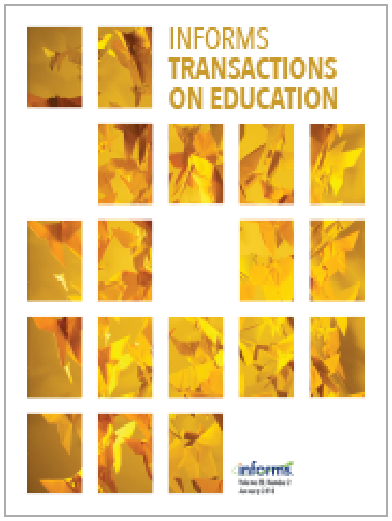

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Case

The MotoTech Manufacturing Company: Process Control and Improvement

Prakash Mirchandani
Katz Graduate School of Business, University of Pittsburgh, 358 Mervis Hall, Pittsburgh, Pennsylvania 15260,
pmirchan@katz.pitt.edu

Introduction

You and four of your ex-classmates run a small, but rapidly growing, management consulting firm that provides advice to high-technology companies. What had started off as a half-baked idea late one night when you were busy working on an MBA project six years ago has resulted in a highly successful consulting firm today. Indeed, who would have dreamed that all of the fights and the arguments your group had had when doing school projects could possibly result in such a closely-knit team just a few years later? You still challenge each other, still debate the pros and cons of each issue, and are often frustrated with each other, but the end-product is always much better as a consequence.

Today is special. You are visiting a company called MotoTech Manufacturing (MM) that was founded by another former batch mate. You were a bit surprised to get a phone call from the old friend requesting that one of you go over for a plant visit. That is how it typically works in your business: Just one of the five visits the client along with some junior members of the consulting staff. In this case though, because all of you know the founder, and all five of you had wanted to go.

You discuss the potential assignment during your car ride to MM and conclude that you probably would be required to make recommendations about MM's manufacturing process. Almost all domestic manufacturing firms have been under pressure to improve their processes, and you speculate that you would probably be investigating how to improve manufacturing both in the short term and the long term. In doing so, you anticipate having to first determine whether MM's process is capable of producing products that meet the customer requirements and, if not, to recommend ways of doing so.

The Situation

MotoTech Manufacturing (MM) is a medium-sized firm that produces integrated circuits for the electronics—particularly, the consumer electronics—industry. Integrated circuits are used in computers, automobiles, airplanes, appliances, toys, watches, cell phones, cameras, televisions, stereo components, medical diagnostic equipment, etc. Integrated circuits allow electronic products to be smaller in size, have greater functionality, and faster speed, yet they are lower in cost. The electronics and computer industry has grown steadily over the past several years and now employs more people in the United States than the steel, automobile, and pharmaceutical manufacturing industries put together.[1]

The demand for integrated circuits has also grown sharply during the past decade, with newer applications being identified every day, and this trend is expected to continue into the future. This increase in demand for integrated circuits has, in turn, resulted in several highly profitable years for MM. MM is proud to be a part of this growth in the United States: Roughly 45% of the worldwide integrated circuit demand of $256 billion is met from domestic production.[2]

More recently, though, John Tagole, MM's founder and CEO, has been troubled by MM's lower yield

[1] http://www.bls.gov/oco/cg/indchar.htm. Checked on June 6, 2009. Latest available data on this *Bureau of Labor Statistics* website are for 2006—before the 2008–2009 reorganization of the domestic automotive industry.

[2] http://www.sia-online.org/cs/industry_resources/industry_fact_sheet. The United States continues to be a market leader in this industry. One reason is that the rate of innovation in the technology for this industry is high, with annual research and development expenses touching 16% of sales.

(higher rejection rate) values, compared to those of its competitors. Moreover, overseas competitors, particularly from Taiwan, Japan, Singapore, Korea, Thailand, and now China, have started to encroach upon MM's traditional customer base. It has been six years since John Tagole started MM after getting his MBA from the Great Western Pennsylvania Graduate School of Business (GWPGSB), but the competitive pressures attributable to global competition have never been higher. While John Tagole knows that this type of competition is good for the consumer in the long run because it forces companies to continuously make productivity improvements, he also realizes that his dreams of growing MM into a global chip supplier for the consumer electronics industry might evaporate in thin air if he makes a bad decision now in what is clearly a critical juncture in MM's short history.

