57	25	52	48	55										
80-4009121				1	57	25	52	48	55										
80-4009262				1	57	25	52	48	55										
80-4009263				1	57	25	52	48	55										
80-4009270				1	57	25	52	48	55										
80-4010346				1	57	25	52	48	55										
80-4010348				1	57	25	52	48	55										
80-4010349				1	57	25	52	48	55										
80-4010350				1	57	25	52	48	55										
80-4010351				1	57	25	52	48	55										
80-4010352				1	57	25	52	48	55										
80-4010809				17	39	40	26	57	55										
80-4010965				17	39	40	26	57	55										
80-4011714				1	26	57	52	48	55										
80-4011725				1	57	25	52	48	55										
80-4012169				1	26	57	52	48	55										
80-4012174				1	26	57	52	48	55										
80-4012179				1	26	57	52	48	55										
80-4012212				1	26	57	52	48	55										
80-4012213				1	26	57	52	48	55										
80-4030339				1	27	9	57	48											

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Table 1(b) P-Q-R-\$ Information for each Product (contd.)

Product No.	6-Month Quantity	Sell Price	6-Month Total \$	Product Routings															
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
80-4030341				1	27	9	57	48											
80-4035144				1	28	50	27	48	55										
80-4035149				1	28	50	27	48	55										
80-4039260				1	28	50	27	48	55										
80-4041707				1	57	25	52	48	55										
80-4049822				17	39	40	21	22	53	29	28	27	48						
80-4049823				17	39	40	21	22	53	29	28	27	48						
80-4056191				17	39	40	21	22	53	29	28	27	48						
80-4059989				1	26	57	52	48	55										
80-4067179				17	39	40	26	57	54	57	55								
80-4103404				17	42	41	26	53	29	28	27	48							
80-4104280				56	1	26	57	55											
80-4123817				17	16	11	10	26	57	55									
80-8001394				17	21	22	57	29	28	57	48								
80-8005665				17	21	22	26	29	28	27	48								
80-8005667				17	21	22	26	29	28	27	48								
80-8005669				17	21	22	26	29	28	27	48								
80-8005911				17	21	22	26	29	28	27	48								
80-E111-1007				17	21	22	26	29	28	27	48								
80-F121-1000				17	3	7	5	57	8	55									
80-F112-1000				17	39	40	26	53	29	28	48								
80-20NV500				17	3	7	5	57	8	55									
80-4030011870964				17	39	40	21	22	53	29	28	4	55						
80-150T084LT				17	6	2	7	12	8	42	41	57	55						
80-G121-1002				17	6	2	7	12	8	42	41	57	55						
80-NL150T060LT				17	6	2	7	12	8	42	41	57	55						
80-NL150T072LT				17	6	2	7	12	8	42	41	57	55						
80-NL150T084LT				17	6	2	7	12	8	42	41	57	55						
80-NL150T096LT				17	6	2	7	12	8	42	41	57	55						
80-NL150T120LT				17	6	2	7	12	8	42	41	57	55						
80-70-2				17	32	31	53	4	55										
80-G122-1000				17	39	40	29	53	4	55									
80-G104-1001				17	39	40	42	41	53	29	28	27	48						
80-G104-1002				17	39	40	42	41	53	29	28	27	48						
80-G104-1003				17	39	40	42	41	53	29	28	27	48						
80-3249869				17	56	1	17	29	26	54	57	48							
80-121009-00				17	39	40	21	22	55										
80-121188-002				17	39	40	21	22	55										
80-121189				17	39	40	21	22	55										
80-671391				17	16	11	10	26	4	55									
80-121018-00				17	39	40	21	22	55										
80-121052-00				17	16	11	10	53	4	55									
80-121148				1	50	26	27	55											
80-121387				17	39	40	21	22	55										
80-ULC0200				17	39	40	21	22	55										
80-35123				17	39	40	26	53	29	28	27	48							
80-36551				17	21	22	53	29	28	27	48								
80-9033704				54	57	48	55												
80-H128-1000				17	3	7	12	57	53	55									
80-1896-9057C-1				17	39	40	8	4	55										
80-6547J				17	39	40	42	41	30	29	14	57	55						
80-8567615				17	14	13	57	55											
80-8567621				17	14	13	57	55											
80-8567636				17	53	13	57	55											
80-C125086G				17	53	13	57	55											
80-C137587G				17	53	13	57	55											
80-C175090G				17	53	13	57	55											
80-C2250936				17	14	13	57	55											
80-C225093G				17	14	13	57	55											
80-C250096G				17	14	13	57	55											
80-H119-25				17	39	40	53	42	41	30	53	57	55						
80-H119-1000				17	39	40	42	41	30	29	14	57	55						
80-H119-1083				17	39	40	53	42	41	30	53	57	55						
80-H119-1099				17	39	40	42	41	30	14	57	55							
80-H119-1143				17	39	40	42	41	30	14	57	55							
80-H119-1151				17	53	21	24	57	48										
80-H119-1152				17	14	13	57	55											
80-H119-2000				17	14	13	57	55											
80-H119-2001				17	53	14	13	57	55										
80-H119-2002				17	53	14	13	57	55										
80-H119-2005				17	53	14	13	57	55										
80-H119-2006				17	14	13	57	55											
80-H119-2007				17	14	13	57	55											
80-H119-2008				17	3	7	12	8	4	55									
80-H119-2009				17	3	7	12	8	4	55									
80-H119-2010				17	39	40	42	41	26	27	53	55							
80-H119-3.25X62				17	6	2	42	41	30	14	8	57	55						
80-H119-3.75				17	3	7	12	8	4	55									
80-H119-3.75X66				17	6	2	42	41	30	14	8	55							

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Table 1(c) P-Q-R-\$ Information for each Product (contd.)

