Reservoir Continuous Process Improvement Six Sigma Methodology Implementation

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RESERVOIR CONTINUOUS PROCESS IMPROVEMENT SIX SIGMA METHODOLOGY IMPLEMENTATION

A. L. Wannamaker

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Topical Report
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ABSTRACT

The six sigma methodology adopted by AlliedSignal Inc. for implementing continuous improvement activity was applied to a new manufacturing assignment for FM&T. The responsibility for reservoir development/production was transferred from Rocky Flats to FM&T. Pressure vessel fabrication was new to this facility. No fabrication history for this type of product existed in-house. Statistical tools such as process mapping, failure mode and effects analysis, and design of experiments were used to define and fully characterize the machine processes to be used in reservoir production. Continuous improvement with regard to operating efficiencies and product quality is an ongoing activity at FM&T.

SUMMARY

The six sigma methodology has been adopted by AlliedSignal Inc. as a means for implementing continuous improvement activity. Pressure vessel manufacturing operating efficiencies are monitored and specific processes are prioritized and earmarked for six sigma implementation. Process owners throughout the facility are being trained in the six sigma methodology, and this problem solving technique is expected to be used on all product/processes at AlliedSignal, Federal Manufacturing & Technologies (FM&T).

This report is the result of an FM&T machining team effort to improve on process capabilities for the CAP 3 pressure vessel. FM&T became responsible for the fabrication of this component as a result of the Department of Energy's decision to consolidate the nuclear weapons complex and close the Rocky Flats facility.

A multifunctional team was established for this effort, with representatives from engineering, manufacturing, and planning. This component was chosen as a pilot for introducing the six sigma methodology to reservoir machine processes at FM&T. Yields on development fabrication lots of the CAP 3 had been averaging approximately 50%, and major improvements were required prior to production.

The team was successful in improving yields to 100%, reducing cycle time over 25%, and documenting a 1.1 million dollar savings over a five-year period.

DISCUSSION

SCOPE AND PURPOSE

The responsibility for reservoir development/production was transferred from Rocky Flats to AlliedSignal Federal Manufacturing and Technologies (FM&T). Capital equipment, personnel, tooling, material, and processing information were transferred. Pressure vessel fabrication is new to this facility. No fabrication history for this type of product existed in-house. Reservoir machine process capability development at FM&T was required as a result of the Nuclear Weapons Complex Nonnuclear Reconfiguration and Consolidation Project. Statistical tools such as process mapping, failure mode and effects analysis (FMEA), and design of experiments were used to define and fully characterize the machine processes to be used in reservoir production.

PRIOR WORK

A multitude of processing history and data was transferred from Rocky Flats. FM&T personnel were able to capitalize on this knowledge and establish a baseline process with minimal "true" machine process development. Still, machines and equipment were different in many cases, and FM&T had to establish internal baseline process capabilities as processes were generated.

ACTIVITY

The CAP 3 component is classified, and specific configuration and dimensional characteristics will not be discussed in this report. The application of six sigma methodology to this machined component will the subject for this continuous improvement report.

<u>Six Sigma Detailed Process Map</u>

The first step of the six sigma methodology is for team members to gain expert process knowledge of current activity. This understanding of the existing process is achieved by having cognizant team members generate a "detailed process map." The map will identify all the steps in the process being studied and list all possible factors influencing the variation produced at each step. These factors are categorized as "C" for critical, "N" for noise, and "SOP" for standard operating procedure. The critical factors driving process variability must be validated and controlled to maintain process consistency.

Figure 1 is a culmination of the team's efforts to capture the process in this format.

