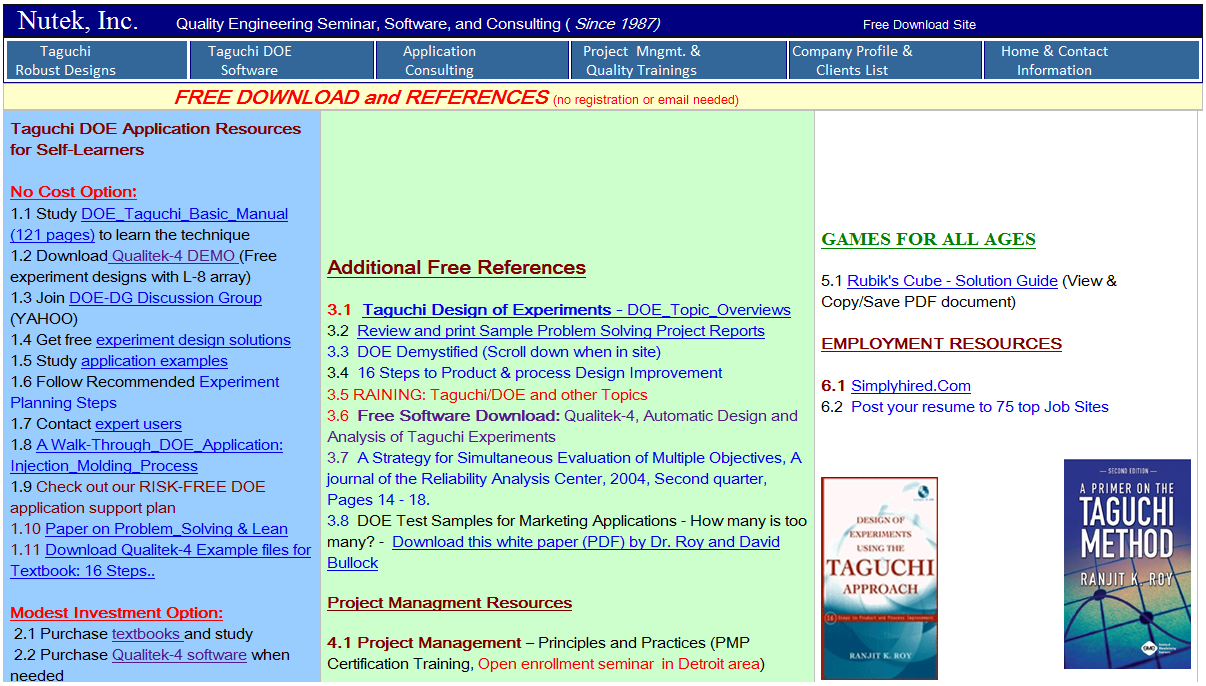
Taguchi DOE Application Discussions

Question and Answers (Q&A) – Part II

This document contains part of discussions that took place during 1996 – 2005 from worldwide practitioners of the Taguchi experimental design technique. There are over 110 Q&A's contained in the two documents (Part I & II). These two documents as well as other materials included in the web site below are available free to all. The Q&A are arranged in reverse chronological manner. To join current discussion group, join forum supported by Google at (http://groups.google.com/group/TDA-DG?hl=en&lnk=gcimh)

- Ranjit Roy, Author and Consultant, Jan. 20, 2011 www.nutek-us.com

Site Link: http://nutek-us.com/wp-free.html



Our Other Reference Sites:

-Robust Product and Process Designs (Taguchi/DOE) *seminar* (http://nutek-us.com/wp-s4d.html)

-Taguchi/DOE, Six Sigma, and Project Management (http://nutek-us.com/wp-sem.html)

-Qualitek-4 Software (Free working DEMO (http://nutek-us.com/wp-q4w.html)

-Free downloadable DOE/Taguchi resources (http://nutek-us.com/wp-free.html)

-References & Textbooks (http://nutek-us.com/wp-txt.html)

-Taguchi DOE Application Discussion Group (TDA-DG), (http://groups.google.com/group/TDA-DG?hl=en&lnk=gcimh)

Topic /Ref : **Sample Size** (DOE-DG56, August 16, 2001)

Question:

I would like to ask you a question about the sample size for conducting a test. What can be a proper number of samples required in an experiment with the Taguchi method and western's (like factorial design)? I want to know the answer particularly for variable data values of quality characteristic and using three-level orthogonal arrays.

Thank you in advance for your time and consideration?

-Younes Leysi

Answer/Comments:

The term "sample size" in design of your experiments refers to the number of sample to be tested in each trial condition (individual recipe). The sample size you chose to use applies to all trial condition and should be kept the same for all trials.

How do you determine what sample size to run? This question is answered mostly subjectively, rather than scientifically. Always, the more the better. A larger sample size will allow you to collect better information about the variability and generate conclusions (factor effects, optimum performance, etc.) with higher confidence level than those generated with smaller sample.

In Taguchi approach, when you include noise factors as part of an outer array in your design, the minimum sample size is dictated by the outer array. For instance, if you have an experiment designed using an L-8 inner array and an L-4 outer array, the sample size is 4, as you need to run 4 samples in each of the 8 trial conditions. If samples are inexpensive and time is available, you may consider running more samples in each of the 32 (= 8x4) unique condition (called a CELL). But, how would you decide the sample size for all experiments without an outer array?

In general, sample size is determined subjectively, based on expected variability of results and cost of running additional samples. Of course, the minimum sample size is ONE. When expected variability is large and/or the cost of sample is low, run LARGE number of samples. Conversely, when expected variability is small and/or the cost of additional sample is high, run SMALL number of samples. Again, what is more and what is LARGE and what is SMALL sample size is subjective. Remember, although, sample size can be statically calculated (using closed form solution) when the desired confidence level or interval (C.I., see optimum screen in Qualitek-4 software) is assumed, there is no way to establish what confidence level is satisfactory (subjective again).

My recommendation is that use sample size of 3 or 4 when you determine that you need SMALL sample. Consider running 8 or 9 samples when you wish to go for a LARGE sample. You will have greatly diminishing returns when you exceed sample size over 10. What I hear and see in the industry is that COST and TIME mostly dictate the SAMPLE SIZE.

DOE – DG members, please comment and share your practices and rationale you use to determine sample sizes.

- RKR

This is one of the frequent questions from many engineers and technicians in organisations. How many samples should I take to obtain some decent results?? I agree with Dr Roy's view on sample size (with a practical engineering point of view). However, there are many scientific ways to calculate the sample size for factorial experiments. One good

reference for this is a book written by Dr Stephen Schmidt and Dr Robert Launsby. The title of the book is ' Understanding Industrial Designed Experiments', published by Air Academy Associates. Again, both George Box and Douglas Montgomery are giving some descent explanation on sample size for factorial experiments. Hope this helps !!

-Jiju Antony

Minitab Software has an application called Power & Sample Size. It can be selected for factorial experiments. It can be used to determine the sample size based on the number of replicates, the power level (or beta risk) and the sensitivity that one must detect for a differential change.

-Clarice Fasano
Six Sigma Champion, Lear Corporation

Topic /Ref : Regression Analysis (DOE-DG57, Aug. 23 , 2001)

Question:

I have the following question.

May you explain why Taguchi method does not use the regression analysis in the analysis of results? I'm asking this question because before getting in touch with your method I usually applied the response surface analysis (of course, working with smaller number of variables) and I was able to get a polynomial model.

-Dr. Mario Villarroel
"Mario Villarroel Tudesca "<

Answer/Comments:

Analyses of results of Taguchi experiments do indeed incorporates (the term regression is never used) a simpler form of regression analysis. When you perform analysis using Qualitek-4 software, the MAIN EFFECT screen displays the average effects of factors at their corresponding level, which is similar to input for relationship between the factors and the response (quality characteristic). The corresponding plots of the main effects show the trend of influence, which is what you are after in regression analysis.