Product No.	6-Month Quantity	Sell Price	6-Month Total \$	Product Routings															
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
80-T6430W				17	39	40	53	42	41	30	53	57	55						
80-T6547G				17	39	40	42	41	30	14	8	4	55						
80-26621				17	3	7	12	29	48										
80-26622				17	3	7	12	29	48										
80-D10-517RCH				17	3	7	12	29	48										
80-90001033				17	21	22	26	53	29	28	27	48							
80-B155				17	16	11	10	4	53	55									
80-J110-1013				17	16	11	27	55											
80-J110-1014				17	16	11	27	55											
80-J110-1015				17	16	11	27	55											
80-J110-1016				17	16	11	27	55											
80-PDR42-F03				17	16	11	10	29	27	55									
80-PDR48-F02				17	16	11	10	29	27	55									
80-PDR48-F03				17	16	11	10	29	27	55									
80-PDR50-F01				17	16	11	10	29	27	55									
80-TR310-F01				17	16	11	10	29	27	55									
80-TR310-F02				17	16	11	10	29	27	55									
80-TR310-F07				17	16	11	10	29	27	55									
80-B107-1000				17	21	22	26	53	29	28	51	48							
80-B107-1001				17	21	22	48												
80-B107-1002				17	21	22	26	53	29	28	51	48							
80-J116-1000				17	39	40	26	53	29	28	27	48							
80-66007				17	39	40	26	53	48										
80-J117-1000				17	39	40	42	41	53	14	26	29	4	55					
80-K110-1000				17	16	11	10	15	53	29	4	55							
80-K108-1003				17	39	40	31	26	53	55									
80-K109-1001				17	16	11	10	15	29	4	55								
80-C0120				17	21	22	26	53	29	28	27	48							
80-C0122				17	39	40	21	22	53	29	28	27	48						
80-19542				17	39	40	21	22	53	29	28	27	48						
80-62695				17	39	40	42	41	53	29	28	27	48						
80-63006				17	39	40	21	22	53	29	28	27	48						
80-63231				17	42	41	26	53	48										
80-6761342				17	39	40	21	22	53	57	55								
80-J62124				17	39	40	21	22	53	57	55								
80-L104-1015				17	39	40	21	22	53	29	28	27	48						
80-L104-1016				17	39	40	21	22	53	29	28	27	48						
80-L104-1028				17	39	40	42	41	53	29	28	27	48						
80-L104-1054				17	39	40	42	41	53	29	28	27	48						
80-L104-1055				17	39	40	42	41	53	29	28	27	48						
80-L104-63244				17	39	40	42	41	53	29	28	27	48						
80-RS25				17	16	11	10	15	53	57	55								
80-RS38				17	16	11	10	15	53	57	55								
80-ULD-0151				17	13	42	41	53	8	4	55								
80-L119-81426				17	6	2	42	41	8	55									
80-L108-1001				17	39	40	21	22	53	29	28	27	48						
80-L108-1003				17	39	40	21	22	53	29	28	27	48						
80-0101295A				17	5	57	4	55											
80-L116-1000				17	39	40	17	26	4	55									
80-L116-1004				17	5	57	4	55											
80-L111-1004				17	3	7	12	57	53	4	55								
80-L111-1008				17	6	2	7	12	42	41	33	57	55						
80-L111-1014				17	3	7	12	57	53	4	55								
80-L125-1000				17	3	7	12	57	4	8	53	55							
80-A140-1000				17	39	40	42	41	53	29	28	26	27	48					
80-501386-0100				17	39	40	42	41	53	29	28	26	27	48					
80-BU7A-516				17	39	40	16	11	10	29	4	55							
80-2776118				17	16	11	10	55											
80-35-B357				17	1	57	4	54	55										
80-M106-1000				17	39	40	42	41	26	29	28	27							
80-M112-1005				17	39	40	21	22	26	53	57	55							
80-M112-1006				17	39	40	21	22	26	53	29	28	27	48					
80-M134-1000				17	3	7	12	8	4	53	55								
80-N103-1008				17	39	40	42	41	53	26	29	28	4	55					
80-N119-1000				17	39	40	42	41	53	26	29	28	27	48					
80-6-064288-001				17	53	55													
80-O100-1002				17	6	2	7	12	42	33	41	29	28	4	54	55			
80-O100-1005				17	39	40	26	29	28	55									
80-O100-1009				17	6	2	7	12	42	33	41	29	28	4	54	55			
80-O100-1011				17	6	2	7	12	42	33	41	29	28	4	54	55			
80-O100-1012				17	6	2	7	12	42	33	41	29	28	4	54	55			
80-O100-1015				17	6	2	7	12	42	33	41	29	28	4	54	55			
80-O100-1018				17	42	41	26	53	29	28	27	48							
80-O100-1019				17	39	40	17	4	53	29	28	55							
80-O100-1020				17	39	40	17	4	53	29	28	55							
80-O101-1000				17	6	2	7	12	42	33	41	29	28	4	54	55			
80-O101-1001				17	39	40	21	22	26	53	29	28	27	48					
80-O101-1002				17	39	40	21	22	26	53	29	28	27	48					
80-O101-1004				17	39	40	42	41	26	29	28	27	53	57	55				

Table 1(d) P-Q-R-\$ Information for each Product (contd.)

Product No.	6-Month Quantity	Sell Price	6-Month Total \$	Product Routings															
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
80-27750-01				17	39	40	42	41	3	7	12	57	54	55					
80-37355-1072				17	6	2	7	12	8	42	41	57	55						
80-37355-1084				17	6	2	7	12	8	42	41	57	55						
80-O104-1008				17	42	41	26	53	29	28	48								
80-135692209D				17	39	40	26	29	28	48									
80-325-921-02C-15"				17	39	40	26	29	28	48									
80-717692209D				17	39	40	26	29	28	48									
80-C5010040				17	39	40	26	29	28	48									
80-LB0492207C				17	39	40	26	29	28	48									
80-P101-1000				17	39	40	26	29	28	48									
80-P101-1001				17	39	40	26	29	28	48									
80-746100010				17	21	22	26	53	21	22	26	29	28	48					
80-P128-1000				17	39	40	42	41	53	29	28	27	57	55					
80-U104-1011				17	3	7	12	8	57	4	53	57	55						
80-051-1				17	1	26	4	54	55										
80-071-50M				1	26	4	54	57	55										
80-071-54				1	4	54	55												
80-8051400053				17	56	1	26	48											
80-R100-1014				17	1	57	26	48											
80-R100-1016				17	1	57	26	48											
80-R100-1017				17	1	57	26	48											
80-R100-1018				17	56	1	26	54	57	26	55								
80-R100-1031				17	1	57	26	48											
80-R100-1032				17	1	57	26	48											
80-R100-1033				17	1	57	26	48											
80-R103-1014				17	1	57	26	48											
80-4707-01				17	3	7	12	57	54	57	55								
80-R-23004				17	1	15	57	54	55										
80-REL-15500				17	3	7	12	57	54	57	55								
80-R134-1000				17	39	40	42	41	29	28	27	53	57	55					
80-R132-480001				17	16	11	10	29	28	4	55								
80-9610320				1	19	20	53	29	28	27	57	48							
80-9610400				17	39	40	19	20	53	29	28	27	57	48					
80-9610680				17	39	40	21	22	53	29	28	27	57	48					
80-9610840				17	39	40	21	22	53	29	28	27	57	48					
80-961260				17	39	40	21	22	53	29	28	27	57	48					
80-9651680				17	53	27	57	48											
80-9652080				17	53	27	57	48											
80-S100-1003				17	39	40	21	22	53	29	28	27	57	48					
80-S141-1003				17	3	7	12	8	53	55									
80-S121-1002				17	39	40	21	22	26	53	29	28	27	48					
80-S121-1003				17	39	40	21	22	26	53	29	28	27	48					
80-12123				17	16	11	10	57	54	55									
80-8653				17	16	11	10	57	54	55									
80-99-327				17	16	11	10	57	54	55									
80-S136-1004				17	39	40	29	28	27	53	55								
80-010401-0				17	39	40	21	22	26	53	29	28	27	48					
80-101011				17	32	31	26	53	29	28	27	48							
80-101991				17	39	40	21	22	26	53	29	28	27	48					
80-102008				17	32	31	26	53	29	28	27	48							
80-102010				17	32	31	26	53	29	28	27	48							
80-102012				17	32	31	26	53	29	28	27	48							
80-103247				17	32	31	26	29	28	27	48								
80-103250				17	39	40	17	26	29	28	4	55							
80-103267				17	39	40	17	4	53	29	28	4	55						
80-103356				17	39	40	17	4	53	29	28	4	55						
80-108513				17	42	41	26	53	29	28	27	48							
80-109014				17	42	41	26	53	29	28	27	48							
80-110006				17	32	31	26	53	29	28	27	48							
80-110012				17	32	31	26	53	29	28	27	48							
80-157000B				1	26	29	28	27	48										
80-191820				17	16	11	10	26	29	28	27	48							
80-191832				17	3	7	12	26	29	28	27	48							
80-191850				17	32	31	29	26	27	48									
80-308070				17	16	11	10	29	28	27	48								
80-308513				17	3	7	12	29	28	27	48								
80-312069				17	42	41	26	53	29	28	27	48							
80-522500				17	16	11	10	26	29	28	27	48							
80-533140				17	3	7	12	29	28	27	48								
80-551500				17	16	11	10	26	29	28	27	48							
80-551611				17	42	41	26	53	29	28	27	48							
80-551616				17	42	41	26	53	29	28	27	48							
80-551652				17	42	41	26	53	29	28	27	48							
80-551703				17	42	41	26	29	28	27	48								
80-551706				17	42	41	26	29	28	27	48								
80-553607				17	42	41	26	53	29	28	27	48							
80-605908A				17	39	40	42	41	26	53	29	28	27	48					
80-605909A				17	39	40	42	41	26	53	29	28	27	48					
80-605910A				17	39	40	42	41	26	53	29	28	27	48					

Table 1(e) P-Q-R-\$ Information for each Product (contd.)