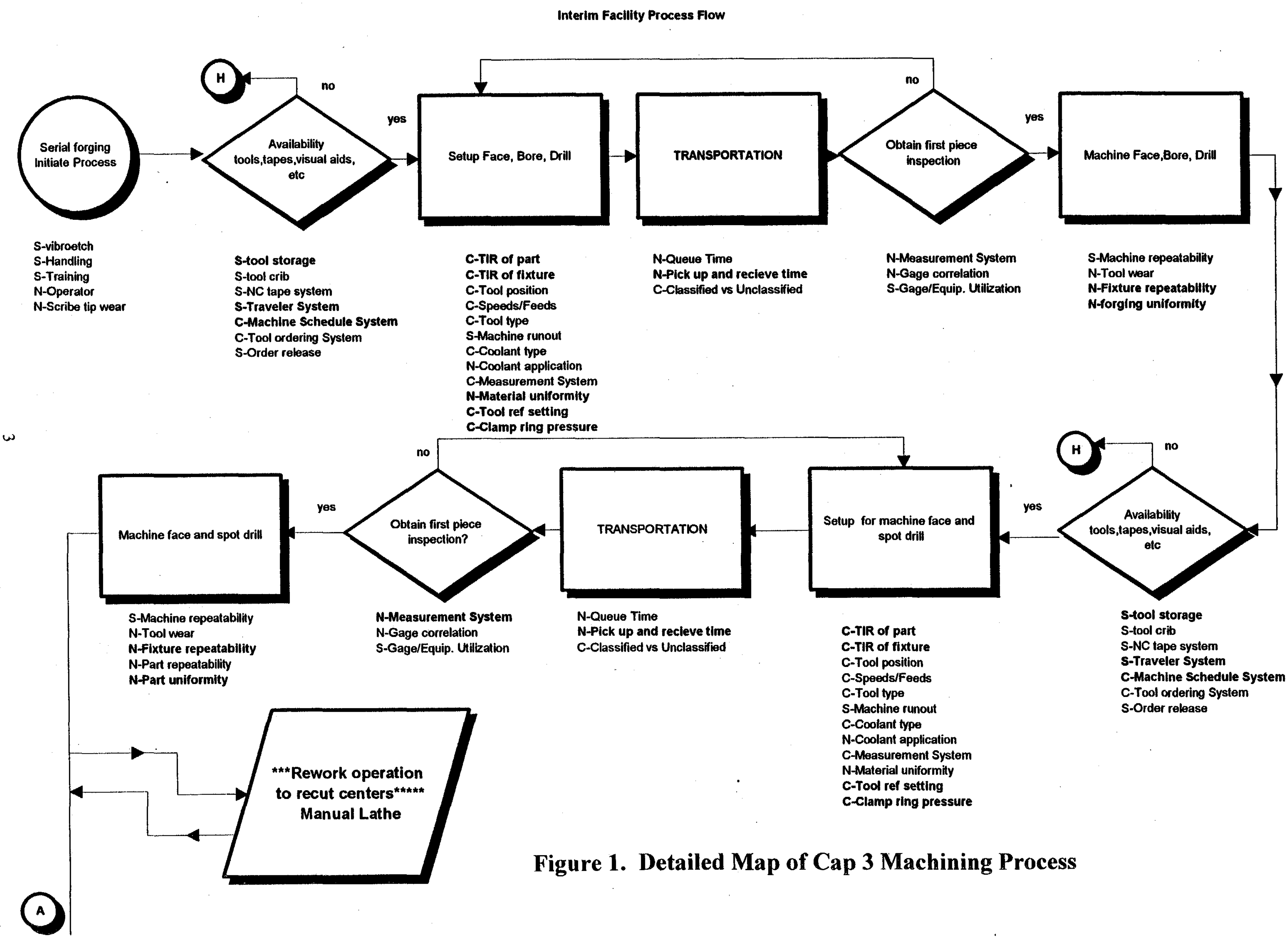


Figure 1. Detailed Map of Cap 3 Machining Process

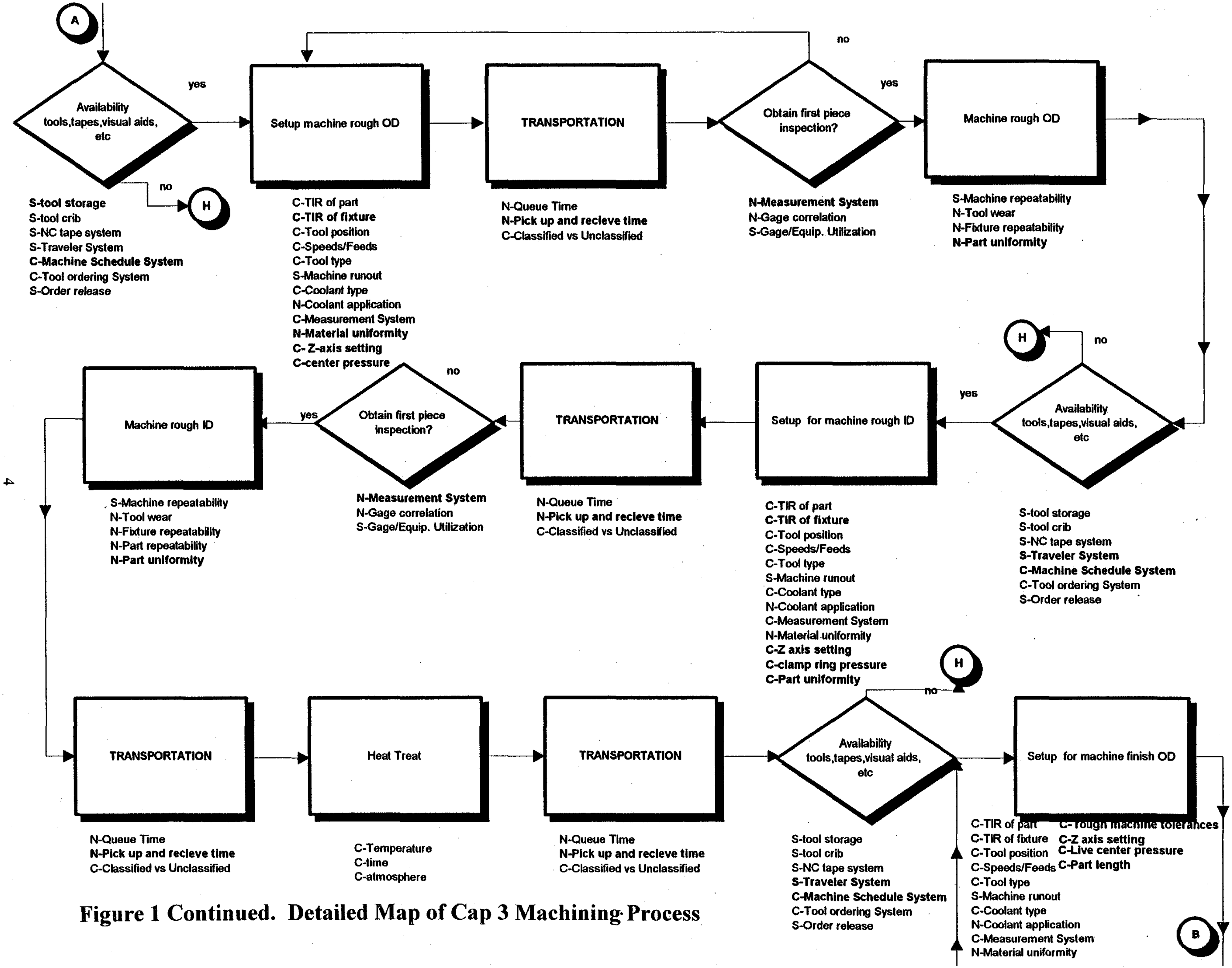


Figure 1 Continued. Detailed Map of Cap 3 Machining Process

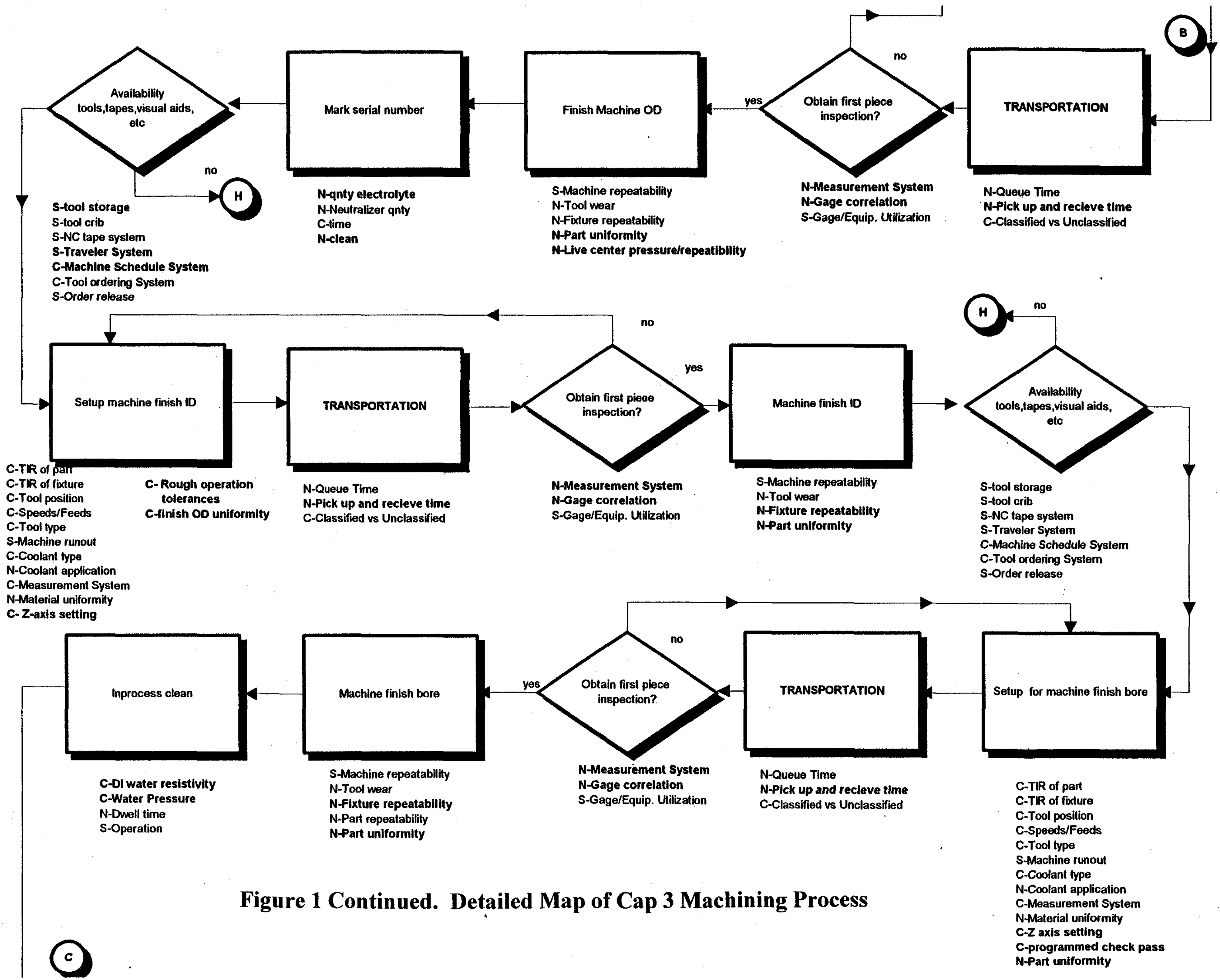


Figure 1 Continued. Detailed Map of Cap 3 Machining Process

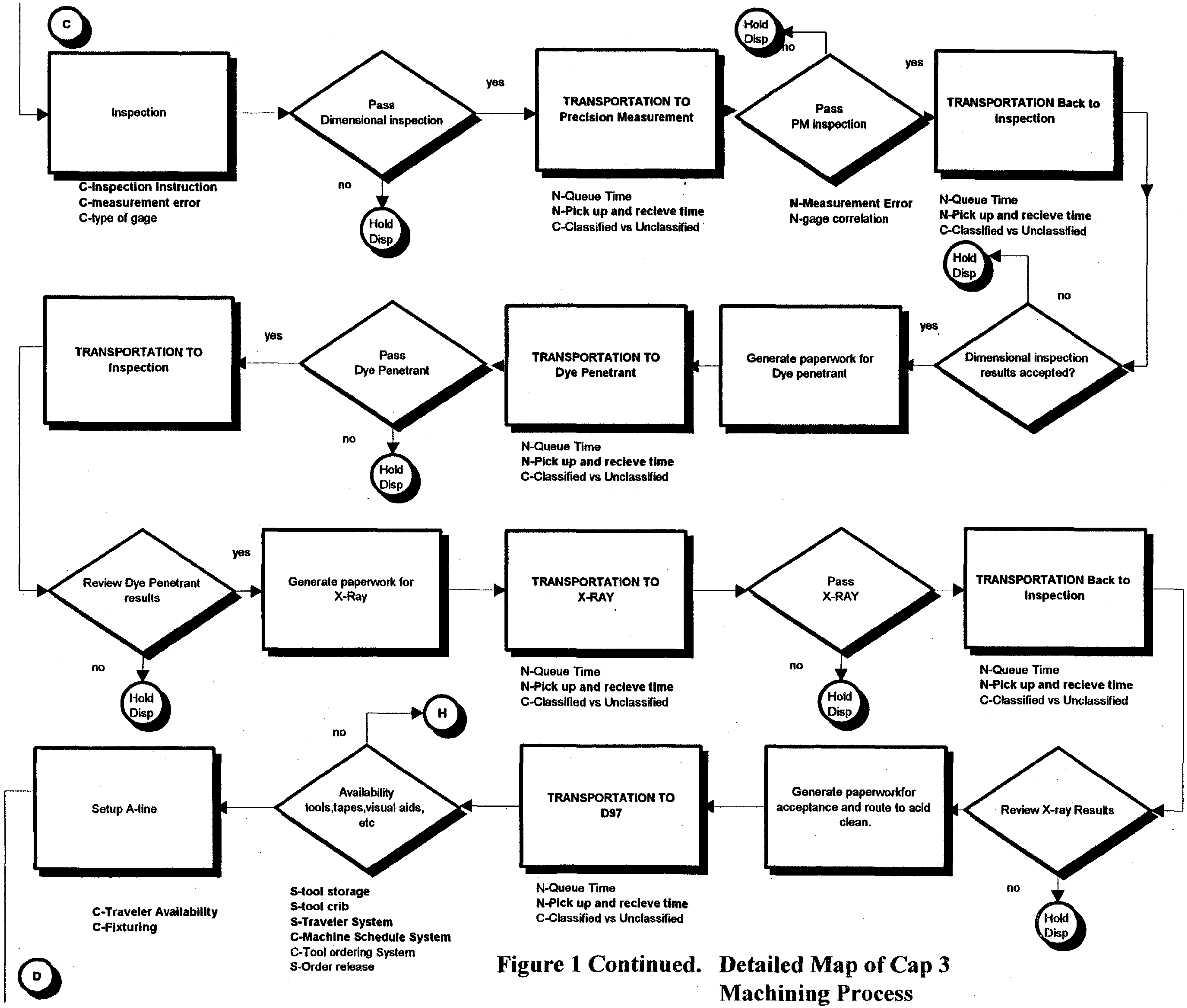


Figure 1 Continued. Detailed Map of Cap 3 Machining Process

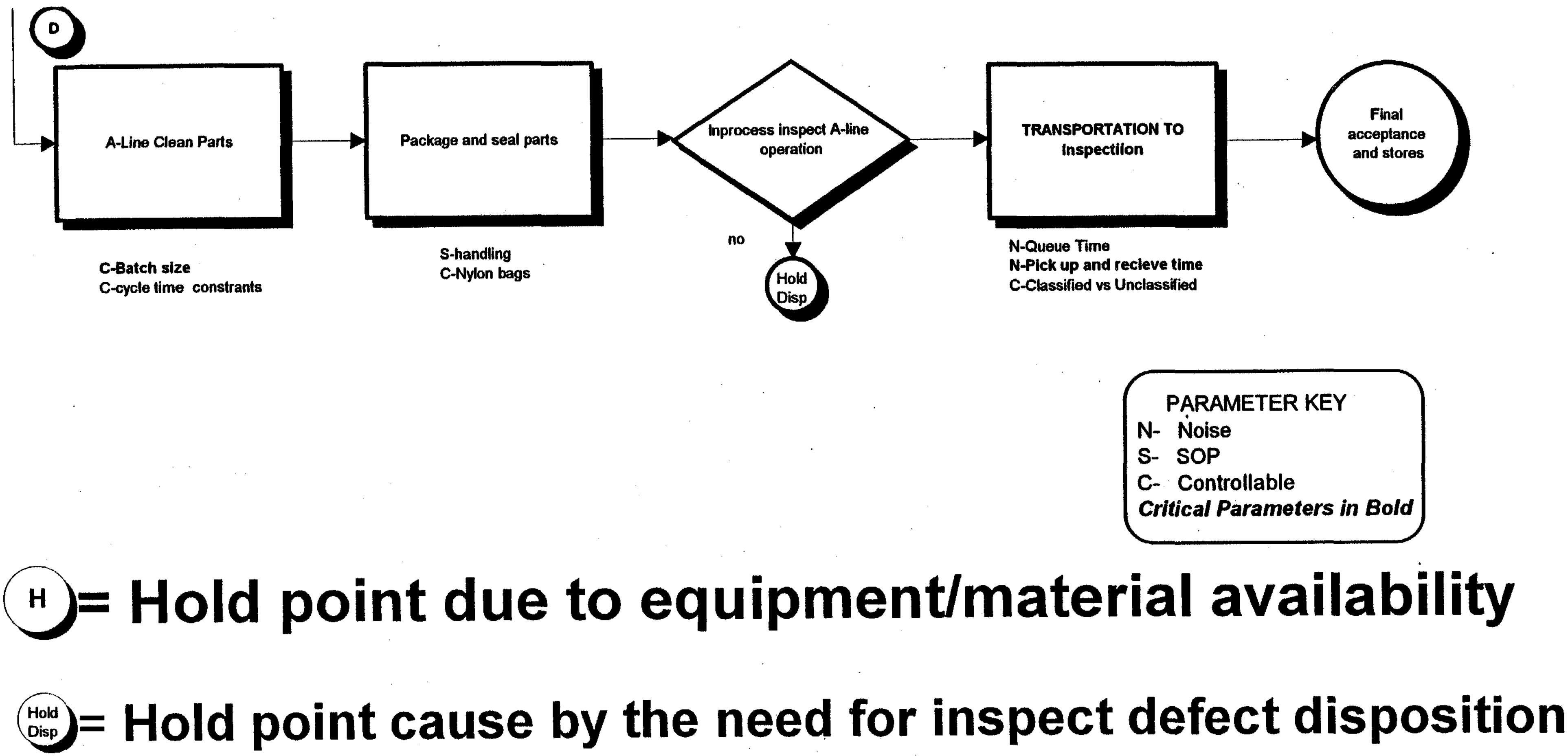


Figure 1 Continued. Detailed Map of Cap 3 Machining Process

The detailed process map is instrumental in establishing a process baseline from which to launch process improvement efforts. The team was able to identify several areas for improvement and correlate lower level response variables to customer requirements.

Failure Mode and Effects Analysis

The failure mode and effects analysis (FMEA) was used to assist team members in prioritizing which problem areas to tackle first. This tool allows the team to reveal all possible causes for not meeting customer requirements. It is designed to rank these failure modes so that team members can realize where the product is most likely to fail. The high priority failure modes are where the team wants to focus energy first. The FMEA for the CAP 3 machining process is shown in Table 1.

Failure modes were identified as (1) not meeting the dimensional requirements of the machined component, (2) not meeting customer delivery expectations, and (3) failure to comply with customer cost and quality expectations. The FMEA allows the team to quantify which improvement efforts will have the most favorable impact on the customer. The FMEA should always be generated with direct customer participation. In many cases, the supplier does not know what is truly important to the customer.

Defect Analysis: Establishing Metrics

The team knew that yields were too low, defects were too high, and cycle time was too long for this particular product. Defect tracking was initiated at each level of the process to determine the lowest possible level of detection. An example of a CAP 3 machine process defect tracking log can be seen in Figure 2.

Once the team captured where the defects were occurring, specific actions to prevent re-occurrence could be initiated. The detailed process map allowed team members continuity in reviewing the process. In many cases, defects resulting in scrap at the finish machine operations could be attributed to dimensional parameters generated at an earlier operation. The team found that controlling the roughing operation variability greatly facilitated the final machining operation. In some cases, additional tooling and gauging was fabricated to establish reduced variability at the roughing operation.

The detailed process map was instrumental in revealing areas where operations could be combined to reduce setup time. Inspection delays and hidden factory rework were also apparent upon team review of the map. Additional tooling and gauging was fabricated to ensure that parameters were generated "right the first time" and eliminate the need for inspection department verification. In one instance, a heat treat operation was eliminated when a process review raised the question as to the validity of the operation. In all, over 30 specific actions were initiated to improve yields and reduce cycle time. An example of the action tracking log can be see in Table 2.