On this cool November morning, John Tagole has a premonition of receiving some adverse news. Sure enough, he gets a call from Danika Katz, VP of Procurement, Semicon International, one of MM's largest customers. Semicon Transcontinental is a consumer electronics manufacturer. Danika first discusses the long and successful vendor-buyer relationship that MM and Semicon have had for six years. Then she informs MM that Semicon engineers have drastically tightened the design specifications for the components going into the new line of super-high-definition televisions with three-dimensional-like imagery. Danika informs John Tagole that although MM's products meet Semicon's current specification limits, they do not meet the newly designed specification limits, and unless MM can meet the new specification, Semicon might have to take its business elsewhere.

After the call John Tagole wonders, "Should I just ignore this call? Are these new specification limits temporary—imposed by a young, overenthusiastic design engineer?" "Maybe," he speculates, "if we wait long enough, Semicon will eventually be forced to relax the specifications and buy MM's current product, especially if none of the other chip manufacturers can meet the new specifications. On the other hand, what if Semicon does not relax the specifications and drops MM as its supplier? Can I really afford to lose such an important customer?"

He makes a quick decision and decides to call "The Famous Five"—his batch mates who are now running a consulting company. (As he places the call, why, he tries to remember, were they called "The Famous Five" at GWPGSB?)

The Process

John Tagole describes the manufacturing process to The Famous Five during their visit: "The critical raw material for virtually all integrated circuits is silicon, which is the primary constituent of common sand. The circuits are manufactured from many "die" that are fabricated on silicon wafers (in a facility referred to as a "fab"). The die are also known as chips. The silicon wafer can be from about four to 10 inches in diameter and may contain from a hundred to several thousand chips. During the wafer fabrication process, each wafer goes through several steps to produce the final chip. These steps include processes such as plasma etching, ion implantation, chemical deposition, and photolithography. Once a wafer has been processed and tested, it is cut into individual chips. The chips are then packaged for sale and used in the electronic systems of cars, computers, and many other products."

The End of the First Visit

John Tagole is clearly proud of his success as he finishes giving The Famous Five a tour of his plant. They too must be proud of his achievement (as he is of theirs), because all five of them have shown up for this fact-finding trip. They ask the right questions, and John Tagole is impressed by the speed with which they zero in on the problem. The "diffusion" stage, The Famous Five conclude, is the problem with the current process. "Let's address the problems at the diffusion stage first, and then we will look at the remaining stages of the process." John Tagole marvels: "These people must have a sixth sense. Danika Katz's new specs all deal with the diffusion stage." In any event, he goes ahead and describes the diffusion stage to The Famous Five.

"In many process steps, the wafers are processed in a batch, with several wafers processed together at the same step. One such process is the diffusion step. As many as two hundred wafers may be batch processed together in a diffusion furnace. During this step, a layer of material (e.g., silicon dioxide) is deposited onto each wafer. The thickness of the deposit must be tightly controlled at a specified target thickness. The target thickness for this diffusion process is 3,000 Å.[3] To ensure the desired functionality and reliability of the chip, the deposit thickness must lie in the range of 2,900 to 3,100 Å."

The Famous Five go into a "huddle." John Tagole is used to their loud arguments from his time back at the GWPGSB—but his staff is not. He chuckles to himself as he overhears worried staff members muttering about calling plant security.

After about an hour, The Famous Five emerge and discuss their plan of action with John Tagole. They

[3] An angstrom (Å) is a unit for measuring length and equals 10^{-10} meters.

instruct John Tagole on what data to collect, and then say, "Play time, John. You owe us at least a lunch! Let's catch up on what's been happening on the personal front."

Part A. Should John Tagole have "waited out the storm," hoping that Semicon will relax its new, more stringent specifications? Would this strategy have worked in the short term? In the long term?