Product No.	6-Month Quantity	Sell Price	6-Month Total \$	Product Routings															
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
80-605912A				17	39	40	42	41	26	53	29	28	27	48					
80-609020SP				17	42	41	26	53	29	28	27	48							
80-611007B				17	32	31	26	53	29	28	27	48							
80-611007P				17	32	31	26	53	29	28	27	48							
80-611008B				17	32	31	26	53	29	28	27	48							
80-611008P				17	32	31	26	53	29	28	27	48							
80-611009B				17	32	31	26	53	29	28	27	48							
80-611009P				17	32	31	26	53	29	28	27	48							
80-611010B				17	39	40	26	53	29	28	27	48							
80-611010P				17	32	31	26	53	29	28	27	48							
80-611012B				17	39	40	26	53	29	28	27	48							
80-611012P				17	32	31	26	53	29	28	27	48							
80-611056B				17	39	40	26	53	29	28	27	48							
80-611056P				17	32	31	26	53	29	28	27	48							
80-611057B				17	39	40	26	53	29	28	27	48							
80-611058B				17	39	40	26	21	22	53	29	28	27	48					
80-611605				17	21	22	26	29	28	27	48								
80-611606				17	21	22	26	29	28	27	48								
80-611711				17	21	22	26	53	29	28	27	48							
80-612008A				17	41	42	26	29	28	27	48								
80-612328				17	41	42	26	53	41	42	29	28	48						
80-612337				17	41	42	26	53	41	42	29	28	48						
80-612418				17	21	22	26	53	21	22	29	28	48						
80-612804				17	16	11	10	51	48										
80-613106				1	50	26	57	55											
80-613107				1	50	26	57	55											
80-616318				17	21	22	26	53	21	22	29	28	48						
80-616321				17	21	22	26	53	21	22	29	28	42						
80-616505A				17	41	42	26	29	28	48									
80-632014B				17	39	40	26	41	42	53	29	28	27	48					
80-632014P				17	39	40	17	27	53	29	28	27	48						
80-632020B				17	6	2	7	12	42	33	29	28	53	48					
80-632020P				17	39	40	17	27	53	29	28	27	48						
80-632028B				17	6	2	7	12	42	33	29	28	53	48					
80-632028P				17	39	40	17	27	53	29	28	27	48						
80-632122B				17	6	2	7	12	42	33	29	28	53	48					
80-632122P				17	39	40	17	27	53	29	28	27	48						
80-784000				17	21	22	26	53	29	28	27	48							
80-784300				17	16	11	10	26	53	29	28	27	48						
80-793410				17	39	40	31	21	22	53	29	28	27	48					
80-793411				17	39	40	31	21	22	53	29	28	27	48					
80-793412				17	39	40	31	21	22	53	29	28	27	48					
80-793416				17	39	40	31	41	42	53	29	28	27	48					
80-793504				17	16	11	10	29	27	48									
80-793508				17	16	11	10	29	27	48									
80-793609				17	39	40	31	21	22	53	29	28	27	48					
80-793610				17	39	40	31	21	22	53	29	28	27	48					
80-793611				17	39	40	31	21	22	53	29	28	27	48					
80-797009				17	39	40	31	21	22	53	29	28	27	48					
80-797109				17	39	40	31	21	22	53	29	28	27	48					
80-810105				17	39	40	31	21	22	53	29	28	27	48					
80-810107				17	39	40	31	21	22	53	29	28	27	48					
80-810108				17	39	40	31	21	22	53	29	28	27	48					
80-810109				17	39	40	31	21	22	53	29	28	27	48					
80-810110				17	39	40	31	21	22	53	29	28	27	48					
80-810112				17	39	40	31	21	22	53	29	28	27	48					
80-810206				17	39	40	31	21	22	53	29	28	27	48					
80-810211				17	39	40	31	21	22	53	29	28	27	48					
80-810212				17	39	40	31	21	22	53	29	28	27	48					
80-810306				17	39	40	31	21	22	53	29	28	27	48					
80-810512				17	39	40	31	21	22	53	29	28	27	48					
80-810806				17	39	40	31	21	22	53	29	28	27	48					
80-810807				17	39	40	31	21	22	53	29	28	27	48					
80-810808				17	39	40	31	21	22	53	29	28	27	48					
80-810809				17	39	40	31	21	22	53	29	28	27	48					
80-810810				17	39	40	31	21	22	53	29	28	27	48					
80-810812				17	39	40	31	21	22	53	29	28	27	48					
80-810814				17	39	40	31	21	22	53	29	28	27	48					
80-811206				17	39	40	31	21	22	53	29	28	27	48					
80-811208				17	39	40	31	21	22	53	29	28	27	48					
80-811210				17	39	40	31	21	22	53	29	28	27	48					
80-811211				17	39	40	31	21	22	53	29	28	27	48					
80-812611				17	42	41	26	29	28	27	48								
80-817406				17	39	40	31	21	22	53	29	28	27	48					
80-817410				17	39	40	31	21	22	53	29	28	27	48					
80-817411				17	39	40	31	21	22	53	29	28	27	48					
80-817413				17	39	40	31	21	22	53	29	28	27	48					
80-8337138				42	41	48													
80-932022A				17	6	2	7	12	42	33	57	53	48						

CONFIDENTIAL

Table 1(f) P-Q-R-\$ Information for each Product (contd.)

Product No.	6-Month Quantity	Sell Price	6-Month Total \$	Product Routings															
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
80-961165				17	42	41	53	26	29	28	27	48							
80-R109-1049				17	39	40	31	42	41	53	29	28	27	48					
80-R109-1050				17	39	40	31	21	22	53	29	28	27	48					
80-R109-1051				17	39	40	31	42	41	53	29	28	27	48					
80-R109-1052				17	39	40	31	42	41	53	29	28	27	48					
80-S109-1004				17	39	40	31	21	22	53	29	28	27	48					
80-S109-1005				17	39	40	31	21	22	53	29	28	27	48					
80-S114-1000				17	3	7	12	4	53	55									
80-S111-1001				17	6	2	7	12	42	33	29	28	4	55					
80-S113-1000				57	53	57	48												
80-S113-1001				17	16	11	10	57	53	55									
80-S113-1004				17	16	11	10	57	53	55									
80-S113-1012				17	6	2	7	12	42	33	29	28	4	55					
80-S113-1012				17	6	2	7	12	42	33	29	28	4	57	55				
80-957-21				17	54	57	55												
80-23193				17	16	11	10	29	4	55									
80-30311				17	16	11	10	29	4	55									
80-34673				17	56	1	57	54	55										
80-37914				17	56	1	57	54	55										
80-27708-302UP				17	39	40	16	9	11	10	39	40	57	54					
80-9033023-303				57	54	57	55												
80-9033704UP				57	55														
80-9434913-301UP				17	16	11	10	57	54	55									
80-9434913-303UP				17	16	11	10	57	54	55									
80-9434913-307UP				17	16	11	10	57	54	55									
80-9434913-309UP				17	16	11	10	57	54	55									
80-9434913-311UP				17	16	11	10	57	54	55									
80-9627637-3UP				17	3	7	12	57	54	57	55								
80-9627637-4UP				17	3	7	12	57	54	57	55								
80-9627637-5UP				17	3	7	12	57	54	57	55								
80-9627637-6UP				17	3	7	12	57	54	57	55								
80-9627712-301UP				17	6	56	16	11	10	6	7	12	8	54	57	54	53	8	55
80-9627713-301UP				17	6	56	16	11	10	6	7	12	8	54	57	54	53	8	55
80-9627714-301UP				17	6	56	16	11	10	6	7	12	8	54	57	54	53	8	55
80-9627715-301UP				17	6	56	16	11	10	6	7	12	8	54	57	54	53	8	55
80-9627716-301UP				17	6	56	16	11	10	6	7	12	8	54	57	54	53	8	55
80-9627787-1F				17	3	7	12	8	57	55									
80-SW25085JI				57	55														
80-SW25435JI				57	55														
80-SW25473JI				57	55														
80-SW27049JI				57	55														
80-SW28173-1UP				17	40	39	16	11	10	40	39	26	57	54					
80-SW32217JI				57	55														
80-SW32972JI				57	55														
80-WP32969-5JI				57	55														
80-3260-041				17	6	2	11	10	29	28	54	57	55						
80-3260-0980				17	6	2	11	10	29	28	54	57	55						
80-3260-503				17	6	2	11	10	29	28	54	57	55						
80-W131-1000				17	3	7	12	4	53	55									
80-W131-1001				17	3	7	12	4	53	55									
80-U104-1012				17	3	7	12	4	53	55									
80-U104-1013				17	3	7	12	4	53	55									
80-U104-1016				17	3	7	12	4	53	55									
80-U104-1017				17	3	7	12	4	53	55									
80-U104-1018				17	3	7	12	4	53	55									
80-671635-00				17	3	7	12	26	4	55									
80-4030007296089				17	3	7	12	8	4	54	29	4	55						
80-4030007296090				17	3	7	12	8	4	54	29	4	55						
80-4030007296091				17	3	7	12	8	4	54	29	4	55						
80-4030007296094				17	3	7	12	8	4	54	29	4	55						
80-U110-1000				17	6	9	57	4	55										
80-V104-1000				17	3	7	12	4	53	55									
80-V104-1002				17	3	7	12	4	53	55									
80-27377				17	16	11	10	26	4	55									
80-36318				17	3	7	12	29	4	55									
80-36892				17	3	7	12	29	4	55									
80-37626				17	3	7	12	29	4	55									
80-37772				17	40	39	6	11	10	29	4	55							
80-37773				17	40	39	6	11	10	29	4	55							
80-39320				17	40	39	6	11	10	29	4	55							
80-39321				17	40	39	6	11	10	29	4	55							
80-7549				17	16	11	10	29	4	55									
80-7551				17	3	7	12	29	4	55									
80-7633				17	16	11	10	29	4	55									
80-13217E7085				17	40	39	21	22	26	50	53	29	28	27	48				
80-921790				17	3	7	12	8	54	29	28	4	55						
80-W101-1001A				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W101-1003				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W101-1006				17	6	2	7	12	42	41	33	29	28	51	54	55			