Project:CAP 3 Process Improvement

Part/process	Failure Mode	Failure Effects	SEV	Causes	OCC	Controls	DET	RPN	Actions	Plans	pS	pO	pD	prpn
Manuf. reservoir containment vessel	Failure to contain	Structural integrity compromised	5	Sub surface stress	5	NC machine parameters	2	50	control speeds and feeds	comp.	5	1	1	5
			5	wall thickness too thin	1	Tool settings Zero reference	1	5	detail x-axis offset procedure	comp.	4	1	1	4
			5	wall thickness too thin	1	Tool settings Zero reference	1	5	detail z-axis ref. establishment	comp	5	1	1	5
			5	Forging not to specification	1	Detail forging requirements	1	5	none; material acceptable	comp	5	1	1	5
			5	unit damaged scratched and ding	3	Detail handling procedures	3	45	SOP released ,training complete	comp.	5	1	1	5
			5	laser penetration	4	verify at laser operation	5	20	characterize process and control	comp.	5	1	1	5
			5	tool malfunction	2	validate tooling	2	20	physically	comp	5	1	1	5
			5	part fixture stability	2	rigid, dead stop fixtures	2	20	define fixturing	OD fixt	5	1	1	5
			5	incorrect equip. utilization	3	certify operator/SOP	1	15	Equipment certification		5	1	1	5
			5	machine malfunction	2	PM and first piece	2	20	Schedule developed needs validation		5	1	1	. 5
			5	Measuremnt error , thin wall	5	improper system used	4	100	Perform MSE		5	1	3	15
			5	tolerancing noise, thin wall	5	control roughing operations	4	100	traveler in review		5	1	1	5
			5	Process not robust	5	not characterized	3	75	establilsh capability					
			5	gaging inaccurate, thin wall	5	probe tips on depth check	3	75	Investigate options		5	1	1	5
	Failure to comply with drawing	Part dimensions not met	4	fixture clamping pressure	3	mandate torque	2	24	define torque		5	1	1	5
			4	live center pressure	5	mandate pressure	2	40	define pressure		5	1	1	5
			4	calibration/gage and equipment	4	SOP	1	16	DOE to validate cal impact on perform.		5	1	1	5
			4	setup incorrect	3	certify op. on equip. use	2	24	part specific cert. in-process		4	1	1	4
			4	setup incorrect	3	traveler not ROBUST	2	24	detail seetup in traveler		4	1	1	4

Table 1. FMEA for the CAP 3 Machining Process

Project:CAP 3 Process Improvement

Part/process	Failure Mode	Failure Effects	SEV	Causes	OCC	Controls	DET	RPN	Actions	Plans	pS	pO	pD	prpn
Manuf. reservoir containment vessel	Failure to comply with drawing	Part dimensions not met	4	fixture unstable	3	fixture inadequate	2	24	validate fixture		4	1	1	4
			4	Measuremnt error	5	improper system used	4	100	Perform MSE		5	1	3	15
			4	rough tolerances to loose	2	traveler	2	16	detail tighter tolerances		4	1	1	4
			4	NC program implementation	5	Operator certification	1	20	Part specific programs being devl.		4	1	1	4
			4	program not optimized	4	Results not analyzed by engr.	2	32	DOE to be conducted		4	1	1	
			4	Traveler not consistant w/NC	3	Inadequate detail	2	24	process engr to correct narritive		3	1	1	3
	Failure to comply with cycletime	Delivery/cost not met	3	Process flow inadequate	5	no opt. of interim facil.	4	60	KAIZEN by CFM		3	1	1	3
			3	leadtime not realistic	3	planning inadequate	4	36	Resource mngt training		3	1	1	3
			3	transportation excessive	2	PM and first piece inspect	2	12	Schedule developed needs validation		3	1	1	3
			3	too many QA inspection points	5	no opt. of interim facil.	4	60	KAIZEN by CFM		3	1	1	3
			3	performing unnecessary ops.	4	Combine roughing ops.	4	48	process change		3	1	1	3
			3	performing unnecessary ops.	4	Eliminate heat treat	4	48	process change		3	1	1	3

Table 1 Continued. FMEA for the CAP 3 Machining Process

Op.	Description	Defects	Comments	Mfg. Investigative Updates
10	Serialize	0 of 15	Defect free operation.	Serialize and generate cactus tags need improvement, though no defects.
20	Face,bore,drill	0 of 15	Difficult to measure depth to point of drill. Illustration changed to allow depth of major diameter to be checked. Traveler needs clarification.	Probe tip to compensate for forging surface irregularities when measuring face to bottom of ID. Must hold tighter tolerances for all dimensions. To assure finish dimensions.
30	Face and spot	15 of 15	All parts failed true position on the drill machined centers. Traveler needs clarification. Narrative to follow NC.	Clamp ring pressure to be controlled. Part runnout and stability during machine is critical.
****Rework operation to recut centers required.				
40	Rough OD	4 of 15	Lost two parts due to confusion on Z-axis tool setting and program start vs. cycle start. Traveler tolerancing may not be adequate for assuring finish operation success. 2 parts outside traveler tolerance. Traveler needs clarification.	Tape request generated to combine with op. 030 above. Same fixture and Z-axis reference point. Must control live center pressure form tailstock. Combine op 30 traveler narrative to follow NC tape. Tolerance to be tighter to assure finish.

Figure 2. Cap 3 Yield Data, PPI Lot; 15 Pieces, Cap 3 Process Improvement Team

Op.	Description	Defects	Comments	Mfg. Investigative Updates
50	Rough ID	6 of 13	Lost one part due to z-axis setting confusion. Traveler clarification required. Parts outside traveler tolerance 6 each.	Z-axis reference position on road map to be clarified using theoretical centerline. Tolerance to be tightened.
60	Heat treat	0 of 12	Benefit of this operation is being questioned by team members. Will DOE to reevaluate elimination.	Evaluate possible improved machining with heat treat. Is it true?
80	Finish OD	12 of 12	Diameter OK. TIR to part centerline questionable. MSE on CMM required. Fixture repeatability and live center pressure need review. Traveler needs clarification.	Correlation with CMM necessary to validate first piece. Need traveler clarification with NC process flow.
90	Mark S/N	0 of 12	No defects.	Desirable to perform laser scribe rather than electro-chemical etch. Eliminate waste stream.
120	Finish ID	0 of 12	Z-axis reference point needs clarif. Use of theoretical center point for for z-zero.	Finish ID must be held to assure fit to finish C'bore fixture.
130	C/O, bore	2 of 12	Traveler callout for cutoff tool needs clarif. Loss two parts for 0.060 dim. Traveler to specify compensation for face stock.	Add op stops to T4 and T6 to assure come up. Tape to allow check of small bore for T4 for C'bore offset.

Figure 2 Continued. Cap 3 Yield Data, PPI Lot; 15 Pieces, Cap 3 Process Improvement Team

Op.	Description	Defects	Comments	Mfg. Investigative Updates
140	Pressure Clean			
160	Dye Penetrant			
170	X-Ray			
180	Dimensional Inspect			
210	A-line			
230	Inspection			

PPI: 10 of 15 parts; product accepted at final(est)

CAP 3 Final Yield 32 of 65 = 50% I-T-D

Schedule 1250 (start qty to yield 840 units) x 6 earned std. Hours, 7500 hrs.
7500 hrs. x 119.19 (dir/dir rate 196) = $893,925.00
Potential Scrap 0.5 x $893,925 = $446,962.50

Figure 2 Continued. Cap 3 Yield Data, PPI Lot; 15 Pieces, Cap 3 Process Improvement Team