The purpose of regression analysis (Refer to A PRACTICAL GUIDE TO STATISTICAL QUALITY IMPROVEMENT – Beauregard, Mikulak & Olson, 1992, page 232 -) is to study relationship between two or more variables. In DOE investigations, generally, there is one dependent variable (say response, Y) and many independent variables (called factors or parameters, A, B, C, D,….which can be CONTINUOUS or DISCRETE.). In the simplest form, regression analysis will help you develop relationship between a factor (say A) and the dependent variable Y. In the complex form, the dependent variable (response) Y can be expressed in terms of many factors (A, B, C, etc. all of which must be of CONTINUOS type.). The relationship is linear in case of two data points and a polynomial (Use a least-squares curve fit.) when there are multiple data points.

The thing to note is that, in regression analysis the focus is to establish a relationship between the dependent variables with one or more independent variables, with as much details as data permits. Where as, the main purpose of DOE is to arrive at the OPTIMUM design combination and estimate the performance expected with least number of experiments. In that sense regression analysis is used as a component to whole analysis of DOE results keeping the polynomial

formulation to simpler (linear) form. In DOE/Taguchi analysis the expression of optimum performance (Yopt) in terms of all variables included in the study, is the first order (linear) equation relating the dependent variable (Y) with the independent variables (factors studied, A, B, C, D, etc). As you know, the expression for Yopt can be used to estimate the performance not only of the optimum condition, but of all possible combination (full factorial combinations) of the factor levels. Thus, if you studied seven 2-level factors using an L-8 array, the expression for Yopt can be used to predict (calculate) performance at all (128) of the full-factorial conditions. The predicted performance in such cases would always produce an approximate value and must always be validated by running confirmation experiment.

In analysis of DOE/Taguchi experimental results, analysis of variance (abbreviated as ANOVA) plays a greater role than regression analysis. ANOVA determines the relative influence of variables to the response. This relative factor influence values help determine the roles each factor play and how their tolerances are adjusted in the production process. [Read more about ANOVA in Step 7 of Design of Experiments Using Taguchi Approach: 16 Steps to Product and Process Improvement - Ranjit Roy]

- **RKR**

Very interesting question indeed !! I am not sure whether or not you had a chance to read Taguchi's 'System of Experimental Design' book written by Dr Genichi Taguchi. This is the two original volumes of Taguchi's contribution to quality engineering. In this book, he does talk about regression analysis. In classical DoE, you develop a regression model to predict the process performance using the significant terms (linear, quadratic, interaction terms, etc.). In Taguchi methods, the same thing is done in a different form. Taguchi did not call 'regression analysis' for his version. But fundamentally they are same. Always remember, Taguchi Method is different from what he has shown in the two volumes. There is a simple logic behind this. Taguchi Method (TM) is a trade mark of ASI, US. They have simplified the original work of Taguchi and make it a more practical and convincing tool for the engineering fraternity. Hope this helps. If you need more information, please do not hesitate to contact me.
-Dr Jiju Antony

Topic /Ref : Analysis using S/N (DOE-DG58, Aug. 28 , 2001)

Question:

I would like to know more about the concept of S/N ratio. How can we compare the results of standard method and S/N ratio? Could you please explain it.

-F.Tabandeh "fatemeh tabandeh"

Answer/Comments:

Analysis of results by first calculating the Signal-to-Noise (S/N) ratios of the trial results is a recommended method when the number of samples tested in each trial exceeds one sample.

*The concept of S/N has been traditionally used frequently in electrical and electronic engineering. Applied to DOE results, S/N implies a ratio of the response due to signal factor to that due to noise factor. While this definition of S/N is still meaningful in DOE results, it is quite a task to interpret and understand without spending too mush time in the background of the Taguchi technique. Your best reference will be the System of Experimental Designs by Dr. Taguchi (www.**nutek-us.com**/wp-txt.html).*

You can get a better appreciation for S/N by understanding it's formulation and reasons for the use. S/N is a function of two quantities, standard deviation and mean [S/N = f (s , a)]. In standard analysis (when you are not using S/N), only the mean (average) of the trial results are used to determine the main effect, and subsequently optimum condition. When you only use average of the trial results, you are not able to learn about the variability caused by the factors to the results. Often variability is more important than the mean. Therefore, the way to learn about which factors does what to the variability is use the standard deviation (s) of the trial results and analyze the experimental results. Dr. Taguchi chose to analyze the results using both the mean and the standard deviation, which is what S/N contains. Except, note that S/N is just not a function of the two quantities (a & S), but a LOG (to the base 10) transformation of the function. The purpose of the LOG transformation is to linearize any potential nonlinear behavior of the factors. When LOG transformed S/N is used for analysis, the optimum performance so estimated is more likely to be reproducible.

When should you perform S/N analysis?

*You should always prefer S/N analysis when there are two or more samples tested in each trial condition. The optimum design and predicted performance you estimated from S/N analysis will be statistically more accurate when you have the option to validate a larger number of samples. (Visit www.**nutek-us.com**/wp-doe.html for little more information on S/N).*

When your experiments include multiple samples in each trial condition, you could analyze results both ways, i.e, perform standard analysis and S/N analysis. Expect the optimum condition and performance to be different, but rely more on the S/N analysis. Often the trend of influence will be expected to be the same. It would highly unusual to find that 90% of the factors are not showing similar trends.

How can you compare S/N analysis with standard method?

*If you are using Qualitek-4 software, you can indeed compare S/N analysis with standard method. First, perform standard analysis (use PISTON.Q4W file) and note expected performance at the optimum condition. Now perform S/N analysis. From OPTIMUM screen, transform the expected S/N value in to the original result (Click on TRANSFORM button). The transformed value you get should compare well with that you obtained from the standard analysis. You can read more about S/N analysis and review example experiments in Step 12 of Design of Experiments Using the Taguchi Approach : 16 Steps to Product and Process Improvement- R. Roy (www.**nutek-us.com**/wp-txt.html).*

- **RKR**

I would like to add some concepts to the interesting explanation of Dr. Roy's answer. There are also some differences in ANOVA Tables of S/N ratio and Standard methods. The first one is degree of freedom (DOF) for the experiment: DOF is N-1 in which N is the total number of the samples for the Standard method but the N is numerator of the OA was used for the S/N ratio. For example, if an L9 (3^4) orthogonal array was used in three repetitions, DOF for the Standard method is 3*9-1=26 but 9-1=8 for the S/N ratio. Also the sum
of squares (SS) is different in these respects: you should consider all of the results (27 numbers in the above examples) for the standard method, but the S/N ratio amounts (columns) for the S/N method (9 numbers in the example).

Consequently the rest columns in the ANOVA tables will be different. The most important point in using the S/N method is pooling concept which should be done if all of the columns of an OA are used, especially when you want to know the F-Ratio (variance ratios) amounts in comparing with the F Value of the table.

-"Younes Leysi

I am not sure what do you mean by ' standard method'. In my terminology, Standard method is Classical DOE. You have then traditional method as well. In traditional approach, we generally analyse mean response only. In Standard method, we analyse both response mean and variability. Taguchi's S/N ratio cannot tell you what factors are affecting mean response and what factors are affecting response variability. It rather measures robustness of your performance using a single metric. Taguchi's S/N ratio has been controversial among western statisticians because of the above reason. However for a practical engineer, S/N ratio has been proved to be useful for achieving process and product performance robustness. Interestingly enough, analysis of experimental data using the S/N ratio and Classical methods

(separate analysis on mean and variance) will end up with similar results (80 - 90%) of the time.