CONFIDENTIAL

Table 1(g) P-Q-R-\$ Information for each Product (contd.)

Product No.	6-Month Quantity	Sell Price	6-Month Total \$	Product Routings															
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
80-W101-1019				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W101-1019P				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W101-1020				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W101-1022				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W101-1028				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W101-1030				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W101-1036				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W101-1037				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W101-1058				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W101-1060				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W101-1083				17	40	39	21	22	26	50	53	29	28	27	48				
80-W101-1116				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W101-1120				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W101-1153				17	40	39	29	28	4	54	55								
80-W101-1154				17	40	39	29	28	4	55									
80-W101-1155				17	40	39	21	22	26	50	53	29	28	27	48				
80-W101-1156				17	57	55													
80-W101-1157				17	57	55													
80-W101-1158				17	57	55													
80-W101-2000				17	40	39	21	22	26	50	53	29	28	27	48				
80-W101-2001				17	40	39	21	22	26	50	53	29	28	27	48				
80-W101-2002				17	40	39	21	22	26	50	53	29	28	27	48				
80-W101-2003				17	40	39	21	22	26	50	53	29	28	27	48				
80-W101-2004				17	40	39	29	28	4	54	55								
80-W101-2005				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W101-2006				17	6	2	42	33	41	54	57	4	55						
80-W101-2007				17	40	39	42	41	51	53	29	28	27	48					
80-W101-2008				17	40	39	21	22	26	50	53	29	28	27	48				
80-W101-2009				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-150SLA				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-150SLAW				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-175SLAW				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-175SLC				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-175SLCW				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-200SLA				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-200SLAW				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-200SLCW				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-225SLA				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-225SLC				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-250SLA				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-250SLAW				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-250SLC				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-2687				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W102-1006				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W102-1007				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W102-1008				17	6	2	7	12	42	41	33	29	28	51	54	55			
80-W102-1063				17	6	2	42	41	33	54	57	4	55						
80-W102-1063B				17	6	2	42	41	33	54	57	4	55						
80-W103-1000				17	42	41	57	26	54	57	48								
80-ULC0078				17	3	7	12	29	4	55									
80-W120-1000				17	42	41	51	53	29	28	48								
80-575V87				17	21	22	51	53	29	28	48								
80-V1280				17	21	22	51	53	21	22	29	28	48						
80-111199				17	42	41	51	53	29	28	48								
80-12706-D				17	42	41	53	29	28	27	48								
80-Y102-1001				17	6	2	42	41	53	57	55								

CONFIDENTIAL

Table 2(a) Attributes for each Equipment Type

NUMBER	EQUIPMENT	MOVEABLE	COST OF DUPLICATION
1	700 TON PRESS	YES	EXPENSIVE
2	5" UPSETTER	NO	EXPENSIVE
3	5000# Area FURNACE	YES	
4	LARGE ROTOBLEASTER	YES	
5	350 TON PRESS	YES	EXPENSIVE
6	5" UPSETTER FURNACE	YES	
7	5000# Area HAMMER	NO	EXPENSIVE
8	GRINDING TABLE	YES	
9	60 TON PRESS	YES	
10	150 TON TRIM PRESS	YES	EXPENSIVE

Table 2(b) Attributes for each Equipment Type (contd.)

NUMBER	EQUIPMENT	MOVEABLE	COST OF DUPLICATION
11	3000# Area HAMMER	NO	EXPENSIVE
12	158 TON TRIM PRESS	YES	EXPENSIVE
13	HYDRAULIC BENDER	YES	
14	4" THREADER	YES	
15	4" BELT GRINDER	YES	
16	3000# Area FURNACE	YES	
17	BAND SAWS	YES	
18	200# Area OPEN DIE HAMMER	NO	EXPENSIVE
19	400# Area FURNACE	YES	
20	400# Area OPEN DIE HAMMER	NO	EXPENSIVE
21	600# Area FURNACE	YES	
22	600# Area OPEN DIE HAMMER	NO	EXPENSIVE
23	STONE GRINDER	YES	
24	HYDRAULIC BENDER	YES	
25	DUAL BELT GRINDER	YES	
26	BELT GRINDER	YES	
27	SMALL ROTOBLEASTER	YES	
28	TEMPER FURNACE	YES	
29	QUENCH FURNACE	YES	
30	HORIZONTAL BORING MACHINE	YES	
31	3 POST HYDRAULIC PRESS	YES	
32	INDUCTION HEATER	YES	
33	3 POST HYDRAULIC BENDER	YES	
34	DIE MILLING MACHINE	NO	
35	DRILL PRESS	YES	
36	VERTICAL LATHE	YES	
37	VERTICAL MILL	YES	
38	TOOL GRINDER	YES	
39	SLOT FURNACE	YES	
40	2.5" UPSETTER	YES	EXPENSIVE
41	1500# Area OPEN DIE HAMMER	NO	EXPENSIVE
42	1500# Area FURNACE	YES	
43	DIE MILLING MACHINE	YES	
44	EDM MACHINE	YES	
45	VERTICAL MILL	YES	
46	TURRET LATHE	YES	
47	ENGINE LATHE	YES	
48	SHIPPING DESK	YES	
49	H.T. TESTING AREA	YES	
50	SMALL TUMBLER	YES	
51	LARGE TUMBLER	YES	
52	CLEAR COAT DIP TANK	YES	
53	MANUAL MACHINE SHOP	YES	EXPENSIVE
54	CNC MACHINE SHOP	YES	EXPENSIVE
55	SHIPPING AREA	YES	
56	5" UPSETTER	YES	EXPENSIVE
57	OUTSIDE PROCESSING	YES	