CAP 3 Reservoir Process Improvement

First Cut ; Following Detailed Process Map and FMEA Analysis

Item(op)	*Description*	*Actionee*	*ECD*	*Comment*
1(20)	Op 020 need depth mic probe tip to compensate for forging irregularity.	Process Eng.	15-Nov	Tool and Gage crib have no tips. Need to fabricate. **COMPLETE**
2(20)	Clarify traveler for Z-axis Ref. pt.	Process Eng.	15-Nov	Action Complete
3(20)	Overall length, drill point depth, and diameter to be controlled tighter to facilitate finish ops.	Team	15-Nov	Proposed Op 020 tolerances have been submitted to team members for review. **COMPLETE**
4(25)	Replace damaged pie jaws.	Teamleader	15-Nov	**Complete**
5(25)	Assure jaws are drilled and tapped for clamp ring assembly	Teamleader	15-Nov	**Complete**
6(25)	Traveler to specify clamp ring pressure.	Process Eng.	15-Nov	Torque wrench adapter being investigated
7(25)	Incorporate rough OD into traveler.	Process Eng.	15-Nov	Traveler update. **COMPLETE**
8(25)	Generate combined NC program	NC Engr.	15-Nov	**Complete**
9(25)	Investigate option of getting a more accurate machine to perform this operation	Teamleader	30-Nov	Inprocess
10(25)	Traveler narrative to clearly detail NC tape sequence.	Process Engr.	15-Nov	Revised narrative routed for review **COMPLETE**
11(25)	Traveler to specify live center tail stock pressure.	Process Engr.	15-Nov	Inprocess of determining specification. **COMPLETE**
12(25)	Illustrations to specify tighter control depth and length parameters.	Process Engr.	15-Nov	Proposed tolerancing being reviewed by team members **COMPLETE**
13(30)	Eliminate and combine with op 025 setup and run	Process Engr.	15-Nov	**Complete**
14(40)	Traveler narrative to clearly describe NC sequence. (rough I.D operation)	Process Engr.	15-Nov	**Complete**

Table 2. Example of Action Tracking Log

CAP 3 Reservoir Process Improvement

First Cut ; Following Detailed Process Map and FMEA Analysis

Item(op)	Description	Actionee	ECD	Comment
15(40)	Traveler to clarify z zero pt. input using theoretical ctr pt.	Process Engr.	15-Nov	**Complete**
16(40)	Tolerancing to be established to minimize noise at finishing operations.	Process Engr.	15-Nov	Proposed tolerances have been submitted to team members for review. **COMPLETE**
17(60)	Eliminate heat treat operation.	SP Engr. Prod. Engr.	30-Nov	Data to support this suggestion is being compiled for team review **COMPLETE**
18(80)	Traveler narrative to better reflect NC tape sequence and detail when to perform check pass measurements	Process Engr.	15-Jan	Traveler being reviewed by team members. **COMPLETE**
19(80)	MSE required on Precision measurement of finish OD contour. Repeatability and correlation with measurement at machine is in doubt.	Black Belt	15-Apr	Parts are being identified for this study.
20(80)	Finish OD fixture locating surface is in-adequate. Needs team evaluation/ recommendation	Team	15-Feb	Control of rough parameters may allow use for this fixture "as is". **COMPLETE**
21(80)	Traveler narrative to better reflect proper installation of part into fixture to minimize runout.	Process Engr	10-Jan	Inprocess **COMPLETE**
22(100)	Eliminate chemical etch and perform laser scribe. Reduce process waste stream.	Prod. Engr	15-Apr	Product engr. to review with design agency **COMPLETE** pending new DA review.
23(120)	Traveler to detail part clamping pressure, and better reflect NC tape sequence in narrative.(Finish ID)	Prod. Engr	15-Apr	Inprocess
24(120)	MSE required on CMM of this part.	Black Belt	30-Apr	Parts being identified for this effort
25(130)	Finish bore NC requires op stops to allow come up measurements. T4 and T6	NC Engr.	15-Nov	**COMPLETE**

Table 2 Continued. Example of Action Tracking Log

CAP 3 Reservoir Process Improvement

First Cut ; Following Detailed Process Map and FMEA Analysis

Item(op)	Description	Actionee	ECD	Comment
26(130)	Traveler to clear specify NC tape sequence	Process Engr.	30-Nov	Inprocess
27(130)	Traveler to clearly state when come up measurements require to be compensated by taking into consideration stock yet to be removed.	Process Engr.	10-Jan	**COMPLETE**
28(140)	Actions on this process are TBD (clean)	TBD	30-Nov	No activity to date.
29(160-200)	Excessive Transport and routing between NDT needs Investigation	Quality Engr.	15-Apr	QE requested to investigate
30(210)	A-line process requires investigation to assure adequate tooling/traveler documentation.	Process Engr.	30-Mar	No activity to date.
31(misc)	All inprocess inspections and related transportation, to be evaluated for possible elimination. Validate process at the source.	Team	10-Jan	Preliminary investigation **COMPLETE.** Need implementation of hard gaging.
32	Hard gaging would eliminate the need for CMM and the delays experienced in obtaining first pc.	Process Engr.	30-Mar	PTO generated 1/96. Fab. promise /96 Fixture for rough and finish OD. **COMPLETE**
33	NC tape revisions are required to allow setup check passes and op stops to enable mahinist to know where he is at.	Team	10-Jan	NC tape revisions have been completed based on cognizant team member discussions. Need implementation of hard gaging. **COMPLETE**
34	Inprocess data sheets to be reviewed and updated to become more user friendly.	Team	15-Feb	Inprocess data verification sheets have been reviewed and eliminated or updated to better reflect/track processing **COMPLETE**

Table 2 Continued. Example of Action Tracking Log

Team efforts to eliminate and combine operations resulted in reduced cycle times. The product maps in Table 3 depict the before and after cycle times for CAP 3 machining. The amount of time needed to produce CAP 3s was also greatly reduced by the yield improvement realized by eliminating defects. Planned start quantities could be cut in half when anticipated yields were 100% versus 50%. The detail process map for the (improved) current process is seen in Figure 3.

Statistical Process Evaluation

In order to retain the gains achieved by this team effort, constant process monitoring is required. Remaining actions are to perform measurement system evaluations (MSE) in areas where critical parameters are being measured. The MSEs allow one to determine what portion of measurement variability can be attributed to the measurement system versus the actual component being produced. By comparing the amount of measurement system variability to the tolerances expected to be held, one can determine if a particular type of measurement device is capable of measuring a specific parameter. Measurement systems incapable of picking up slight variations in response variables cannot be utilized in reducing variability.

FM&T team members are also tracking specific parameters using statistical process control (SPC) charts. This data is used to calculate process capabilities. See Figures 4 and 5 for an SPC example and process capability determination.

	Reservoir			**Product Name:**						
	Product Process Map									
				Part Name:	Cap 3					
							Convert Standard Hours			
	Process Eng: A.L.Wannamaker			**Part No:**					by Net Efficiency:	40%
	Black Belt: A.L.Wannamaker									
									Lot Size:	40
				Type of Activity						
			Machine	Actual Hrs		Std Hrs	Unit Std Hrs			Actual Hrs
	Activities of the Product	Dept	Code	Transp	Wait	Setup	Prod	Insp	Lot Size	Per Lot
1	Release Job				16					16.0
2	Move to D25			4						4.0
3	Serialize	25	Z902				0.035		40	3.5
4	Queue				8					8.0
5	Setup*	25	A821			3.500				8.8
6	Face, Bore, & Drill*	25	A821				0.406		40	40.6
7	Setup*	25	A821			3.500				8.8
8	Face & Spot Drill*	25	A821				0.200		40	20.0
9	Setup*	25	A821			3.500				8.8
10	Rough OD*	25	A821				0.869		40	86.9
11	Setup*	25	A821			3.500				8.8
12	Rough ID*	25	A821				1.162		40	116.2
13	Move to D98			4						4.0
14	Queue				8					8.0
15	Heat Treat	98	K613				0.750		40	75.0
16	Move to D25			4						4.0
17	Queue				8					8.0
18	Setup*	25	A840			3.500				8.8
19	Finish OD*	25	A840				0.500		40	50.0
20	Move to D95			4						4.0
21	Queue				8					8.0
22	Electro Chem Etch	95	Z901				0.035		40	3.5
23	Move to D25			4						4.0
24	Queue				8					8.0
25	Setup*	25	A840			3.500				8.8
26	Finish ID*	25	A840				0.800		40	80.0
27	Setup*	25	A840			3.500				8.8
28	Finish Bore*	25	A840				0.325		40	32.5
29	Queue				8					8.0
30	Deburr	25	Z901				0.205		40	20.5
31	Queue				8					8.0
32	Aqueous Clean	25	J110				0.075		40	7.5
33	Queue				8					8.0
34	Move to D431			4						4.0
35	Dye Penetrant	431	X110					0.150	40	15.0
36	Queue				8					8.0
37	Radiography	431	X110					0.200	40	20.0
38	Move to D420			4						4.0
39	Queue				8					8.0
40	Dimensional Insp	420	X110					0.200	40	20.0
41	Move to D426			4						4.0
42	Queue				8					8.0
43	CMM Insp	426	X110					0.200	40	20.0
44	Move to D420			4						4.0
45	Insp Paperwork	420	X110					0.050	40	5.0
46	Move to D92			4						4.0
47	Queue				8					8.0
48	Final Aqueous Clean	92	J110				0.075		40	7.5
49	Move to D97			4						4.0
50	Queue				8					8.0
51	Acid Clean	97	J450				0.115		40	11.5
52	Queue				8					8.0
53	Final Insp	497	X110					0.050	40	5.0
54	Move to Stores			4						4.0
55	Store Completed Job				16					16.0
	*2 Shift Operations								Total Hrs:	893.5
								Total Working Days:		111.7
								(8 Hrs / Day)		
					Total Working Days after reducing indicated					
					operations by 25% to account for 2 shifts:					96.4