- Dr Antony

Topic /Ref : Taguchi Approach -References (DOE-DG59, Sept. 5, 2001)

Question:

I am the student of final year mech.engg. & as a part of our curriculum, i want to deliver the seminar on the topic "Taguchi methods". so, i want ur kind help in collecting the followings & i hope u will frankly assist us.

1.the technical papers or seminars which the scientists like u have presented (also the source of getting its literature).

2.the technical journals which have been previously published related to this topic & also the source i.e.library or address of concern from where i can get it.

3.about the case studies previously conducted by the scientists using Taguchi methods & case study work work which is recently being carried out. i expect ur full co-operation.sorry for trouble.

thanking u in anticipation.

-Kirtikumar Nerkar

Answer/Comments:

Your best source of information will be the local library. There are a number of books published on the subject. To review a list, visit www.nutek-us.com/wp-txt.html .

You can also get a list of current publications (books and articles) by visiting a few popular SEARCH ENGINES (yahoo, excite, google, etc) and searching by using keywords like, Taguchi Approach, Case studies, Design of Experiments, etc. If you have unlimited access to internet, you would be surprised how much free information you can gather. To gather some preliminary understanding of the subject, feel free to explore site www. nutek-us.com/wp-doe.html .

Magazines & publications like Quality Progress, Quality Digest, Quality, etc. have published a number of articles. In your search, you will be sure to hit some of them. For case studies, review our site www. nutek-us.com/wp-ine.html .

- RKR
-

Please let me have your postal address. I am more than happy to send you few of my case studies. I have also written a book on Taguchi methods. The title of the book is ' Experimental Quality: A Strategic Approach to Achieve and Improve Quality'. It is published by Kluwer Academic Publishers in 1999.

Good luck with your presentation.

-Dr Antony

Topic /Ref : Gear Noise Reduction (DOE-DG60, Sept. 5, 2001)

Question:

In the process of reducing Noise Level of an Automotive Transmission, I have designed experiments with some parameters like Gear Lead, Profile, Runout, etc. But it is not an easy exercise to collect Gears having different combinations of levels chosen (like a gear having Runout more than 40 micron but with Lead within specs, etc..).

How can I go ahead in such situation?

Could you pl suggest any such case study for ready reference?

- VM Rao

Answer/Comments:

Many companies have effectively done applications of DOE technique for design/development of gears. It seems in your situation, you are trying to collect already made samples that fit the planned experiments (trial condition). Generally, the approach should be to define the design factors (Gear Lead, Profile, Runout, etc) and then build gear samples to run test. Since the gears are already made, you need to be very flexible with the factor-level definitions. For example, in case of RUNOUT as a factor, instead of looking for 20 micron and 40 micron as the two levels, consider them as LOW and HIGH runout. This way you can take a group of samples close to 20 micron as low, etc. You can not afford to be exact in this case. This might still give you better design direction than trying to do things by judgement.

In terms of getting hold of some case studies, you should not be surprised not to find too many published works. This tends to be too much of a proprietary work for most company. I have included one example in my recent book: Example 13.3, page 421, Design of Experiments Using Taguchi Approach: 16 Steps to Product and Process Improvement - Ranjit Roy (with a CD-ROM, ISBN: 0471361011, Published by John Wiley 2001, www.nutek-us.com/wp-txt.html .

For additional case studies, don't forget to search the internet.

- RKR

Generally, to set factors is much more simple, when factors are selected from process. Thus,setting up process factors like conveyor speed or machine rpm is quite simple (turn the button,etc.).

Product factors is usualy bigger problem. To collect sample from already made products is difficult. This activity may last several months. I would like to add some suggestions to approach proposed by Dr.Roy. From historical data you can see minimum and maximum for gear parameters. Collect samples about this minimum and maximum, with no fixed value. We assume specifications are ok. So noise is due extreme values of factors. We consider, noise is growing, when value of factor is different from nominal value. So low level is under nominal value (as far as possible from nominal) and high level above nominal value (as far as possible from nominal).

-Pavel Blecharz

The purpose of Experimental Design is to plan, design, execute, analyse and confirm the experimental results so that optimal design can be investigated. In your case, you have designed an experiment and the data collection is not made from the designed experiment. It comes from your existing process which is not a good practice ! You don't learn much from this process to be honest. You need to collect data strictly based on your design matrix so that good statistical

analysis can be carried out.

You need to search the internet for obtaining further information. Good luck.

-Dr Antony

Topic /Ref : Analysis Using Qualitek-4 Software (DOE-DG61, Sept. 6 , 2001)

Question:

Hello,
I would like you to help me with two topics after i have download your FREE Qualitek-4 :

1. How can i save on floppy on what i have done?
2. When i am trying to design an experiment and i want to know what factors are the most important and what levels should i use do i have to do all the experiments in order to fill the results screen?

Thank you very much.

-"dafna yaroslawitz"

Answer/Comments:

1. *To save your experiment file that you created using Qualitek-4 software in floppy disk, you could follow one of the following options:*
   - *While naming file, use name as A:FILENAME.Q4W (assuming the floppy drive is A:)*
   - *You can also change with directory in the save screen from c: to A: then save your file the normal way. You do not need to put A: before your file name.*
   - *Save files as usual. Then save file using WINDOWS EXPLORER to copy file from C:\Program Files\Q4Q\UsrFiles directory onto the floppy disk in A: drive.*
   -
2. *Before you analyze results, you must carry out experiments for all trial conditions. Once you have entered the results, you will be able to perform analysis using Qualitek-4. As you proceed with analysis, the MAIN EFFECT screen will show you the factor influences (average effects). Based on your quality characteristic, you will be able to identify the levels of the factors for OPTIMUM performance. The ANOVA screen, which comes next, contains the information about the relative influence of the factors to the variation of results. ANOVA tells you which factors are important and which are not. If you need some guidance on how to run Qualitek-4 software, please review the README.Q4W file that came with the downloaded ZIPPED file or visit www.nutek-us.com/wp-q4w.html .*
   - RKR

Topic /Ref : Instructional Use of Qualitek-4 (DOE-DG62, Sept.. , 2001)

Question:

Thank you for the Qualitek - 4 which I have successfully downloaded and installed! I found your e-mails upon my return from holidays (where I had no Internet access) and this is why I am responding only now.

The software is operational now on my computer and highly interesting! I so much look forward to the beginning of the academic year to start working with it with my students. I shall let you and other colleagues on your mailing list too know

about the most interesting and challenging issues I shall encounter while teaching and experimenting with Taguchi and Qualitek-4.

Your books indicated as references in your e-mails would be most useful to me in upgrading and adding value to my lectures and seminars and also for ongoing PhD research (pursued within my department) dealing with the application of Taguchi methods in mechanical engineering (finishing processes of high quality metal surfaces). Regrettably though, given the restrictive financial situation of eastern European countries, of Romania, the dwindling resources available in higher education, access to highly specialised and to-date western literature is unlikely to be achievable at present, both at academic library and individual level.

Once again I should like to thank you for your support of my scientific and teaching interest in Taguchi and I shall provide feedback on its application and operation at my department/university. Further I shall be glad to share opinions and observations with any other colleague involved in this field.
With the best of regards,
Yours sincerely,

-Prof.dr.ing. Tudor DEACONESCU

Answer/Comments:

Thank you for considering to use Qualitek-4 for your training needs. All though you did not pose a question at this time, I wanted to share your comments with the Discussion Group with the hope that members could come to help.