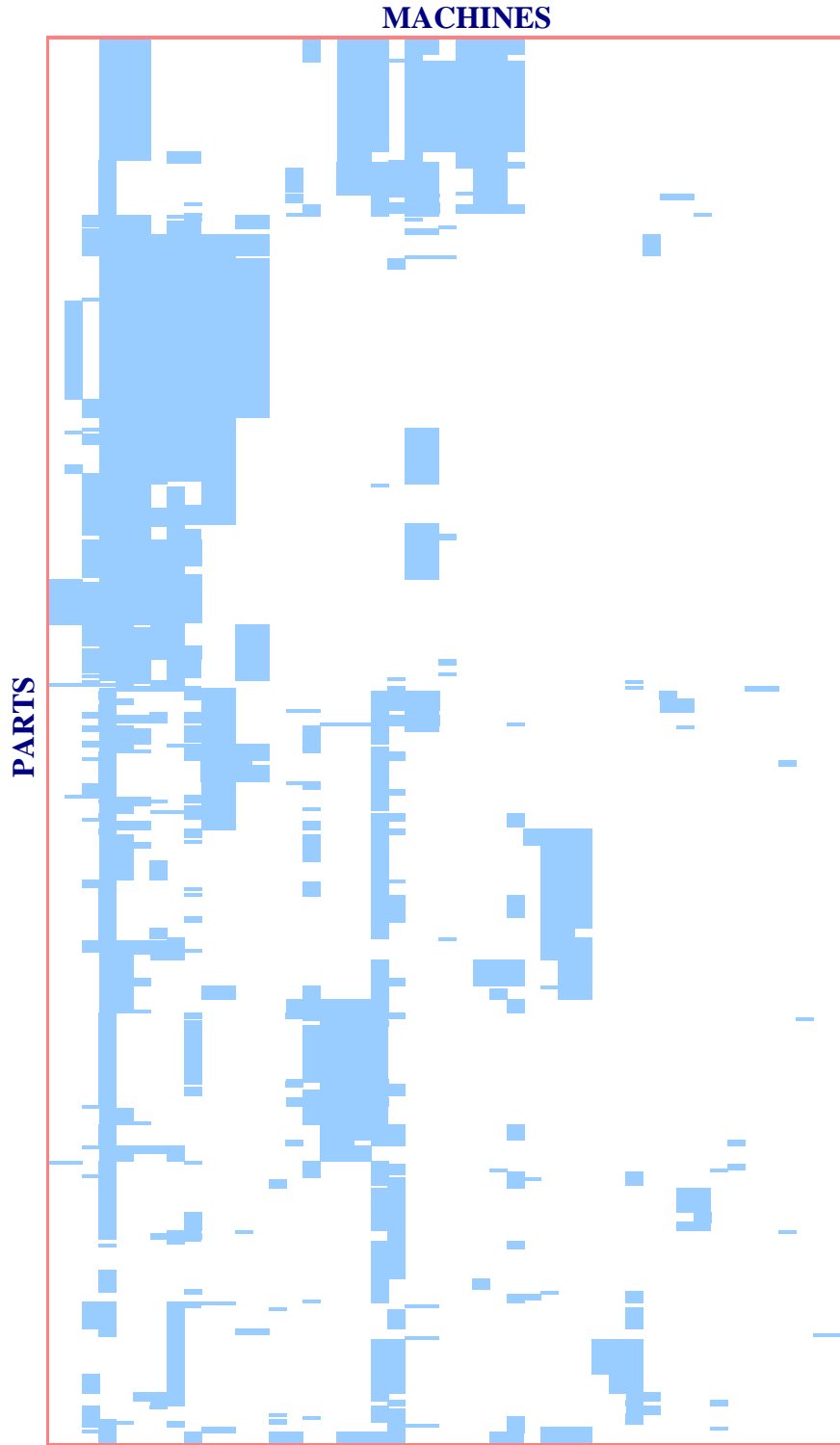


Figure 1 Optimized Machine-Part Matrix Clustering for 500+ Routings

Product Mix Segmentation

The results of both P-Q Analysis and P-Q-\$ Analysis were generated, as shown in Figures 2 and 3 respectively. Based on these analyses (and indicated by the dotted line circling the sample of products selected in Figure 3), only those products produced in quantities greater than 1800 and earning revenues higher than \$30,000 were selected in the sample of products (Table 3) on which to base the facility layout design. The number of products included in this sample is 44, which is only about 8% of the total number of products in the complete population. However, this sample of products accounts for 68% of the Total Production Volume and 46% of the Total Revenue for the company.

