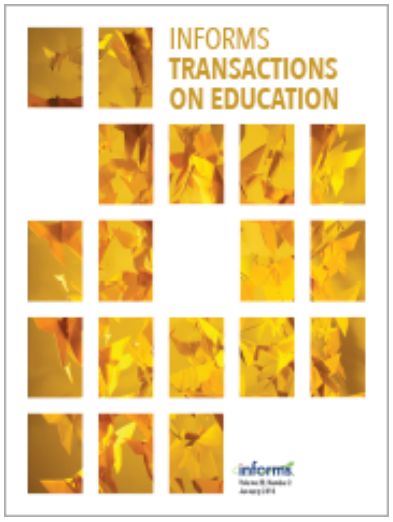

INFORMS Transactions on Education

Publication details, including instructions for authors and subscription information:
http://pubsonline.informs.org

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To cite this article:
Prakash Mirchandani, (2010) Case—The MotoTech Manufacturing Company: Design of Experiments/ANOVA. INFORMS Transactions on Education 10(2):85-89. https://doi.org/10.1287/ited.1090.0041cs-b

Vol. 10, No. 2, January 2010, pp. 85–89
ISSN 1532-0545 | 10 | 1002 | 0085
INFORMS Transactions on Education
DOI 10.1287/ited.1090.0041cs-b

Case

The MotoTech Manufacturing Company: Design of Experiments/ANOVA*

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The Sequel

"I am so glad that we could help out John Tagole the last time around," you say to your fellow Famous Five partners as you are driving to visit MotoTech Manufacturing (MM) once again.

"After MM installed the new air-conditioning equipment, the diffusion process was brought under control, and the quality of the product improved. Do you know whether MM ordered the more advanced diffusion equipment as we had recommended?", you ask no one in particular.

One of your partners responds: "Yes, I saw a press release announcing the purchase. Unfortunately, the press release also said that the equipment supplier is backed-up, and MM does not expect delivery of the new machine for another nine to twelve months, possibly longer. I believe the special lease-promotion that the supplier was having, and the improving domestic economy spiked the supplier's order volume, and they are having difficulty filling the demand."

"Maybe, that's why John Tagole has requested us to visit MM again," you remark as you take the turnpike exit for MM headquarters. "He must be in quite a pickle with Semicon wanting tighter specifications, his current process still lacking, even after the improvements that have been made, and the incessant pressure from other competitors wanting to grab his business."

The Meeting

John Tagole starts the meeting. "Greetings, and thanks for visiting MM again! The advice you provided us previously helped us improve our quality significantly. Danika Katz of Semicon International called just the other day and we have been selected to be their sole supplier of integrated chips for the next three years. Was that a relief! Rather than lose one of our biggest customers, we signed a three-year contract. More than the contract itself, I was delighted when Danika Katz told us that she has complete trust in our ability to continue improving the quality. Thanks, once again, for the job you did for us. Another piece of good news is that we are about to sign a long-term contract with World Motor Company, and negotiations with another big automotive manufacturer are ongoing. As you know, modern cars have several hundred integrated chips per vehicle to control everything from brakes to ignition to airbags; these new developments will provide a solid boost to our sales volume and profitability."

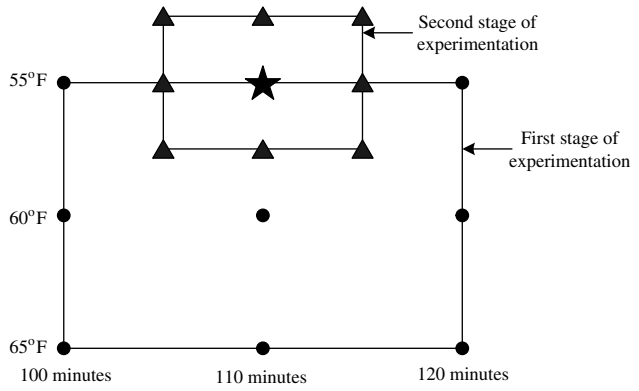
You are relieved to hear this news, as John Tagole continues. "While our quality has improved, it is still far short of where I want to be. As your previous analysis had shown, our rework costs are high. You had therefore recommended getting the new diffusion equipment. We have ordered the diffusion equipment but the supplier has pushed back the delivery date by several months, possible even a year or two."

"I want to stay ahead of the curve this time around, and so, I want to see how we can improve our current process instead of simply waiting for the new diffusion equipment to be delivered. In the old days, a mean difference of 10 Å to 15 Å[1] or even higher between two processes was considered to be insignificant. But now, with our customers becoming ever

*The case "The MotoTech Manufacturing Company: Process Control and Improvement" discusses the first stage of analysis and provides the background information for this case. However, this case can be studied independently of that case.