Table 3. Product Process Map Showing Before and After Cycle Times

	Reservoir			**Product Name:**						
	Product Process Map									
				Part Name:	Cap 3					
							Convert Standard Hours			
	Process Eng: A.L.Wannamaker			**Part No:**				by Net Efficiency:		40%
	Black Belt: A.L.Wannamaker									
									Lot Size:	40
				Type of Activity						
			Machine	Actual Hrs		Std Hrs	Unit Std Hrs			Actual Hrs
	Activities of the Product	Dept	Code	Transp	Wait	Setup	Prod	Insp	Lot Size	Per Lot
1	Release Job				16					16.0
2	Move to D25			4						4.0
3	Serialize	25	Z902				0.035		40	3.5
4	Queue				8					8.0
5	Setup*	25	A821			3.500				8.8
6	Face, Bore, & Drill*	25	A821				0.406		40	40.6
7	Setup*	25	A821			3.500				8.8
8	Face & Spot Drill/RghOD*	25	A821				1.069		40	106.9
11	Setup*	25	A821			3.500				8.8
12	Rough ID*	25	A821				1.162		40	116.2
17	Queue				8					8.0
18	Setup*	25	A840			3.500				8.8
19	Finish OD*	25	A840				0.500		40	50.0
21	Queue				8					8.0
22	Electro Chem Etch	95	Z901				0.035		40	3.5
24	Queue				8					8.0
25	Setup*	25	A840			3.500				8.8
26	Finish ID*	25	A840				0.800		40	80.0
27	Setup*	25	A840			3.500				8.8
28	Finish Bore*	25	A840				0.325		40	32.5
29	Queue				8					8.0
30	Deburr	25	Z901				0.205		40	20.5
31	Queue				8					8.0
32	Aqueous Clean	25	J110				0.075		40	7.5
33	Queue				8					8.0
34	Move to D431			4						4.0
35	Dye Penetrant	431	X110					0.150	40	15.0
36	Queue				8					8.0
37	Radiography	431	X110					0.200	40	20.0
38	Move to D420			4						4.0
39	Queue				8					8.0
40	Dimensional Insp	420	X110					0.200	40	20.0
41	Move to D426			4						4.0
42	Queue				8					8.0
43	CMM Insp	426	X110					0.200	40	20.0
44	Move to D420			4						4.0
45	Insp Paperwork	420	X110					0.050	40	5.0
49	Move to D97			4						4.0
50	Queue				8					8.0
51	Acid Clean	97	J450				0.115		40	11.5
52	Queue				8					8.0
53	Final Insp	497	X110					0.050	40	5.0
54	Move to Stores			4						4.0
55	Store Completed Job				16					16.0
	*2 Shift Operations								Total Hrs:	766.2
								Total Working Days:		95.8
								(8 Hrs / Day)		
					Total Working Days after reducing indicated					
					operations by 25% to account for 2 shifts:					80.8