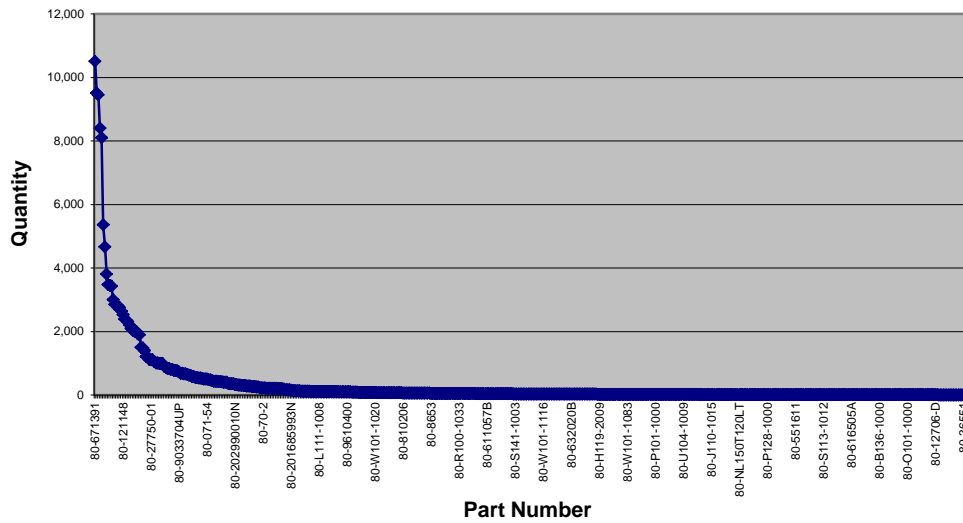


Figure 2 P-Q Analysis

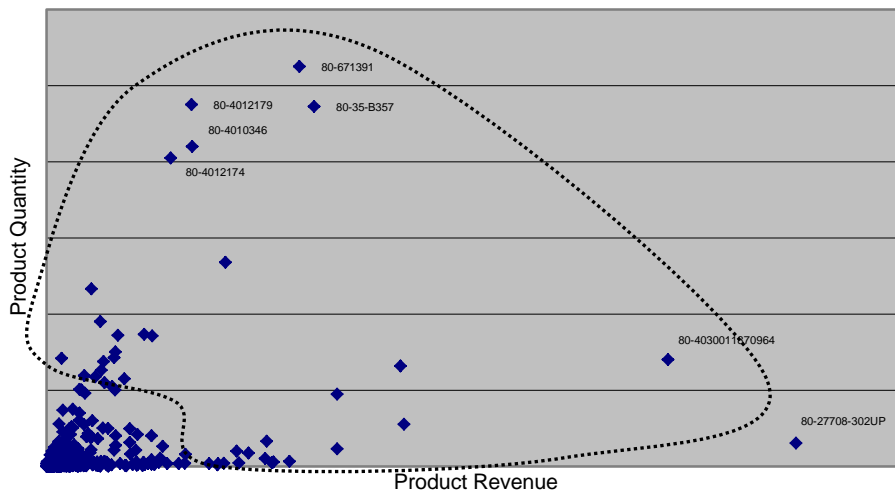


Figure 3 P-Q-\$ Analysis

Table 3 Initial Working Sample of Products

Product No.	6-Month Quantity	Sell Price	6-Month Total \$	Product Routings															
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
80-4011714				1	26	57	52	48	55										
80-4012169				1	26	57	52	48	55										
80-4012174				1	26	57	52	48	55										
80-4012179				1	26	57	52	48	55										
80-4030339				1	27	9	57	48											
80-4030341				1	27	9	57	48											
80-4035149				1	28	50	27	48	55										
80-121148				1	50	26	27	55											
80-4009121				1	57	25	52	48	55										
80-4009263				1	57	25	52	48	55										
80-4009270				1	57	25	52	48	55										
80-4010346				1	57	25	52	48	55										
80-4010348				1	57	25	52	48	55										
80-4010350				1	57	25	52	48	55										
80-4041707				1	57	25	52	48	55										
80-051-1				17	1	26	4	54	55										
80-35-B357				17	1	57	4	54	55										
80-671635-00				17	3	7	12	26	4	55									
80-4030007296091				17	3	7	12	8	4	54	29	4	55						
80-4030007296094				17	3	7	12	8	4	54	29	4	55						
80-921790				17	3	7	12	8	54	29	28	4	55						
80-C27416-2				17	6	2	11	10	29	54	55								
80-150T084LT				17	6	2	7	12	8	42	41	57	55						
80-NL150T060LT				17	6	2	7	12	8	42	41	57	55						
80-NL150T072LT				17	6	2	7	12	8	42	41	57	55						
80-37355-1072				17	6	2	7	12	8	42	41	57	55						
80-37355-1084				17	6	2	7	12	8	42	41	57	55						
80-3260-041				17	6	2	11	10	29	28	54	57	55						
80-W101-2006				17	6	2	42	33	41	54	57	4	55						
80-9627713-301UP				17	6	56	16	11	10	6	7	12	8	54	57	54	53	8	55
80-9627715-301UP				17	6	56	16	11	10	6	7	12	8	54	57	54	53	8	55
80-671391				17	16	11	10	26	4	55									
80-191820				17	16	11	10	26	29	28	27	48							
80-S113-1001				17	16	11	10	57	53	55									
80-4067179				17	39	40	26	57	54	57	55								
80-4030011870964				17	39	40	21	22	53	29	28	4	55						
80-121009-00				17	39	40	21	22	55										
80-121188-002				17	39	40	21	22	55										
80-121018-00				17	39	40	21	22	55										
80-27750-01				17	39	40	42	41	3	7	12	57	54	55					
80-27708-302UP				17	39	40	16	9	11	10	39	40	57	54					
80-3249869				17	56	1	17	29	26	54	57	48							
80-B113-1001				17	56	57	54												
80-9033023-303				57	54	57	55												

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Among the 486 products that were excluded from the sample, there were 35 products with routings identical to the 44 selected products. That is, they belonged to the same product families as these 44 products do, and thus could be included in the Working Sample. After the inclusion of those additional 35 products, the final Working Sample of products (Table 4) now included about 15% of the total number of products in the original sample, yet accounted for 74% of the Total Production Volume and 54% of the Total Revenue earned by the company.

Machine-Part Matrix Clustering

The Machine-Product Matrix Clustering result (Table 5) for the Working Sample of products showed that there would still be considerable machine sharing and overlap if it was desired to design stand-alone manufacturing cells. Since the blocks of operations (indicated by “1”s) could not be isolated into independent clusters, it was concluded that independent product-focused (or product family-based) manufacturing cells were infeasible for the custom forge shop. Therefore, it was decided to explore a Hybrid Cellular Layout to achieve streamlined flow for the diverse sample of products.

Table 4 Final Working Sample of Products

Product No.	6-Month Quantity	Sell Price	6-Month Total \$	Product Routings															
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
80-A37353				17	6	2	11	10	29	54	55								
80-C27416-1				17	6	2	11	10	29	54	55								
80-C27416-2				17	6	2	11	10	29	54	55								
80-C46806-1				17	6	2	11	10	29	54	55								
80-C55581				17	6	2	11	10	29	54	55								
80-C558-1				17	6	2	11	10	29	54	55								
80-D8097				17	6	2	11	10	29	54	55								
80-B113-1001				17	56	57	54												
80-4003111				1	57	25	52	48	55										
80-4009121				1	57	25	52	48	55										
80-4009262				1	57	25	52	48	55										
80-4009263				1	57	25	52	48	55										
80-4009270				1	57	25	52	48	55										
80-4010346				1	57	25	52	48	55										
80-4010348				1	57	25	52	48	55										
80-4010349				1	57	25	52	48	55										
80-4010350				1	57	25	52	48	55										
80-4010351				1	57	25	52	48	55										
80-4010352				1	57	25	52	48	55										
80-4011714				1	26	57	52	48	55										
80-4011725				1	57	25	52	48	55										
80-4012169				1	26	57	52	48	55										
80-4012174				1	26	57	52	48	55										
80-4012179				1	26	57	52	48	55										
80-4012212				1	26	57	52	48	55										
80-4012213				1	26	57	52	48	55										
80-4030339				1	27	9	57	48											
80-4030341				1	27	9	57	48											
80-4035144				1	28	50	27	48	55										
80-4035149				1	28	50	27	48	55										
80-4039260				1	28	50	27	48	55										
80-4041707				1	57	25	52	48	55										
80-4059989				1	26	57	52	48	55										
80-4067179				17	39	40	26	57	54	57	55								
80-4030011870964				17	39	40	21	22	53	29	28	4	55						
80-150T084LT				17	6	2	7	12	8	42	41	57	55						
80-G121-1002				17	6	2	7	12	8	42	41	57	55						
80-NL150T060LT				17	6	2	7	12	8	42	41	57	55						
80-NL150T072LT				17	6	2	7	12	8	42	41	57	55						
80-NL150T084LT				17	6	2	7	12	8	42	41	57	55						
80-NL150T096LT				17	6	2	7	12	8	42	41	57	55						
80-NL150T120LT				17	6	2	7	12	8	42	41	57	55						
80-3249869				17	56	1	17	29	26	54	57	48							
80-121009-00				17	39	40	21	22	55										
80-121188-002				17	39	40	21	22	55										
80-121189				17	39	40	21	22	55										
80-671391				17	16	11	10	26	4	55									
80-121018-00				17	39	40	21	22	55										
80-121148				1	50	26	27	55											
80-121387				17	39	40	21	22	55										
80-ULC0200				17	39	40	21	22	55										
80-35-B357				17	1	57	4	54	55										
80-27750-01				17	39	40	42	41	3	7	12	57	54	55					
80-37355-1072				17	6	2	7	12	8	42	41	57	55						
80-37355-1084				17	6	2	7	12	8	42	41	57	55						
80-051-1				17	1	26	4	54	55										
80-191820				17	16	11	10	26	29	28	27	48							
80-522500				17	16	11	10	26	29	28	27	48							
80-551500				17	16	11	10	26	29	28	27	48							
80-S113-1001				17	16	11	10	57	53	55									
80-S113-1004				17	16	11	10	57	53	55									
80-27708-302UP				17	39	40	16	9	11	10	39	40	57	54					
80-9033023-303				57	54	57	55												
80-9627712-301UP				17	6	56	16	11	10	6	7	12	8	54	57	54	53	8	55
80-9627713-301UP				17	6	56	16	11	10	6	7	12	8	54	57	54	53	8	55
80-9627714-301UP				17	6	56	16	11	10	6	7	12	8	54	57	54	53	8	55
80-9627715-301UP				17	6	56	16	11	10	6	7	12	8	54	57	54	53	8	55
80-9627716-301UP				17	6	56	16	11	10	6	7	12	8	54	57	54	53	8	55
80-3260-041				17	6	2	11	10	29	28	54	57	55						
80-3260-0980				17	6	2	11	10	29	28	54	57	55						
80-3260-503				17	6	2	11	10	29	28	54	57	55						
80-671635-00				17	3	7	12	26	4	55									
80-4030007296089				17	3	7	12	8	4	54	29	4	55						
80-4030007296090				17	3	7	12	8	4	54	29	4	55						
80-4030007296091				17	3	7	12	8	4	54	29	4	55						
80-4030007296094				17	3	7	12	8	4	54	29	4	55						
80-27377				17	16	11	10	26	4	55									
80-921790				17	3	7	12	8	54	29	28	4	55						
80-W101-2006				17	6	2	42	33	41	54	57	4	55						

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Table 5 Machine-Product Matrix Clustering for the Final Working Sample