Your comments about lack of funds for books and equipment in Rumania,brings up many of my memories while growing up in the Indian subcontinent (undergraduate studies) during 50's and 60's. Toys & games were never affordable, so we had to be creative. In schools and colleges, books were unreachable. Even the college libraries could only afford only a limited number of western books reprinted for the Indian market. On the positive side, the process screened out and keept only those intent on learning. Bottom line, my book (www.nutek-us.com/wp-txt.html 16 Steps to …) cost $99 US dollars and I have no control and hands in it. It's publisher's call. I believe the publisher is willing to grant reprint rights to local printer/publisher. If you want, please put one of your local publisher in touch with John Wiley.

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- RKR

Topic /Ref : Factor Level Selection (DOE-DG63, Sept. 7, 2001)

I have made a plan for an experimental study. I can not decide for the levels of two factors. (Factor 1 and 2).

Factors
1- Material A (0-5-10)
2- Material B (0-10-20)
3- W/C(low-medium-high)
4- Type of Aggregate (low-medium-high)

Which levels is better for Factor A and B. Material A First choice (0-5-10) second choice (5-10-15). Material B First choice (0-10-20) or (10-20-30) second choice. In the first choices, there are two advantages
1- The first test is a test without Material A and B.
2- In some test, it is possible to have information with only one of two factors (A or B). But in the second choice, there is one important advantage. So it is possible to have more information than that of the first choice plan.

If you give some suggestions I will be very grateful.

-Dr. Sinan Hýnýslýoðlu

Answer/Comments:

Four factors at THREE levels each, would make a good experiment designed using L-9 array. This would certainly be a preferred way rather than, as I suspect, going for two smaller experiments with some of the factors in each.

Regarding the selection of levels for factors A and B, I recommend the following philosophy for a three level factor: Select level-2 as the value of the factor that is the current working condition. In many instances, this is the nominal of the current production specification. If this is a new process, and you have no idea about nominal level, you should select the middle of the expected working range. For level-1 and level-3, you should select the two values for the factor that on the either side of level-2, as far away as possible from level-2. Attempt to select Level-1 and level-3 fartest from level-2, yet making sure that the conditions (trial condition from experiment designs) are valid and you are able to complete them. In your situation, for example, if 0, 5, 10, 15 are all possible level values, you should select 0 7.5 and 15 as the three levels for the factor.

Hope this will get you started.

- RKR

Topic /Ref : Experiment with Production Process (DOE-DG64, Sept. 21, 2001)

We have a large manufacturing facility (150 tons per day fibre) and do not have any pilot plants. Under the circumstances, carrying out any experiment or trials in our plant is difficult. This is because of reasons of producing off-spec product. Do you have any case studies where experimentation have been planned in large chemical plants.

-Saleel R Nayak

Answer/Comments:

Running experiment online with production process is quite risky. Since experimental layout is likely to contain both good and bad process conditions, rejects might be prohibitively large.

As you are aware, Dr. Taguchi's robust design methodology (commonly known as Taguchi method or Taguchi approach) applies to off-line process optimization rather than on-line activities. In this area, you may be interested in the method prescribed in STATISTICS FOR EXPERIMENTERS by Box, Hunter & Hunter. (published by John Wiley, 1978, ISBN 0-471-09315-7). In this book the authors describe a method of using simple experimental designs to find improvements in an operating full-scale production process, which they call EVOP or Evolutionary Operation. Their Example 11.4 at page 362, SIMPLE FACTORIALS USED SEQUENTIALLY IN EVOLUTIONARY OPERATION-PETROCHEMICAL PLANT might be of interest to you.

- RKR

Topic /Ref : Quality Characteristic for OEC (DOE-DG65, Sept. 27, 2001)

Question:

I purchased your book DOE using the Taguchi Approach a few days ago. I am reading it and running through the experiments as I go. At the end of chapter 2 there is an example which deals with a plastic molding facility and their molding machine. It calls for me to use the QT4 OEC program for determining QC values. I was wondering if you could tell me how to change the QC of overall evaluation criterion from bigger is better to smaller is better etc. I can't seem to get it to change to smaller is better for this experiment. It is a great book to learn Taguchi methods and I want to continue to onward to the next examples.

-Thomas E. Lamb (Professor)
University of Michigan-Dearborn, Dept. of Engineering and Computer Science

Answer/Comments:

Thank you for reading my book. After you have a chance to review it, I would be interested in your comments. I hope you will take the time to forward your review.

Assuming you are referring to the OEC screen shown in page 57, there are two ways you can obtain SMALLER QC for the OEC. (This is example POUND.Q4W available also with the downloadable Qualitek-4 DEMO program. You can view this screen by selecting OEC from the EDIT menu of Experiment Configuration screen.)

1. For TASTE put 12 as the worst value and 0 for the best value. Be sure to mouse-click on B>> to change it to S>>, if it doe not set it automatically. The QC will be smaller now. You can test it by assigning 0, 45, and 2 for Sample 1 data.

This should show OEC =0 for sample 1, which is the best performance in case of QC = Smaller.

3. *Assign 15 (instead of 55) as the relative weight for TASTE and 55 (in place of 15) for VOIDS. Click on results several time until program accepts the new values (all Rel. Wt. Must adds to 100). This should set your QC of the OEC to be SMALLER. Again, the best way to verify is to set dummy data as extreme values (best or worst) and see that it corresponds to the QC.*

- RKR

Topic /Ref : Application Case Studies (DOE-DG66, Nov 14, 2001)

Question:

i am a student of Indian Institute Of Technology, MADRAS . I am studying in fourth year Mechanical Engineering , and as part of my curriculum i am doing a course titled PRODUCT RELIABILITY . As part of the course i am planning to give a presentation on TAGUCHI METHOD by emphasizing its importance with a simple but interesting case study on the application. in this regard i want your kind help in getting some case study about a simple but interesting application of the great TAGUCHI METHOD , and any related matter in this respect to enlighten the importance of reliability and its application. hope to get a positive reply in this regard. looking forward to your reply .

-SATISH AVK

Answer/Comments:

Your best chance of getting hold of some case studies will be to search the net. I suggest you do the following.

1. *Search (in Yahoo, Google, Excite, etc.) using key words like: Taguchi + case studies, Taguchi + application example, etc. There a large selection of reports available from people who have posted their reports.*
2. *Visit www.nutek-us.com and explore a number of case studies posted. You have option to copy/download some complete reports from www.nutek-us.com/wp-ine.html .*
3. *Look for Design of Experiments Using Taguchi Approach: 16 Steps to Product and Process Improvement - Ranjit Roy (with a CD-ROM, ISBN: 0471361011, Published by John Wiley 2001, also available as eBook version). In your library or visit AMAZON.COM (click below) :*

http://www.amazon.com/exec/obidos/ASIN/0471361011/o/qid%3D976111069/sr%3D8-1/ref%3Daps%5Fsr%5Fb%5F1%5F3/002-5635357-6846418

This book has many case studies.

- RKR

Topic /Ref : Experiments to Study Three Factors (DOE-DG67, Nov. 16, 2001)

Question:

I wan to plan an experiment with three factors and one response. The three factors behave linearly. Could help me, advising which kind of the experiment I should select?

-Alberto

Answer/Comments:

If your requirements are as simple as you stated, you will have a simple experiment. Since the factors are expected to behave linearly, you can study them at two levels each. In this case you will design an experiment using an L-4 array. Assign the factors in random order.

In terms of the results, you can collect & record single or multiple responses as applicable. If you happen to have different criteria of evaluation for different responses, you should analyze the results separately.

In the event you suspect nonlinear behavior and can afford the increased size of the experiment, you should consider studying these factors at three levels each. You will need to design the experiment, in this case, using an L-9 array.

On the other hand, if you were interested in the interactions (three interactions among the three factors) among the three factors, you should use an L-8 array, and use its six columns for the study. The triangular table for 2-level columns should help you decide the columns, which you need to reserve for the interaction.