Part B. John Tagole provides your group, The Famous Five, with the data set in Table 1 and in the "Pre_Improvement" worksheet of the file "*MotoTech (PCI) Data.xls*." The data were taken from the diffusion process. Samples of three wafers were randomly selected from each batch of 200 wafers, and the thickness of the silicon dioxide deposition was measured on the wafers. The data are from 72 batches.

Answer the following questions for this data set.

1. For this data set, construct the X-bar and range control charts. Attach a printout showing your X-bar and R control charts.

2. Use the range chart to determine whether the process variation is in control.

3. Use the X-bar chart to determine if the process mean is in control.

4. If the range chart is found to be out of control in Part B2 above, would the control limits of the X-bar chart have been valid? Why or why not?

Part C. After observing the control charts in Part B, The Famous Five investigate the reasons for the identifiable causes of variation. They find that the process went out of control during times when the plant air conditioning system was shut down for preventive maintenance. They recommend that a back-up air conditioner be installed and that the temperature in the diffusion room be maintained at 60°F. This recommended temperature setting is based on The Famous Five's general experience, although local atmospheric conditions and raw-material composition can also potentially affect the recommended temperature. Until the new air conditioner can be installed, The Famous Five recommend that the preventive maintenance be carried out on weekend nights, when the diffusion process is stopped. They ask John Tagole to collect data for an additional 72 batches under these controlled conditions. These data are enclosed in Table 2 and in the worksheet "Post_Improvement."

1. For this data set, construct the X-bar and range charts. Attach a printout showing your control charts.

2. Use the range chart to determine whether the process variation is in control.

3. Use the X-bar chart to determine whether the process mean is in control.

Part D. Based on your analysis in Parts B and C, what would you recommend?

Part E. In Part C, we found that the process is in control when we set the temperature in the diffusion room to 60°F. The Famous Five construct a histogram of the "Post_Improvement" observations and conclude that the distribution is normal.[4] Answer the following questions for the data used in Part C.

1. What is the *cumulative* probability for a single wafer to have a thickness of 3,000 Å?

2. What is the percentage of defectives being produced under the current setup?

3. Compute the process capability index, C_p, for this situation. Is the process capable of meeting the customer's requirements? Is C_p the appropriate metric for measuring process capability in this case? If so, why? If not, why not? What other metric would you suggest?

4. Is this a six sigma process? If not, what is its sigma level? Assuming that the process mean can drift by, at most, 1.5 sigma in either direction of the target without being detected, compute the approximate number of defectives out of a million. (*Hint*: In Motorola's experience, process mean shifts of up to 1.5 sigma can go undetected, and so they recommended the use of this assumption to calculate the proportion of defectives for a given sigma level.)

Part F (Looking Ahead).

John Tagole is pondering over what to do next... the secret of his success has been making many small process improvements continuously and making fundamental process reengineering changes as and when needed. The diffusion process has been brought under control following the initial analysis done by The Famous Five. However, the rejection rate is still high, which leads to higher unit costs and cuts into MM's profits. He has been advised by The Famous Five to do a "design of experiments"[5] study. This study will help in determining whether 60°F is the right temperature, or whether this setting needs to be fine-tuned. He believes that such experimentation is in line with the philosophy of continuous improvement—advocated by many quality gurus. This approach has made Toyota an automotive powerhouse worldwide, resulting in its overtaking General Motors in 2008 global sales,[6] even before the reorganization of GM. Through this investigation, he hopes to identify the right temperature setting, possibly also identifying any underlying interaction between temperature and other input factors. This study is ongoing, and its findings will be implemented in the next few weeks.

[4] You should check this by constructing your own histogram using Excel or by doing a check for normality, using a statistical package.

[5] The case "The MotoTech Manufacturing Company: Design of Experiments/ANOVA" shows how to use Design of Experiments for making further quality improvements.

[6] "GM Fell Behind Toyota in 2008." 2009. *The Wall Street Journal* (January 22). (Toyota sold almost nine million vehicles in 2008 worldwide, while GM sold about 8.3 million.)