Product No.\ Equipment No.	39	40	21	22	4	3	29	28	55	57	17	54	7	12	8	6	2	42	41	11	10	16	53	56	9	27	50	26	1	48	52	25	33		
80-9033023-303								1	1	1																									
80-B113-1001										1	1	1													1										
80-35-B357					1			1	1	1	1																				1				
80-051-1					1			1		1	1	1																			1	1			
80-3249869							1			1	1	1													1						1	1	1		
80-4067179	1	1						1	1	1	1																				1				
80-27750-01	1	1				1		1	1	1	1	1	1	1					1	1															
80-27708-302UP	1	1								1	1	1									1	1	1			1									
80-S113-1001								1	1	1											1	1	1	1											
80-9627713-301UP								1	1	1	1	1	1	1	1	1					1	1	1	1	1										
80-9627715-301UP								1	1	1	1	1	1	1	1	1					1	1	1	1	1										
80-C27416-2							1	1		1	1					1	1				1	1													
80-3260-041							1	1		1	1	1				1	1				1	1													
80-150T084LT								1	1	1	1	1	1	1	1	1	1	1	1	1															
80-NL150T060LT								1	1	1	1	1	1	1	1	1	1	1	1																
80-NL150T072LT								1	1	1	1	1	1	1	1	1	1	1	1																
80-37355-1072								1	1	1	1	1	1	1	1	1	1	1	1																
80-37355-1084								1	1	1	1	1	1	1	1	1	1	1	1																
80-W101-2006					1			1	1	1	1	1				1	1	1	1																
80-671635-00					1	1		1		1	1	1	1																						
80-4030007296091					1	1	1	1		1	1	1	1	1	1	1																			
80-4030007296094					1	1	1	1		1	1	1	1	1	1	1																			
80-921790					1	1	1	1	1	1	1	1	1	1	1	1																			
80-671391					1			1		1	1										1	1	1												
80-191820							1	1		1											1	1	1												
80-4030011870964	1	1	1	1	1	1	1	1	1	1	1	1	1											1											
80-121009-00	1	1	1	1	1			1		1																									
80-121188-002	1	1	1	1	1			1		1																									
80-121018-00	1	1	1	1	1			1		1																									
80-4009121								1	1																										
80-4009263								1	1																										
80-4009270								1	1																										
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80-4012179								1	1																										
80-4030339										1																1	1								
80-4030341										1																1	1								
80-4035149							1	1																			1	1							
80-121148								1																			1	1	1	1					

Shared Equipment

Part Families



Table 6 Modified Multi-Product Process Chart for the Final Working Sample

Product No.	Product Routings																																				
80-9627713-301UP	17			6	56			16			11	10			6	7	12	8									54	57	54		53	8	55				
80-9627715-301UP	17			6	56			16			11	10			6	7	12	8									54	57	54		53	8	55				
80-3260-041	17			6			2				11	10														29	28			54	57			55			
80-C27416-2	17			6			2				11	10														29				54				55			
80-121009-00	17	39	40								21	22																							55		
80-121188-002	17	39	40								21	22																							55		
80-121018-00	17	39	40								21	22	M3																					55			
80-4030011870964	17	39	40																							53	29	28		4				55			
80-921790	17														3	7	12	8								54	29	28		4				55			
80-4030007296091	17													M4	3	7	12	8							4	54	29		4					55			
80-4030007296094	17														3	7	12	8							4	54	29		4					55			
80-671635-00	17												M2		3	7	12								26	4								55			
80-671391	17							16			11	10													26	4				54				55			
80-051-1	17	1																							26	4			M5					55			
80-121148	1														50										26			27						55			
80-4035149	1				28										50																			48	55		
80-4030339	1																										27	9		57					48		
80-4030341	1																										27	9		57					48		
80-4009121	1																												57				25	52	48	55	
80-4009263	1			M1																									57				25	52	48	55	
80-4009270	1																												57		M7		25	52	48	55	
80-4010346	1																												57				25	52	48	55	
80-4010348	1																												57				25	52	48	55	
80-4010350	1																												57				25	52	48	55	
80-4041707	1																												57				25	52	48	55	
80-4011714	1																									26			57					52	48	55	
80-4012169	1																								26			57						52	48	55	
80-4012174	1																								26			57						52	48	55	
80-4012179	1																								26			57						52	48	55	
80-9033023-303																													57	54	57					55	
80-4067179	17	39	40																						26				57	54	57					55	
80-27750-01	17	39	40				42	41								3	7	12												M6			57	54		55	
80-150T084LT	17																												42	41		57				55	
80-NL150T060LT	17																												42	41		57				55	
80-NL150T072LT	17																												42	41		57				55	
80-37355-1072	17																												42	41		57				55	
80-37355-1084	17																												42	41		57				55	
80-W101-2006	17															6	2												42	33	41		54	57	4		55
80-35-B357	17	1																															57	4	54		55
80-B113-1001	17				56																												57	54			55
80-3249869	17				56	1	17	29																	26				54	57					48		55
80-191820	17											16		11	10										26			29	28	27					48		55
80-S113-1001	17											16		11	10																	57	53			55	
80-27708-302UP	17	39	40									16	9	11	10	39	40															57	54				55

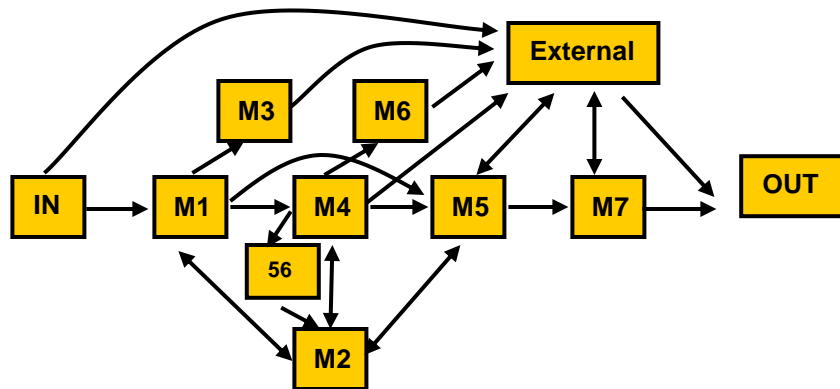


Figure 5 Modular Layout

Evaluation of the Proposed Layout

To evaluate the proposed Modular Layout, it was compared to the existing facility layout of the forge shop. The From-To Chart for the final Working Sample (Table 8) was generated. The flow diagram of the existing layout (Figure 6) shows the flows in the current layout due to the existing locations of various machines and support equipment in the forge shop. The flow path of any product starts from Receiving (IN), goes through the sequence of machines per its routing, and ends in Shipping (OUT). Yellow-colored rectangles represent machines that occur in the product routings of the final Working Sample used to design the layout; whereas, the machines represented by white rectangles are not used by the products in this sample.

The flow diagram for the proposed Modular Layout (Figure 7) shows the recommended relocation and grouping of various sets of machines into layout modules. Figure 7 shows the flows in the Modular From-To Chart superimposed on the proposed layout. Also, the different modules have been assigned to new locations in order to minimize the total distance (and time) of travel between different pairs of modules. Machines represented by white rectangles are the “monuments” that could not be re-located in any new layout that the company decided to implement.

A comparison of the two flow diagrams shows that the new layout would (1) increase the speed of material flows between the modules, (2) increase visual connectivity and communication among inter-dependent machines and (3) allow multi-machine operation by a single cross-trained operator inside any module. Had it been possible to relocate some of the monuments per the improved material flow network, then even more significant reductions in order completion time, material handling costs and labor hours would have been possible.