- RKR

Topic /Ref : Response Surface (DOE-DG68, Nov. 17, 2001)

Question:

I would like to model the results of my experiments, which is possible using full or fractional factorial design and some methods like RSM (response surface Methodology). Could you please inform me if it is practicable by Taguchi method and what its principle is.

-F Tabandeh

Answer/Comments:

Response surface is a term more associated with the practice of classical DOE. Although, it can be generated from the average factor effects in the Taguchi experimental results, it is not commonly done, or even needed. To understand why, you will need to follow the brief discussion below.

Plot of response [Y = f(A)] against a single factor (variable, A) produce a line, linear or nonlinear. It is linear when the factor is of two levels and any interpolation puts all data on the straight line. The similar plot of response against two factors [Y = f(A, B), A, B are factors/variables], produce an inclined plane or a curved (3-D) surface depending on whether the factors are linear or nonlinear. Such surface plot from examination of two factors at one time, may help you identify optimum condition that otherwise may not be obtainable from the routine identification of the optimum condition. But, bare in mind, that this is only possible when the factors are at three levels. This is because when the factors are at two levels, the main effect plot will identify the same optimum.

To generate response surface type data from DOE/Taguchi results, your starting point is the expression [Yopt = T + (A1 –T) + …..] for the expected performance at the optimum condition. The factor contributions in this expressions (A1, B2, C1 etc.) need to be expressed in terms of equation with boundary conditions as the average effects of factor obtained from the experimental results.

For most industrial applications, here are a few considerations that help you determine the level of complexities you want to involve in the analysis of DOE results.

(a) A vast majority of experiments are carried out with factors at two levels. Thus, any interpolation may not ad value to your analysis.

(b) The scheme to interpolate and extrapolate data in linear or nonlinear modes, are generally beyond the understanding of the practicing engineers in the industry (A limited few scientists in the industry with advanced degrees prefers such advance studies.)

(c) In larger experiments (with over TWO factors), it is possible to generate multiple response surfaces [One surface for each pair of factors. Number of pair = n (n-1)/2, n =number of factors.]. When all possible surfaces are studied, it poses a secondary challenge of compromises as a result of conflicting demands for different factor level requirements. The levels of difficulty presented here, are a few notches higher than what one faces when multiple two-factor interactions (AxB, BxC, ExF, etc.) are found significant and subsequent factor level selections are sought.

(d) In any interpolation scheme, such as response surface study, you still will need to make the assumption of a nonlinear behavior (say quadratic, least squares, cubic, etc), which may not necessarily represent the actual behavior.

Hope this will offer you some food for thoughts in your response surface studies.

- RKR

Topic /Ref : Definition of Quality (DOE-DG69, Nov. 21, 2001)

Question:

I am getting a lot of benefits from e-mails I received from your DOE Discussions. I would like to know what is meant by Quality, when Dr. Taguchi explain it and said that it is a loss ? How ? I am getting confused sometimes!!

Best regards,

-Khalid Saleh

Answer/Comments:

Quality is defined by many in many ways. Dr. Taguchi has explained it also several ways. I will discuss the two definitions that are most common.

Quality is consistency of performance – This definition can be applied to all kinds of product and processes. Here the consistency of performance also can be easily calculated in terms of statistical quantities like average and standard deviation. Consistency is achieved when variations around the average of performance or the target are reduced. In layman's term, variation is reduced when most performances (of product or process) are close to the performance of the desirable value. Consider a machine producing 9-volt transistor batteries. When the machine makes most of the batteries whose output measure 9 volts, the machine would be considered to be producing batteries of higher quality.

Quality is loss to the society – This definition is slightly difficult to understand. First of all, it is the lack of loss or reduced loss to the society that indicates quality. The less the loss the more is the quality. The term "loss" means the effect of lack of quality that a product causes to the society in the hands of the customer after it leaves the manufacturer. Usually, this loss is hard to quantify and difficult to evaluate in quantitative terms. But the concept is very powerful and

its evidence is frequent. Like warranty cost for an n automobile manufacturer, the loss to the society can only be minimized.

Consider the case of an automobile of inferior quality purchased by an unsuspecting owner. To repair the problems, the owner needs to take time off from work and spend at the dealers to repair the vehicle. This is a waste to the society on two accounts. First, the owner's absence from work causes loss for his/her employer. Second, the dealer spends time fixing things that should have been right the first time. In this case poor quality of the product caused loss to total production ($$) of the society. When all parts are of superior quality, there is minimum harm (loss) done to the society. For additional discussions on quality and how it is defined and measured, read the Step 2 in my book (16 Steps… www.nutek-us.com/wp-txt.html).

Note to readers*: I will be away on vacation from Nov. 30 – Dec. 30, 2001. My wife and I will be spending time visiting our relatives in different cities (Kolkata, Jamshedpur, New Delhi, etc.) in India. If you have any question, feel free to write to me. I will try to respond to them early in the New Year.*

- RKR

Topic /Ref : Interaction Studies, (DOE-DG70, Nov. 26, 2001)

Question:

I am currently doing project on optimizing cutting tool life(measured as no. of pieces machined between regrinds/ indexings) in machining operations using Taguchi DOE.

I have selected Turning operation , with 4 variables at 2 levels each viz. 1. D: Cutting Speed 2. B: Feed 3. C: Depth of cut 4. A:Tool material (two different makes of tools).

I have selected L8 and would like to study 3 interactions viz: Tool x Feed rate, Tool x Depth of cut, and Tool x Cutting speed.

Kindly check and let me know if i am on the right track. I get this doubt as i could find no such case study/project report on the net/in journals. Kindly let me know at your earliest convenience.

-"G.S.Krishnan

Answer/Comments:

Your experiment plan looks good. Make sure your factors are assigned to the proper column and in agreement with the TRIANGULAR TABLE.

The situation you described, i.e., four 2-level factors (A, B, C, and D) and three interactions (AxB, AxB, and AxD) among them, is commonly studied using an L-8 array. As you are aware, the column assignment of the factors and the columns to be reserved in this case, are determined by following the procedure for interaction studies in Taguchi experiments. You will, of course, need to refer to the TRIANGULAR TABLE (visit www.nutek-us.com/wp-doe.html) for 2-level factors. When you follow the guidelines recommended, your design may be such that you assign factors A to column 1, factor B to column 2, and reserve column 3 to study interaction AxB. The rules of interaction study will also

dictate that you assign factors C to column 4, and factor D to column 6. Also, reserve columns 5 and 7 to study interactions AxC and AxD respectively. For this and other such design, you will benefit by reviewing experiment design tips in our site www.nutek-us.com/wp-tip.html .

For additional discussions on the topic, read the Step 8, Example 8.2 (page 271) in my book (16 Steps… www.nutek-us.com/wp-txt.html).

- RKR

Topic /Ref : Mixed Level Factor & Interaction Design (DOE-DG71, Nov. 29, 2001)

Question:

I would like to ask you about one design DOE problem.

Example: 7 factors 2-level,1factor-4level,1 interaction between 2-level factors.

It would appear that an L-16 modified to upgrade one column to a 4-level column and an additional column for interaction reserved for interaction should be possible? Qualitek-4 does offer this solution in the automatic design option. Wonder why? My clients and students have asked this question in relation to Qualitek.

-Pavel "152 Ing. Pavel Blecharz"

Answer/Comments:

It is definitely possible to use an L-16 array to design experiment with seven 2-level factors (a, B, ….. G), one 4-level factor (H), one interaction between two 2-level factors (say AxB). Your question, of course, is not whether it can be done by modifying an L-16 array or not, but why one should not be able to accomplish using the automatic design option in Qualitek-4 software.