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

Figure 1 Experimental Design



more demanding, process mean differences of even a couple of angstroms has become managerially significant. Of course, the closer we are to the target of 3,000 Å, the higher is our product quality. I had Nadine Pitt do some experimentation with the temperature setting on the new air-conditioning equipment for the diffusion department. Nadine Pitt is one of our best, and I will let her explain what she did."

The Quality Improvement Process

As she walks up to the white board in the committee room, Nadine says: "My plan is to strengthen our culture of constant experimentation and improvement. I believe it is the management's responsibility to make sure that the systems and processes are conducive to producing high quality output. As Deming[2] pointed out, just coming up with fancy slogans—often the only thing that is done in many companies—is not enough."

She elaborates: "The new air-conditioning equipment has a very accurate thermostat so we can control the temperature within a very narrow range. With the temperature set at 60°F, as you had recommended previously, the quality is better than it used to be. But we don't know if this temperature is the best setting or not, and therefore 'design of experiments' is needed. As an illustration, suppose that temperature and time are two factors that we want to experiment with. In the first stage, let's suppose that there are three levels for each: 55°F, 60°F, and 65°F for temperature, and 100 minutes, 110 minutes, and 120 minutes for time. Once we find the best combination, we would search in the region close to that combination in the next stage of experimentation." Nadine Pitt draws the diagram in Figure 1 and explains: "If we find that the combination denoted by the star is the best of the nine combinations, then we will try to fine tune the settings around the star in the second stage. So, in the second stage, we would try the treatments denoted by the star and the eight triangles. Having done that and identifying which of the nine treatments is the best in the second stage, we will repeat the process to fine tune the process even further."

"In the spirit of the above mentioned continuous improvement initiative," Nadine continues, "I identified temperature as one of the factors and supplier as the other factor. We buy our raw materials from three different suppliers: Pinnacle, Allied, and Premier. I chose three temperature levels, high, medium, and low, and collected the data at the diffusion stage. Exhibits 1 and 2 provide excerpts from these data organized, respectively, by supplier and temperature. The full data are available in Exhibits 1 and 2 of the file *MotoTech (DOE) Data.xls*. We used just these two factors because our engineers are quite confident that they have the right settings for the all other factors. They are less sure about temperature and supplier; in fact, there even seems to be some debate about whether temperature and supplier are at all important."

John Tagole steps in. "Nadine has been busy with a number of other projects, so she didn't have the time to do the analysis for this project. And, I felt guilty calling you again, since you gave your advice 'pro bono' the last time around. You literally saved MM from shutting down, so I hope that you will charge me at least your usual consulting fees this time. Anyway, because Nadine Pitt was busy and I didn't want to take another obligation from you all, I hired VR4U Consulting Company to do the data analysis. VR4U is a well-known management consulting company. VR4U recommended doing ANOVA. You remember that from our Statistics and Marketing Research courses, don't you?"

You think to yourself, "Sure, we have used it in several of our consulting projects," but you don't say anything.

John Tagole continues. "VR4U did the ANOVA analysis for supplier and concluded that the diffusion data do not provide sufficiently strong evidence to reject the null hypothesis at an α of 0.05, that is, they reached the conclusion that the mean thickness values do not vary by supplier. They reached the same conclusion for the three temperature settings, that is, the mean thickness values for the three temperature levels are not statistically different from each other at an α of 0.05."

John Tagole continues. "These conclusions just don't gel with my intuition, or with the feedback I sometimes get from some of our associates on the shop floor. Nadine oversaw the data collection, and I am very confident that the data are valid. But I can't explain what is going on here."

One of The Famous Five says: "I was going to ask you about the validity of the data. Checking to make

[2] Point 10 from Deming's 14 points.

Exhibit 1 Format for One Factor ANOVA (Supplier)