Table 1 Pre_Improvement Data

Data and Initial Computations

Sample no.	Thickness (in thousands of Å) 1	2	3	Sample mean	Sample range	Sample no.	Thickness (in thousands of Å) 1	2	3	Sample mean	Sample range
1	3.265	3.097	3.201	3.1877	0.1680	38	3.170	3.171	3.229	3.1900	0.0590
2	3.273	3.244	3.125	3.2140	0.1480	39	3.067	3.146	3.178	3.1303	0.1110
3	3.197	3.174	3.186	3.1857	0.0230	40	3.819	3.898	3.309	3.6753	0.5890
4	3.215	3.158	3.122	3.1650	0.0930	41	3.216	3.253	3.310	3.2597	0.0940
5	3.321	3.200	3.320	3.2803	0.1210	42	3.156	3.200	3.067	3.1410	0.1330
6	3.253	3.254	3.177	3.2280	0.0770	43	3.141	3.019	3.162	3.1073	0.1430
7	3.186	3.172	3.138	3.1653	0.0480	44	3.226	3.236	3.250	3.2373	0.0240
8	3.255	2.927	3.173	3.1183	0.3280	45	3.247	3.250	3.233	3.2433	0.0170
9	3.195	3.145	3.125	3.1550	0.0700	46	3.164	3.051	3.136	3.1170	0.1130
10	3.205	3.160	3.131	3.1653	0.0740	47	3.012	3.260	3.202	3.1580	0.2480
11	3.008	3.098	3.094	3.0667	0.0900	48	3.209	3.002	3.174	3.1283	0.2070
12	3.191	3.122	3.151	3.1547	0.0690	49	3.125	3.132	3.134	3.1303	0.0090
13	3.108	3.103	3.105	3.1053	0.0050	50	3.111	3.023	3.177	3.1037	0.1540
14	3.005	3.301	3.010	3.1053	0.2960	51	3.306	3.119	3.133	3.1860	0.1870
15	3.228	3.007	3.000	3.0783	0.2280	52	3.170	3.203	3.210	3.1943	0.0400
16	3.080	3.069	3.063	3.0707	0.0170	53	3.011	3.197	3.076	3.0947	0.1860
17	3.152	3.029	3.202	3.1277	0.1730	54	3.137	3.031	3.039	3.0690	0.1060
18	3.144	3.133	2.993	3.0900	0.1510	55	3.178	3.003	3.193	3.1247	0.1900
19	3.244	3.308	3.202	3.2513	0.1060	56	3.105	3.068	3.249	3.1407	0.1810
20	3.062	3.100	3.091	3.0843	0.0380	57	3.044	3.005	3.010	3.0197	0.0390
21	3.141	3.025	3.113	3.0930	0.1160	58	3.164	3.058	3.197	3.1397	0.1390
22	3.179	3.037	3.207	3.1410	0.1700	59	3.008	3.025	3.053	3.0287	0.0450
23	3.180	3.137	3.171	3.1627	0.0430	60	3.236	3.091	3.271	3.1993	0.1800
24	3.195	3.098	3.173	3.1553	0.0970	61	3.011	2.982	2.959	2.9840	0.0520
25	2.960	3.051	3.046	3.0190	0.0910	62	3.170	3.176	3.098	3.1480	0.0780
26	3.175	3.215	3.096	3.1620	0.1190	63	3.304	3.243	3.064	3.2037	0.2400
27	3.286	3.212	3.265	3.2543	0.0740	64	3.037	2.968	2.959	2.9880	0.0780
28	3.005	3.123	3.138	3.0887	0.1330	65	3.075	3.174	3.027	3.0920	0.1470
29	3.065	3.062	3.030	3.0523	0.0350	66	3.255	3.245	3.241	3.2470	0.0140
30	3.173	3.177	3.075	3.1417	0.1020	67	3.273	3.067	3.000	3.1133	0.2730
31	3.068	3.090	3.064	3.0740	0.0260	68	3.108	3.132	2.904	3.0480	0.2280
32	2.919	2.970	2.979	2.9560	0.0600	69	3.001	2.987	3.064	3.0173	0.0770
33	3.001	3.021	2.930	2.9840	0.0910	70	2.978	2.890	2.952	2.9400	0.0880
34	3.250	3.127	3.230	3.2023	0.1230	71	3.116	3.110	3.115	3.1137	0.0060
35	3.179	3.104	3.194	3.1590	0.0900	72	3.022	3.007	2.997	3.0087	0.0250
36	3.109	3.100	3.227	3.1453	0.1270						
37	2.996	3.042	3.063	3.0337	0.0670	Mean				3.1326	0.1165