Qualitek-4 has over 500 experiment design situations for which the software automatically selects arrays, modifies the columns, and assigns the factors. Unfortunately, it does not include situations where experiments involve mixed-level factors and interactions among the factors.

The experiment design in this case is accomplished by combining the three 2-level columns (say cols. 1, 2, & 3) into a 4-level column for the 4-level factor first. The other seven two level factors now can be assigned to the available columns making sure that an appropriate column (from Triangular table) is reserved for the interaction to be studied. A possible design will be where the interacting 2-level factors, A & B to columns 4 & 8. Reserve column 12 for interaction AxB. The remaining 2-level factors can go to the available columns in any order you like.

- RKR

Topic /Ref : Interaction Severity Index (DOE-DG72, Nov. 30, 2001)

Question:

.I am aware that Taguchi's philosophy put emphasis in studying the effect of control factors on the response, putting

aside the interaction effects. At present I'm investigating the influence of four factors (at three working levels each) on pectin yield extraction from a vegetal resource growing in the southern part of Chile. The data obtained were analyzed using qualitek-4 software. Looking at the graphics obtained it seem to me that some interaction effects may be influencing the pectin extraction, therefore I studied the interactions, but the software measures the degree of them using the term "severity index".

Question.- What amount of "severity index" will be necessary to deduce that interaction is significant?.
I woud apppreciate very much yours comments.

- Dr. Mario Villarroel

Answer/Comments:

True indeed that Dr. Taguchi puts less emphasis in interaction only because it is generally difficult for industrial experimenters to study them take appropriate corrective actions. Be aware, however, that it can be effectively studied by the experiment design using the orthogonal arrays. In my books and Qualitek-4 software, interaction studies between two 2-level factors (not among many factors or between two mixed-level factors) are described for the practitioners.

Severity Index is a term I defined to measure the angle between the two straight line in an interaction plot (say, between two 2-level factors). The angle between the interaction lines, of course, indicates the strength of presence of interaction. The angle between two lines, which can range between 0 – 90 degrees, is expressed in a scale of 0 – 100 as the Severity Index. In qualitek-4, there is a brief description given. You may benefit by examining the definition.

What value of Severity Index (SI) is important? Unfortunately, there is no short answer for this question. Qualitek-4 checks all possible factor interactions and rank them in the descending order of SI (it also finds interactions about those factor combination that you may not have included in the study). Thus, you can be certain about the fact that the first few are stronger than the others are. However, just because interaction is present (higher SI), does not necessarily mean that they are significant. This is the difficulty. To learn whether an interaction is significant, you needed to sacrifice a column such that it appears in the ANOVA table, and you are able to test for significance and also see its relative influence (last column value in ANOVA) t the variation of the results. So, unless you have the interaction suspected and included in your study (it appears in ANOVA), you will have no way of knowing whether the interaction under question is significant and whether you should adjust the levels of the factors involved based on the interaction.

My recommendation is this. Use the SI values (ranking of all possible interactions) for your knowledge of the project and for future studies. Use the SI to select top ranking interactions, which appear in ANOVA to modify/adjust the factor levels in the optimum condition only when the interaction is found significant.

All discussions about interactions apply to interaction between two 2-level factors. In case of 3-level and 4-level factors, Qualitek-4 uses the first straight-line segment of the plot for the factors higher than 2-level ones. Studying interaction between factors other than at 2-level is much complicated and should be left alone for advance corrections.

To learn more about SI and interaction studies, try capabilities in Qualitek-4 (www.nutek-us.com/wp-q4w.html) main effect screen under automatic interactions. For additional discussions on SI how it is defined and measured, read the Step 8, page 264 in my book (16 Steps… www.nutek-us.com/wp-txt.html).

- RKR

DOEDG73 missing

Topic /Ref : L-12 Orthogonal Array (DOE-DG74 , Jan. 7, 2002)

Question:

Why is a L12 array not recommended for the analysis of interactions?

-Willie "Willie Lottering"

Answer/Comments:

L-12 is a specially designed orthogonal array. Unlike most other arrays, the interaction effect between two columns (say col. 1 & 2) does not get mixed with a single column (like column 3). Instead, the interaction effect of any two columns in L-12 gets evenly distributed to all other columns. It is this lack of concentration of the interaction effect that makes L-12 unsuitable for interaction studies.

But, for the same rationale, L-12 is a highly desirable array to study a set of factors, which you prefer to study without concern for interaction. Realize that interaction among factors is always present whether you decide to study them and make subsequent corrections or not. In situations where you wish to keep your analysis simple, or otherwise your experimental scopes do not allow you to study interactions, you would prefer an L-12 array. For if there were interactions among factors present, being distributed to all columns, it is unlikely to bias your conclusions about the optimum condition. In short, when you do not want to deal with interactions, your conclusions about the factor influences and the optimum condition are expected to be more accurate (reproducible) when you use L-12 to design your experiment. For example, if you have seven 2-level factors, if you can afford the extra experiments, an L-12 will produce better results than an L-8.

Confounding of the interactions to columns, from which Taguchi derived the Triangular Table, can be mathematically established.

- RKR

Topic /Ref : Vending Machine Setup Optimization (DOE-DG75, Jan. 8, 2002)

Question:

An organization wishes to optimize the installation of a drink vending machine in its regional offices.
The main objective is to maximize the turn over of the machine but is also desirable to minimize
the variability of this turnover in order to predict the required frequency of stock replenishments
and cash collection.
It is decided to devote the next 6 months in the New York area trials, which will determine the optimum features of the machines to installation in all the regional offices. It is assumed that the New York office will be representative of all regional offices, personnel levels and backgrounds being similar.
The vending machine manufacturers have agreed to underwrite the cost of these trials on the understanding thatthey will receive a subsequent long-term contract to supply all regional offices.
Brainstorming with to represent a cross-section of the New York work force identified the following control factors and levels.

Factor:-	LEVEL 1 LEVEL 2 LEVEL 3
PRICE	10cents / 20cents/ 30cents
TYPE OF CUP	Plastic /Polysyrene / own
TYPE OF COFFEE	Instant / Fresh / Ground
RANGE OF DRINKS	small / large -

SPEED OF DELIVERY 30 sec 45 sec -
CHANGE Yes / No -
LOCATION Office corridor / staff room reception

A number of possible interactions were also discussed. Price * Range of drinks was considered the most likely to be significant but Price * Type of cup, Price * type of coffee and range of drinks * speed of delivery were not entirely discounted by the team.
It was agreed that the response measured should be daily turnover (to the nearest $) and in order to assess variability of demand from day to day, each trial should run for a week (i.e. 5 working days). Due to holidays, the maximum number of trials allowed, including confirmation trials(only to last 1 week) is 24.
The cost of each vend to the organizations 15cents and the organization intends that all catering services should be self-financing. It would be expected however to be able to negotiate a substantial discount if the average daily turnover exceeds $150.
What array would you choose considering some factors have 3 levels and some don't?
Do i get rid of some levels?

- Sean Graham

Answer/Comments:

You have quite an interesting case of marketing/distribution application. I congratulate you on a good brainstorming. It seems you have established what you are after, that is the evaluation criteria to measure the performance and also have identified the factors. Now you are in a position to lay out an experiment and proceed.

For THREE 3-level factors and FOUR 2-level factors, which you have identified, you should either use an L-16 (3 columns modified to 3-level) or an L-18 array. I would recommend you use an L-16 array. Modify the standard array to create three 3-level columns first. If you are not familiar with the orthogonal arrays or how to modify the column levels, you may solicit help from those around you who can lend a helping hand.

By the way, your factor levels are fine as is. You do not need to sacrifice of reduce levels of any factor.