Table 3 Continued. Product Process Map Showing Before and After Cycle Times

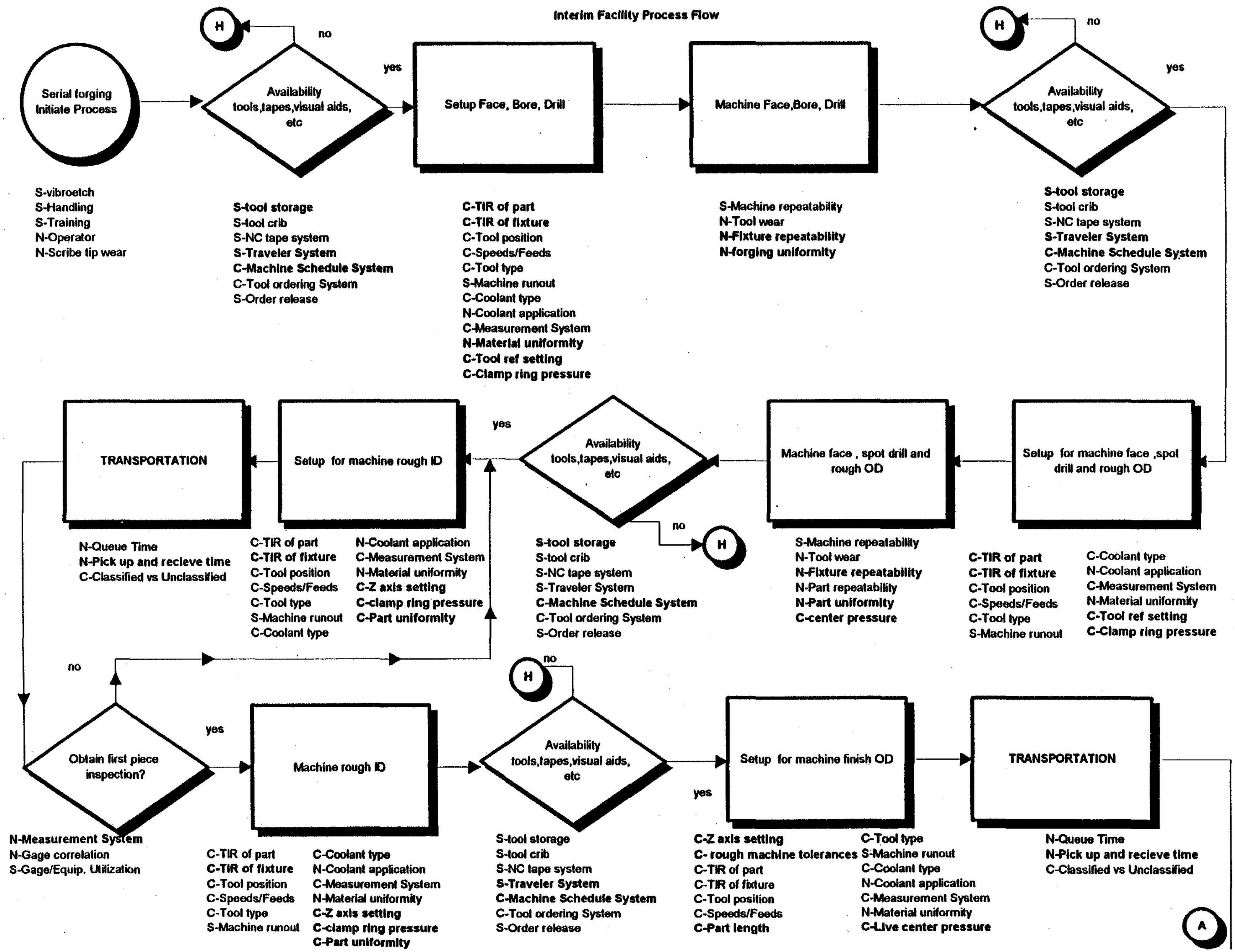


Figure 3. Map of Cap 3 Improved Machining Process

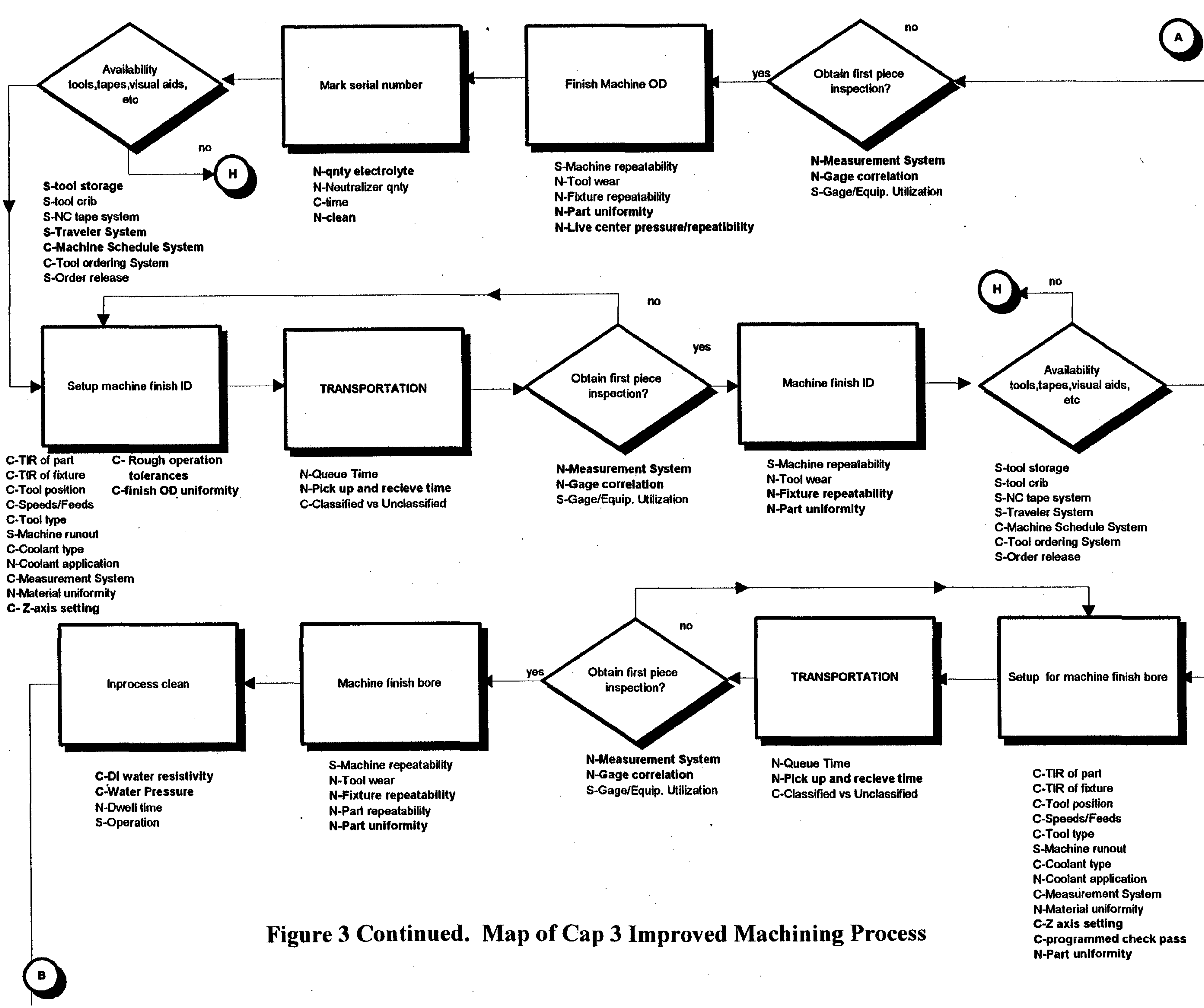


Figure 3 Continued. Map of Cap 3 Improved Machining Process

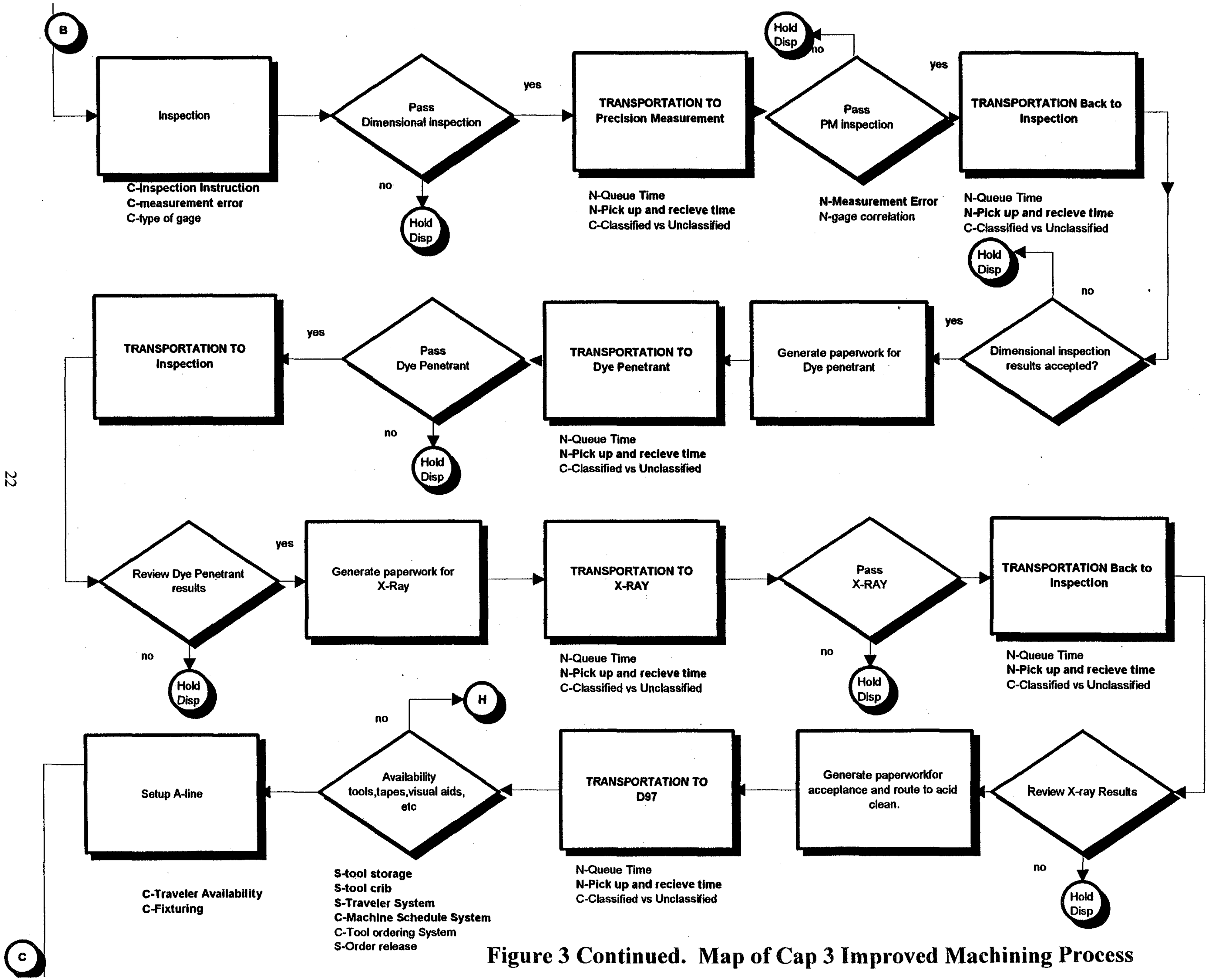
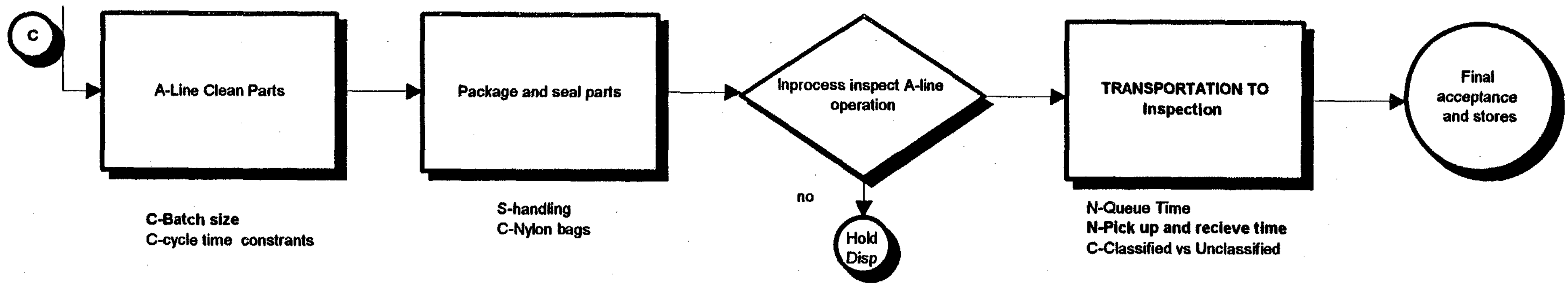