Table 2 Post_Improvement Data

Data and Initial Computations

Sample no.	Thickness (in thousands of Å) 1	2	3	Sample mean	Sample range	Sample no.	Thickness (in thousands of Å) 1	2	3	Sample mean	Sample range
1	3.039	3.011	3.095	3.0483	0.0840	38	3.032	3.105	3.111	3.0827	0.0790
2	3.041	3.071	3.049	3.0537	0.0300	39	3.157	3.079	3.014	3.0833	0.1430
3	3.047	3.089	3.102	3.0793	0.0550	40	3.073	3.049	3.056	3.0593	0.0240
4	3.074	3.047	3.019	3.0467	0.0550	41	3.068	3.041	3.042	3.0503	0.0270
5	3.081	3.109	3.010	3.0667	0.0990	42	3.059	3.024	2.970	3.0177	0.0890
6	3.018	3.148	3.030	3.0653	0.1300	43	3.057	3.109	3.068	3.0780	0.0520
7	3.061	3.093	3.094	3.0827	0.0330	44	3.003	3.032	3.046	3.0270	0.0430
8	3.075	3.080	3.074	3.0763	0.0060	45	3.025	3.051	3.066	3.0473	0.0410
9	3.042	3.067	3.019	3.0427	0.0480	46	3.046	3.105	3.074	3.0750	0.0590
10	3.083	3.133	3.057	3.0910	0.0760	47	3.060	3.133	3.121	3.1047	0.0730

Table 2 Post_Improvement Data (Continued)

Data and Initial Computations

Sample no.	Thickness (in thousands of Å) 1	2	3	Sample mean	Sample range	Sample no.	Thickness (in thousands of Å) 1	2	3	Sample mean	Sample range
11	3.057	3.119	3.105	3.0937	0.0620	48	3.108	3.007	3.108	3.0743	0.1010
12	3.086	3.040	3.021	3.0490	0.0650	49	3.068	3.105	3.007	3.0600	0.0980
13	3.084	3.040	3.087	3.0703	0.0470	50	3.037	3.060	3.074	3.0570	0.0370
14	3.122	3.056	3.033	3.0703	0.0890	51	3.047	3.056	3.067	3.0567	0.0200
15	3.132	2.987	3.048	3.0557	0.1450	52	3.008	3.052	3.004	3.0213	0.0480
16	3.096	3.044	3.126	3.0887	0.0820	53	3.058	3.059	3.095	3.0707	0.0370
17	3.048	3.103	3.057	3.0693	0.0550	54	3.075	3.017	3.043	3.0450	0.0580
18	3.067	3.040	3.108	3.0717	0.0680	55	3.042	3.133	3.111	3.0953	0.0910
19	3.014	3.004	3.062	3.0267	0.0580	56	3.042	3.048	3.041	3.0437	0.0070
20	3.089	3.006	3.038	3.0443	0.0830	57	3.072	3.020	3.034	3.0420	0.0520
21	3.094	3.066	3.005	3.0550	0.0890	58	3.031	2.981	3.053	3.0217	0.0720
22	3.031	3.139	3.106	3.0920	0.1080	59	3.023	3.105	3.075	3.0677	0.0820
23	3.051	3.086	3.058	3.0650	0.0350	60	3.043	3.077	3.085	3.0683	0.0420
24	3.086	3.018	3.104	3.0693	0.0860	61	3.032	3.073	3.060	3.0550	0.0410
25	3.045	3.026	3.036	3.0357	0.0190	62	3.094	2.991	3.080	3.0550	0.1030
26	3.039	2.980	3.034	3.0177	0.0590	63	3.017	3.046	3.044	3.0357	0.0290
27	3.047	3.030	3.099	3.0587	0.0690	64	3.070	3.099	2.970	3.0463	0.1290
28	2.961	3.076	3.015	3.0173	0.1150	65	3.063	2.970	3.057	3.0300	0.0930
29	3.044	3.053	3.027	3.0413	0.0260	66	3.073	3.120	3.086	3.0930	0.0470
30	3.051	2.982	3.137	3.0567	0.1550	67	3.078	3.075	3.109	3.0873	0.0340
31	3.071	3.046	3.074	3.0637	0.0280	68	3.062	3.129	3.002	3.0643	0.1270
32	3.101	3.093	3.007	3.0670	0.0940	69	3.078	3.113	3.051	3.0807	0.0620
33	3.073	2.998	3.103	3.0580	0.1050	70	3.046	3.069	3.079	3.0647	0.0330
34	3.096	3.071	3.040	3.0690	0.0560	71	3.152	3.073	3.053	3.0927	0.0990
35	3.075	3.085	3.049	3.0697	0.0360	72	3.035	3.094	3.127	3.0853	0.0920
36	3.046	3.098	3.046	3.0633	0.0520						
37	3.079	3.030	3.135	3.0813	0.1050	Mean				3.0613	0.0677