You can learn more about how to design experiments with mixed factor levels, read the Step 9, page 285 in my book (16 Steps… www.nutek-us.com/wp-txt.html). Be aware also that Qualitek-4 (www.nutek-us.com/wp-q4w.html) software can automatically modify arrays and design such experiments.

- RKR

Topic /Ref : Interaction & Optimum (DOE-DG76, January 9, 2002)

Question:

I am working on optimizing thermal spray coatings - so came up with 6 factors and 1 interaction (dedicated one column for the interaction)in an L-8. I have collected the data and am analyzing.
I have a major question about "Expected optimum condition". For the QC is smaller the better - the factor level

combinations for optimum performance (obtained by plotting the factors) are A2 B2 D1 E1 F1 G2 (without taking into consideration the interaction between A and B). If I consider the interaction, then A2B1 gives a lower value. According to Qualitek-4, u have suggested to calculate the expected optimum as A2 B2 (AB)2 D1 E1 F1 G2 .

Can you please help me with that? Looking forward for an answer

-Janet Savarimuthu

Answer/Comments:

Your question deals with some finer & subtle issues in interaction studies.

The studies and subsequent corrections due to presence of interaction can be quite complicated. The key to understanding the corrective actions you need to take is to view the (1) OPTIMUM condition and the (2) estimate of EXPECTED PERFORMANCE separately.

(1) The optimum condition is dictated by the factor levels determined from the presence of interaction plot. In your situation, the main effect plots shows A2B2 . . . , but the interaction plot dictates A2B1 . . .. You must therefore, consider A2B1 as the levlels of factors A & B for the optimum condition. In reality, this is the combination you should specify for your final design specification (production release) as this level combination is expected to produce performance that is close to the performance of the confirmations tests. A simple rule to follow here is that let the interaction dictate what the levels of the factors should be. Be aware though that when there are multiple pairs (AxB BxC, CxD, etc) of interactions studied, even this simple guideline may produce conflict as it is possible to arise demands for separate levels for the same factor.

(2) Unfortunately, the estimate of performance at the optimum condition, when interaction is significant, can be slightly confusing. There are two common ways (formulas) to compute the expected performance. Qualitek-4 software uses one approach where the factor levels are kept the same as the originally found levels from main effects alone, and then subsequently apply the corrections form the column effects (AxB column, ..), if it survived the test of significance (not pooled). This approach is logical but can cause some confusion since the levels shown are not exactly the level for the optimum to be prescribed. The alternate approach uses combined level effects (like A2B1, A1B2, etc) used for the interaction plot, to compute the expected performance. Qualitek-4 does not use this approach, as it requires a choice and additional calculation on the part of the user.

To learn more about interaction studies, try capabilities in Qualitek-4 (www.nutek-us.com/wp-q4w.html) main effect screen under automatic interactions. For additional discussions on SI how it is defined and measured, read the Step 8, page 264 in my book (16 Steps… www.nutek-us.com/wp-txt.html).

- RKR

Topic /Ref : ANOVA in Standard Analysis (DOE-DG77, January 31, 2002)

Question:

I am doing PhD at IIT Roorkee (formly Univ. of Roorkee). I used L27 array & repeated each trial thrice. Got 81 values of responses. Please guide me whether the ANOVA should be based upon all the 81 values or it is just sufficient if I do ANOVA for 27 values (average of three repetitions).

I also want to calculate CI for confirmation experiments. Kindly also inform me about any software for ANOVA based upon all the 81 values and for carrying out multi-response optimization in case of Taguchi results.

-Sehijpal Singh (Asstt.Prof, GND Engg College Ludhiana(PB)

Presently Research Scholar , Mechanical & Industrial Engg Deptt , F-11 MR Chopra Bhawan,Indian Institute of Technology, Roorkee-247 667, India.

Answer/Comments:

This discussion will hold true for standard analysis of any size of experiments with multiple samples (results) in each trial condition.

In standard analyses main effect studies do not include sample to sample variations as only the averages of the sample results in trials are used for the calculations of the factor average effects. This is however, not true for the calculation of ANOVA in standard analysis. Here, each sample result is included in the calculation of total sums of squares as well as the sums of squares for the columns (factors and interactions). For example, if 3, 4 , 2, etc. are results of trial condition 1 of your L-27 experiments, the total sums of squares will be calculated by including 3^2 + 4^2 + 2^2, etc. (^ represents squares), and not the squares of the average of 3, 4, 2, etc. only. Likewise, the total degrees of freedom of the experiment, from which the error degrees of freedom is calculated (DOF : error = total – factor DOF), also is based on the total number of results, not the total of trial averages.

This happens to be the common practice used in my textbooks, software (Qualitek-4), and seminar instruction materials. I would have to believe that any software in the market, which calculates ANOVA for DOE, will also follow the same procedure. (Review Chapter 6 in A PRIMER ON THE TAGUCHI METHOD – R. Roy)

By the way, calculation for the Confidence Interval (C.I.) remains unchanged in this case as it uses components (F-ratio, error term, etc) which are calculated based on sums of squares.

- RKR

Topic /Ref : Software for DOE/Taguchi (DOE-DG78, February 5, 2002)

Question:

I recently purchased your book entitled "Design Of Experiments Using The TAGUCHI Approach published in 2001. I have a question about the demo software that you supply with you book. Is this the best or only software on the market for DOE? Does Mini-Tab software have DOE capabilities?

-Gary E. Kilpatrick, PE, NSPE

Answer/Comments:

The demo version of Qualitek-4 software attached in the back of the book allows you to use only the L-8 array to design your own experiments (new ones). It's main purpose is to allow you to review and follow along over 100 solved problems and exercises in the book (16 Steps..).

Qualitek-4 is one of the first software in the market and is specifically designed to perform design and analysis tasks involved in Taguchi experiments. Now that there are over a dozen software, which claim to do the same, I cannot say where it stands in terms of its merit. I suppose users like you are better judge of that.

Magazines such as Quality Progress and Quality Digest have annual listing of all the software in quality engineering activities. This could be a good place for you to see the claims made by different vendors. Most are general-purpose software, which do many kinds of statistical calculations. May I suggest that to find out what's available in the market, search the net using key words SOFTWARE + TAGUCHI or click on this link.

http://google.yahoo.com/bin/query?p=Software%2bTaguchi&hc=0&hs=0

- RKR

Minitab does support both Classical and Taguchi DOE. Both test design and analysis are supported. However, Minitab is a general purpose software while Qualitek-4 is dedicated Taguchi software. Sometimes dedicated software will include special analysis or ease of use features. For me, Minitab is easy since I have used it for many years. Since I haven't used Qualitek-4, I can't make a comparison to Minitab.

By dlc9@daimlerchrysler.com

I want to add information about software (based on my experience). There are a lot of statistical software packages. Some of them contains DOE. In my experience, no software follows Taguchi procedure as Qualitek does. Example: before Qualitek, I used software Statgraphics. There is DOE, but experiment design is not done in accordance with Taguchi (different fractions). As well as analysis, e.g. ANOVA counts only some statistics. There is missing pure sum of squares, percentage and some other items. When user is well familiar with Taguchi approach, he can calculate some missing items manually. It is obvious, it is not too practicable.
Similarly, I have experience with some other kinds of software. When using Qualitek together with Excel, there is no need for other statistical software.

-Pavel Blecharz, lecturer in TQM , lecturer in DOE , Technical University of Ostrava

There are more than 40 software packages and expert systems available in the area of DOE. If you are after Classical DOE which includes fractional factorials, full factorials, Central Composite designs, Box Behnken Designs, D-Optimal designs, Mixture designs, etc., you should look at softwares such as Design Expert, Minitab, etc. If you are interested to specialise in Taguchi Methods of Experimental design, QUALITEK-4 is a useful and powerful tool. I think QUALITEK has more capability features (graphical) than Minitab. In fact, I was involved in pushing Minitab to include Taguchi's OA designs. If you look at Minitab's old version (5 years ago), they did not have Taguchi OA designs at all.
Should you want to know more about software packages in this topic, please do let me know. I have in fact compared 7 packages back in 1995 as part of my PhD research. Good luck.