Figure 3 Continued. Map of Cap 3 Improved Machining Process



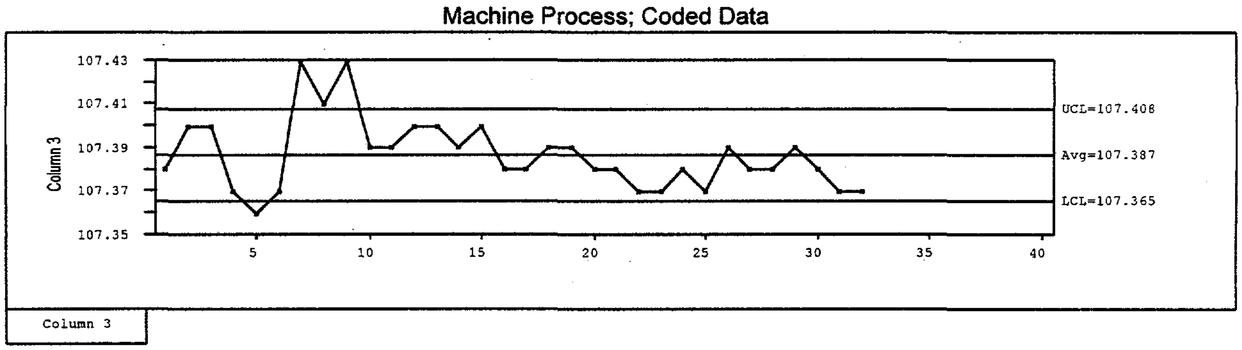
PARAMETER KEY
N- Noise
S- SOP
C- Controllable
Critical Parameters in Bold

H = Hold point due to equipment/material availability

Hold Disp = Hold point cause by the need for inspect defect disposition

Blue designates unplanned rework operation

Figure 3 Continued. Map of Cap 3 Improved Machining Process



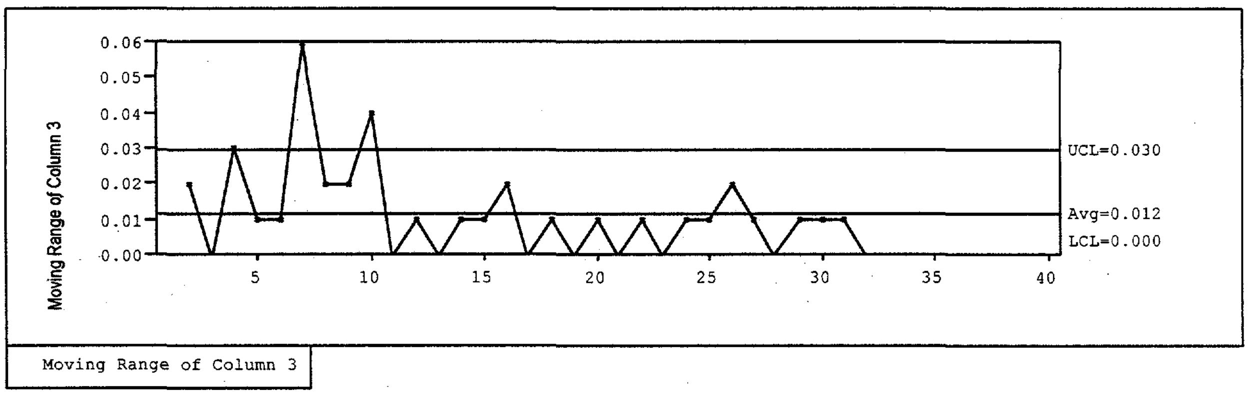
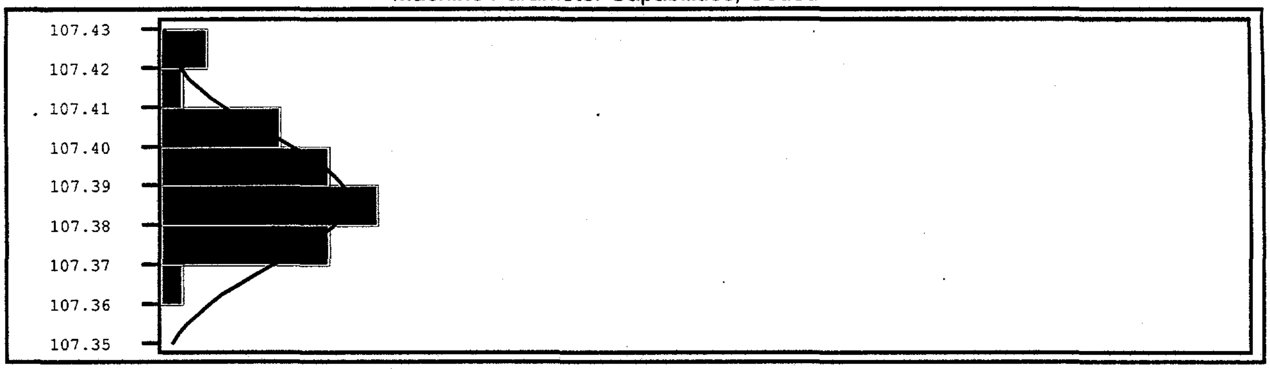


Figure 4. Individual Moving Range Chart

As one can see, the process capability for this particular machined parameter is well within +/- six sigma limits. Additional critical parameters are monitored in a similar fashion.

Design of experiment (DoE) is used when statistical validation of a process parameter's influence on the outcome is needed. This is essential when trying to make adjustments to a process to reduce variability. At the time of this writing, DoE has not been used on the CAP 3. As the process is monitored over time, causes for long term process variation may have to be validated statistically.

Machine Parameter Capabilities; Coded



Quantities

maximum	100.0%	107.43
	99.5%	107.43
	97.5%	107.43
	90.0%	107.41
quartile	75.0%	107.40
median	50.0%	107.38
quartile	25.0%	107.37
	10.0%	107.37
	2.5%	107.36
	0.5%	107.36
minimum	0.0%	107.36

Moments

Mean	107.3866
Std Dev	0.0164
Std Error Mean	0.0029
Upper 95% Mean	107.3925
Lower 95% Mean	107.3807
N	32.0000
Sum Weights	32.0000

Capability Analysis

Specification	Value	Percent	Actual	Normal
Lower Spec Limit	107.2	%Below LSL	0.000	0.000
Upper Spec Limit	107.6	%Above USL	0.000	0.000
Spec Target	107.4			
Sigma	0.016384			

Capability	Index
CPL	3.796
CPU	4.342
CPK	3.796
CP	4.069
CPM	3.146

Test for Normality
Shapiro-Wilk W Test

W	Prob<W
0.892272	0.0038

Figure 5. Process Capability Determination

ACCOMPLISHMENTS

The data supports outstanding success with six sigma implementation on this reservoir machining process. After the first three fabrication lots were run at FM&T, a cumulative yield of only 50% had been documented. This product is extremely difficult to machine and maintain tolerances.

The team did an excellent job detail mapping the process and obtaining expert knowledge on which parameters were driving response variables. Operations were combined/eliminated and tooling/gauging was incorporated to facilitate process control. The two fabrication lots following this teaming activity have yielded 100% on each run. During this time, core team members have been able to transfer the expert knowledge gained during this exercise to additional operators. Several additional operators have been trained to perform critical machining operations during these two flawless production runs.

Data supplied by Program Management supports 1.1 million dollars in labor, support, and material savings over a five-year period.

As part of AlliedSignal's initiative to strive for continual improvement, additional reservoir product will be targeted for operational excellence, six sigma methodology implementation. Product-specific topical reports will document results.