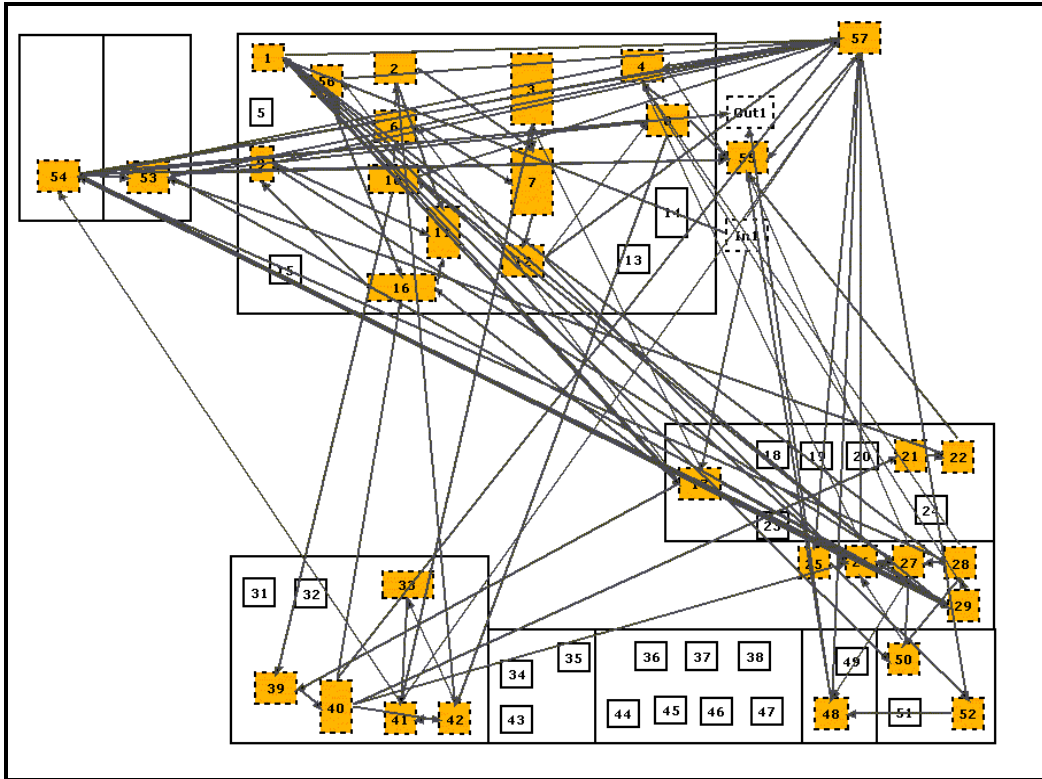


Figure 6 Flow Diagram for the Existing Layout

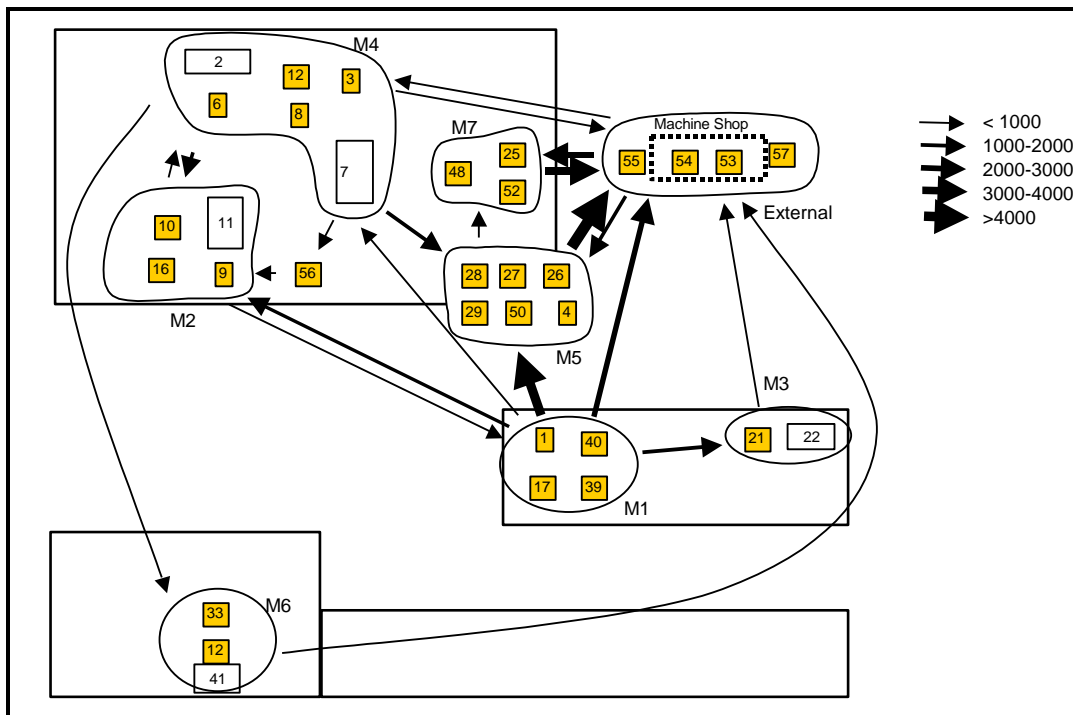


Figure 7 Flow Diagram for the Modular Layout

Implementation and Results

Recommendations were made to the forge shop to make significant layout changes and to invest capital to acquire additional equipment. Their implementation team evaluated and ranked each of the recommendations based on cost and time savings, feasibility, affordability, and ease of implementation. The following changes were made:

- An additional processing area was created in the Drop Hammer building where cleaning, finishing, packaging and shipping were consolidated. This reduced order flow times and increased throughput.
- The 158-ton Trim Press was replaced by a 440-ton press that was positioned next to the 5000 lb. Hammer to form an Upset Forging cell. This eliminated the transportation of large forgings to a distant 350-ton Trim Press. Also, a 350 kW induction heater and conveyor were purchased and co-located in the cell.
- A new 2.5" Upsetter was purchased and positioned next to the 3000 lb. Hammer to form an Upset Forging cell. The benefits included a reduction in part travel distance and increased throughput at the Hammer.
- The 1.5" Upsetter was replaced with a faster machine for shearing the same size of bar stock and positioned next to the 700-ton Press to form an Upset Forging cell. With its faster upsetting/forging cycle time, it drastically increased throughput at the 700-ton press.
- An overhead crane was installed at the 5000 lb. Hammer to reduce piston change-out time, reduce die key tightening time and improve product flow in the area.
- A portable Marvel Hacksaw and 1.5" Bar Shear were acquired.
- In their machine shop, a CNC Mill was acquired and positioned next to the EDM machine to reduce outsourcing costs and lead times because the company could make its own die sets.
- A new Magnaflux test machine was purchased and installed. This eliminated costs and reduced lead times associated with outside testing.

Based on implementing four of the above layout changes that were recommended to them, the forge shop reported a Total Annual Savings of \$137,000. The savings from the individual projects are itemized below:

- 2.5" Upsetter installed next to the 3000 lb. Hammer (Annual Savings = \$37,000)
- 350kW Induction Heater installed next to the 3000 lb. Hammer (Annual Savings = \$49,000)
- Crane installed at the 5000 lb. Hammer (Annual Savings = \$17,000)
- Addition of CNC Mill for die sinking (Annual Savings = \$34,000)

Other results that were achieved:

- The cost of one group of upset-and-forge parts was reduced by 10%-15%
- Savings in handling, finishing and shipping were estimated at 10%-12%. More significant savings were expected as a result of future projects to implement additional manufacturing cells.
- Several jobs took less time to move through the plant due to the speed of handling, processing and finishing. This netted the company more open production time for additional jobs.

For further information on financial benefits realized from this project, please contact Mike Ulven (MikeU@ulvencompanies.com, (503) 651-2101).

Conclusion

Custom forge shops that are suppliers to defense organizations, such as the Defense Logistics Agency, are typically high-mix low-volume (HMLV) jobshops. It is inadvisable to use the

standard tools in the Lean Toolkit based on the Toyota Production System for implementing Lean in a jobshops. A majority of those tools either need significant modification to be applicable, or they must be replaced by alternative methods that address the complexities of a jobshop, such as diverse product mix, variable demand, process layout, different due dates set by many different customers. Production Flow Analysis, with its emphasis on material flow analysis, part family formation and facility layout, proved to be a reliable and effective tool for implementing Lean in this custom forge shop.