			For one-factor ANOVA (supplier)		
Wafer no.	Supplier	Angstroms	Pinnacle	Allied	Premier
1	Pinnacle	3,015.789	3,015.789	3,009.544	3,005.264
2	Pinnacle	3,007.520	3,007.520	3,013.402	3,012.517
3	Pinnacle	3,008.081	3,008.081	3,007.439	3,008.222
4	Pinnacle	3,016.481	3,016.481	3,014.054	3,004.111
5	Pinnacle	3,007.160	3,007.160	3,010.555	3,015.323
6	Pinnacle	3,009.986	3,009.986	3,008.796	3,010.907
7	Pinnacle	3,018.824	3,018.824	3,011.743	3,006.489
8	Pinnacle	3,002.183	3,002.183	3,008.844	3,016.848
9	Pinnacle	3,011.145	3,011.145	3,012.171	3,009.463
10	Pinnacle	3,017.623	3,017.623	3,008.409	3,007.552
11	Pinnacle	3,002.551	3,002.551	3,009.630	3,012.960
12	Pinnacle	3,010.034	3,010.034	3,010.829	3,010.777
13	Pinnacle	3,012.477	3,012.477	3,009.881	3,004.892
14	Pinnacle	3,003.725	3,003.725	3,010.390	3,017.433
15	Pinnacle	3,009.890	3,009.890	3,014.053	3,012.816
16	Pinnacle	3,013.338	3,013.338	3,007.599	3,002.288
17	Pinnacle	3,004.398	3,004.398	3,008.531	3,012.313
18	Pinnacle	3,008.905	3,008.905	3,009.849	3,007.791
19	Pinnacle	3,017.935	3,017.935	3,008.567	3,007.603
20	Pinnacle	3,006.289	3,006.289	3,007.465	3,015.492
21	Pinnacle	3,007.885	3,007.885	3,011.363	3,014.196
22	Pinnacle	3,014.894	3,014.894	3,009.942	3,004.680
23	Pinnacle	3,008.280	3,008.280	3,010.053	3,011.332
24	Pinnacle	3,009.401	3,009.401	3,006.747	3,012.559
25	Pinnacle	3,014.638	3,014.638	3,010.279	3,003.934
26	Pinnacle	3,009.330	3,009.330	3,009.254	3,015.716
27	Pinnacle	3,007.391	3,007.391	3,008.608	3,012.208
28	Pinnacle	3,016.027	3,016.027	3,012.004	3,004.331
29	Pinnacle	3,007.781	3,007.781	3,011.104	3,017.213
30	Pinnacle	3,010.331	3,010.331	3,010.109	3,011.225
31	Pinnacle	3,012.691	3,012.691	3,011.253	3,006.333
32	Pinnacle	3,004.381	3,004.381	3,007.019	3,018.044
33	Pinnacle	3,009.551	3,009.551	3,013.550	3,011.715
34	Pinnacle	3,019.760	3,019.760	3,008.682	3,002.328
35	Pinnacle	3,001.721	3,001.721	3,008.666	3,015.407
36	Pinnacle	3,012.442	3,012.442	3,009.468	3,009.355
37	Pinnacle	3,013.608	3,013.608	3,009.636	3,005.172
38	Pinnacle	3,006.357	3,006.357	3,010.044	3,015.973
39	Pinnacle	3,009.251	3,009.251	3,010.044	3,010.450
40	Pinnacle	3,015.329	3,015.329	3,009.888	3,005.053
41	Pinnacle	3,002.182	3,002.182	3,009.063	3,019.431
42	Pinnacle	3,008.777	3,008.777	3,008.413	3,013.630
43	Pinnacle	3,015.925	3,015.925	3,010.312	3,001.843
44	Pinnacle	3,004.482	3,004.482	3,013.420	3,010.424
45	Pinnacle	3,009.470	3,009.470	3,009.313	3,010.710
46	Allied	3,009.544			
47	Allied	3,013.402			
48	Allied	3,007.439			
134	Premier	3,010.424			
135	Premier	3,010.710			

sure that there were no problems during the data collection stage and that data is valid is the first step of any analysis. Sometimes—especially when the line supervisors and 'project' owners are not on-board a quality improvement project—the data collection is suspect and the data are not useable. Based on what we know about MM's employees, and the culture of training, improvement, and change[3] that is prevalent here, I think we can assume that the data are reliable."

[3] See Deming's 14 points again.

The Famous Five partner then asks: "I see the data in Exhibits 1 and 2 and see that some of the rows have been hidden to fit the table on one page. I presume that in the Excel file, I will be able to unhide the missing rows. But I do have a question. There are 135 data points in each of the two Exhibits. Do the wafer numbers in the two exhibits correspond to the same wafers?"