Planning for the more distant future, John Tagole wants to evaluate if modernizing the diffusion equipment is economically worthwhile. He does not want to purchase new equipment (which can cost several tens of millions of dollars), because Intel has recently claimed[7] that it has found a replacement material for silicon dioxide; the claim, if substantiated, will make the current chip manufacturing technology obsolete in the next five to seven years. Even if Intel's technology is unsuccessful, IBM's new technology, which allows chips to consume less power, might become available in this time frame.[8] (Power consumption by chips has become a major issue with computer manufacturers.)

To summarize: John Tagole's current planning horizon is five to seven years. MM's equipment supplier has informed John Tagole that MM will be able to lease, on an annual basis, very precise diffusion equipment at an incremental (over the cost of the current equipment) leasing and operating cost of \$15,000,000 per year. This new machine will have a process standard deviation of 15 Å, but as with the current equipment, it will be difficult to detect process mean shifts of up to 1.5 sigma. The capacity of the new machine will be the same as that of the current machine. John Tagole calls The Famous Five again to evaluate whether the MM should lease the new equipment.

John Tagole informs The Famous Five that MM produces a million wafers per year. MM has an enviable brand equity that allows it to sell its entire production and has led to a sales growth rate of 20% per year. Now that the quality has been improved, John Tagole expects this growth rate to continue in the near future. You therefore expect the production and sales to increase by 20% per year, starting from the current value of a million wafers per year.

The wafers have a unit contribution of \$150 unless any rework is needed. Because Semicon is a major MM customer, The Famous Five decide to do the analysis using Semicon's specifications which allow thicknesses between 2,900 and 3,100 Å. John Tagole

[7] "Intel claims a breakthrough in chip design," 2003. *The Wall Street Journal* (November 5).

[8] "Start-Up's power-saving chip to be based on IBM technology." 2005. *The Wall Street Journal* (October 24).

informs The Famous Five that the rework costs for wafers with thicknesses in different ranges is as follows:

Thickness between (in Å)	Rework cost per unit ($)
2,860 to 2,880	125
2,880 to 2,900	50
3,100 to 3,120	50
3,120 to 3,140	125

Thus, the unit contribution for a wafer that originally had a thickness of 3,110 Å gets reduced to $\$150 - \$50 = \$100$ because of rework. Any wafers with a thickness exceeding 3,140 Å or less than 2,860 Å cannot be reworked; for these wafers, MM must expense the variable cost of $500, which it has already incurred.

1. Should The Famous Five recommend that MM lease the new equipment?[9] Why or why not? (In the computation of the expected costs, you can ignore the time value of money because some of you have not yet taken the financial management course and may not know how to incorporate it. You can also ignore inflation.)
2. What else would you recommend for the future?

Supplementary Material

Files that accompany this paper can be found and downloaded from http://ite.pubs.informs.org.

Acknowledgments

I am grateful to Dr. Skip Weed, formerly of Motorola University, for suggesting the semiconductor environment as a backdrop of the case and providing a short description of the production process. The actual problem situation has been modified for pedagogical reasons.

[9] To find the probabilities, you can use the normal tables, or you can use Excel's = NORMDIST function.