Nadine responds: "Yes, they do. I had all the data in one file in a nice tabular format, you know, the format we typically use to collect bivariate data. The VR4U

Exhibit 2 Format for One Factor ANOVA (Temperature)

			For one-factor ANOVA (temperature)		
Wafer no.	Temp.	Angstroms	High	Low	Medium
1	High	3,015.789	3,015.789	3,007.520	3,008.081
4	High	3,016.481	3,016.481	3,007.160	3,009.986
7	High	3,018.824	3,018.824	3,002.183	3,011.145
10	High	3,017.623	3,017.623	3,002.551	3,010.034
13	High	3,012.477	3,012.477	3,003.725	3,009.890
16	High	3,013.338	3,013.338	3,004.398	3,008.905
19	High	3,017.935	3,017.935	3,006.289	3,007.885
22	High	3,014.894	3,014.894	3,008.280	3,009.401
25	High	3,014.638	3,014.638	3,009.330	3,007.391
28	High	3,016.027	3,016.027	3,007.781	3,010.331
31	High	3,012.691	3,012.691	3,004.381	3,009.551
34	High	3,019.760	3,019.760	3,001.721	3,012.442
37	High	3,013.608	3,013.608	3,006.357	3,009.251
40	High	3,015.329	3,015.329	3,002.182	3,008.777
43	High	3,015.925	3,015.925	3,004.482	3,009.470
46	High	3,009.544	3,009.544	3,013.402	3,007.439
49	High	3,014.054	3,014.054	3,010.555	3,008.796
52	High	3,011.743	3,011.743	3,008.844	3,012.171
55	High	3,008.409	3,008.409	3,009.630	3,010.829
58	High	3,009.881	3,009.881	3,010.390	3,014.053
61	High	3,007.599	3,007.599	3,008.531	3,009.849
64	High	3,008.567	3,008.567	3,007.465	3,011.363
67	High	3,009.942	3,009.942	3,010.053	3,006.747
70	High	3,010.279	3,010.279	3,009.254	3,008.608
73	High	3,012.004	3,012.004	3,011.104	3,010.109
76	High	3,011.253	3,011.253	3,007.019	3,013.550
79	High	3,008.682	3,008.682	3,008.666	3,009.468
82	High	3,009.636	3,009.636	3,010.044	3,010.044
85	High	3,009.888	3,009.888	3,009.063	3,008.413
88	High	3,010.312	3,010.312	3,013.420	3,009.313
91	High	3,005.264	3,005.264	3,012.517	3,008.222
94	High	3,004.111	3,004.111	3,015.323	3,010.907
97	High	3,006.489	3,006.489	3,016.848	3,009.463
100	High	3,007.552	3,007.552	3,012.960	3,010.777
103	High	3,004.892	3,004.892	3,017.433	3,012.816
106	High	3,002.288	3,002.288	3,012.313	3,007.791
109	High	3,007.603	3,007.603	3,015.492	3,014.196
112	High	3,004.680	3,004.680	3,011.332	3,012.559
115	High	3,003.934	3,003.934	3,015.716	3,012.208
118	High	3,004.331	3,004.331	3,017.213	3,011.225
121	High	3,006.333	3,006.333	3,018.044	3,011.715
124	High	3,002.328	3,002.328	3,015.407	3,009.355
127	High	3,005.172	3,005.172	3,015.973	3,010.450
130	High	3,005.053	3,005.053	3,019.431	3,013.630
133	High	3,001.843	3,001.843	3,010.424	3,010.710
2	Low	3,007.520			
5	Low	3,007.160			
132	Medium	3,013.630			
135	Medium	3,010.710			

consultants said they had to reformat the data so that they could do their analysis. They didn't even create a back-up of my original format. How exasperating, to say the least."

John Tagole ends the meeting by saying that "we need to look at the diffusion data with a critical eye. I am really interested in analyzing this data for two reasons. First, I can see that experimental design can lead to tremendous quality and productivity improvements in the company. As we continue to improve the diffusion process, some other department will become the 'bottleneck' department and we will have to make similar quality improvements there. In addition to thickness, the product has a number of other CTQ[4] dimensions, for example, finish and material composition. Second, I want to use the 'design of experiments' approach for planning our next advertising campaign. We use four media currently: print, radio, television, and Web. But no one has compared

[4] CTQ stands for critical-to-quality. Key stands for measurable product or process characteristics that are critical to customer satisfaction. Here, customers can be internal or external (that is, within or outside of the organization).

the relative efficacies of these four media outlets. My next project will be to conduct such an analysis using design of experiments."

Questions

Part A. Do you agree with Nadine's basic approach, as outlined in Figure 1? Under what conditions will this approach work? Under what conditions will it not work, and therefore have to be modified?

Part B. What does John Tagole mean when he says that some other department can become the bottleneck department?

Part C. For a tangible product or service product that you are familiar with, briefly describe three CTQ dimensions.

Part D. Do you agree with VR4U's recommendation that supplier and temperature do not affect the thickness? If yes, why? If no, why not? What would you recommend?

Supplementary Material

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