-Dr Antony

Topic /Ref : Pooling Consideration (DOE-DG79 ANOVA, Feb. 6, 2002)

Question:

I am doing my undergraduate project at University Science of Malaysia. I read from somewhere that claims the pooling of mean squares in ANOVA is a procedure considerable bias in the test results. Please guide me
whether the ANOVA should be based upon the pooling result? Is qualitek-4 can do autopooling? If can, base on what value or guidance when this software doing the pooling?

-Chin Teck "Chin Teck Chong"

Answer/Comments:

When you "POOL" a column effect (factors or interactions) in ANOVA you will cause the influence (The right column, which is the relative influence of factors to the variation of results) from that you get without pooling. Still, you must always pool column effects when possible. You should always attempt to pool as this will minimize the probability of calling something important while it is not (Called the 'Beta' error in statistics). For pooling decision, you need to understand and follow the guidelines very carefully.

Dr. Taguchi recommends that you should continue to pool until the degrees of freedom (DOF) of the error term is approximately half the total DOF. This is just a guideline. It may not always be possible for you to follow. It is easier when you have higher error DOF to start with such as in case of standard analysis with multiple samples per trial condition.

Understand that which column effect to pool is a decision you will arrive at by comparing experimental F-ratio with the table value (standard) at a desired confidence level (theoretical approach). Here is the weak link. The confidence level (C.L.) you work with is an arbitrary decision (common practice is to work with 80 – 95%). In Qualitek-4 software, you compare the C.L. a factor has with that you desire. Unfortunately, calculation of C.L. is not possible unless you have a non-zero error DOF (<3 gives reliable answer in Qualitek-4). So, what should you do when you have zero error DOF to start with? You start pooling the columns with the least influence (S-values). This is likely to make you little uncomfortable in certain situation since there is no specific level of influence (P% values) below which you could call an effect INSIGNIFICANT and pool.

You can use Qualitek-4 to automatically pool column effects (when possible, that is error DOF is nonzero). Based on your desired minimum C.L., Qualitek-4 will pool all factors with C.L. below the desired level.

To learn more about POOLING, read the Step 7, page 218 in my book (16 Steps… www.nutek-us.com/wp-txt.html).

- RKR

This is a common query from many quality engineers and Taguchi practitioners in organisations. It is always dangerous to pool the factor effects with low sum of squares in magnitude. This is ONLY a guideline and people always use this method when it comes to pooling so that they can create adequate degrees of freedom for the error term and perform the ANOVA. It is not necessary that you always have to replicate or repeat an experimental condition for the analysis. I would strongly advice you to use simple but powerful graphical methods such as Normal probability Plot and the Bayes plot to determine the active factors. There are some excellent research papers published by few well known experts in the area. I would suggest you to refer to the following papers:

1. Schneider, H., Kasperski, W. and Weissfeld, L., Finding significant effects for Unreplicated Fractional factorials Using the n Smallest Effects or Contrasts, Journal of Quality Technology, Vol.25, No.1, January 1993, pp. 18-27

2. Lenth, R.V., Quick and Easy Analysis of Unreplicated Factorials, Technometrics, Vol.31, 1989, pp. 469-473.

3. Box, G.E.P and Meyer, R.D., An Analysis for Unreplicated Fractional factorials, Technometrics, Vol.28, 1986, pp. 11-18.

4. Stephenson, W.R., A Computer Program for the Quick and Easy Analysis of Unreplicated factorials, Journal of Quality Technology, Vol. 23, No.1, January 1991, pp. 63-67.

Hope this helps with your research.

-Dr Antony

For both Classical and Taguchi DOE, the ANOVA table shows the significance of different factors. For each factor, the null hypothesis is that the means of different levels of the factor are not significant. The alternative hypothesis is that the means are significantly different. In the ANOVA table, the F statistic and degrees of freedom are used to determine the statistical significance of mean shifts in the factor. Each factor (and interactions) will have this analysis. For two level DOE, one can calculate the effect of a factor change from level 1 to level 2. If many two level factors and interactions are analyzed, classical theory says the different effects will normally be distributed. If these are plotted on normal probability paper, the majority will fall on a straight line, however, some will not. Checking back to the ANOVA table shows these are the factors that are statistically significant.

I like this graphical technique as a visual confirmation of the ANOVA. Now, a recommendation is to pool those factors and interactions that are statistically insignificant. This would include all main effects and interactions. Those factors that are significant (from the ANOVA table) or fall off the straight line of the normal probability plot, will remain in the analysis. Pooling statistically insignificant factors and interactions will not increase the MS error value very much.

"Dennis Craggs/DCX"<

Topic /Ref : Attribute Characteristics (DOE-DG80, Feb. 27, 2002)

Question:

What is an attribute characteristic?

How do we design and conduct experiments for attribute characteristic?

How can we use signal to noise for attribute characteristic?

- Rida Alfadiah (Student)

Answer/Comments:

Attribute characteristics are those that are evaluated by subjective judgements. Characteristics like "good", "average", or "bad" used to classify, say a plastic part, or "accepted" and "rejected" used to sort a population of soldered printed circuit board, are examples of attribute characteristics. Such method of evaluation of performance characteristics is quite common in the industry.

Designing experiments is determined strictly by the number of factors and their levels. The types of characteristics do not dictate the size of the experiments. Your resources do.

Although, Dr. Taguchi has a special method for analysis of attribute characteristics (called accumulation analysis), it is not very popular, as it requires you to learn this special data collection and analysis schemes separately. If you wish to analyze the attribute results by the common method of analyzing DOE results, you will need to evaluate the attribute characteristics in terms of numbers. For example, for attribute characteristic "accept" and "reject", use number 0 and 1. Better yet, you should consider defining the performance between the two ends, by expanding the range to, say 0 to 5 or higher. This, of course, would require you to define the numbers in the middle, that is 2 – 4. In other words, try to be more discriminatory and be able to define those that are almost rejected and those that are almost accepted. Understand that, although in real life, you only have two conditions (accept/reject, 0 or 1), being able to define the conditions in the middle will be better for analysis of the DOE results during investigations.

Another way to quantify attribute data will be to run multiple samples (10, 20, 100, etc.) and consider the % good/bad etc.

The considerations for S/N analysis remain unchanged. That is, if you have multiple columns of results (many sets/samples per trial condition), you should prefer to analyze it by transforming each trial results to S/N ratios.

To learn more about attribute data, read the pages 29, 30, & 68 in my book (16 Steps… www.nutek-us.com/wp-txt.html).

- RKR

Topic /Ref : Data Types (DOE-DG81, April 21, 2002)

Question:

My name is Madeleine and now I'm studying at Trisakti University. I'm recently read your book, "A Primer on The Taguchi Method," and I'm currently working on my thesis based on Taguchi. After reading your book, I had a few questions that I hope you would be willing to answer.

1.In Taguchi Method, how many types of data are there? And what are they?

2. I also read a book by Stuart Peace and he categorize the types of data into Measurable Data, Attribute Data, and Dynamic Data. Do you have the same opinion as his?

(+ more questions)

-Laksana Madeleine

Answer/Comments:

The results of your designed experiments can be of two types: measurable (quantified and expressed in terms of numbers) and attribute. Although, Dr. Taguchi has a special method of dealing with attribute data, which he called accumulation analysis, the simpler ways to handle it is to first express the attribute data in terms of some assigned numeric data. This is what you will need to if you have attribute data and you want to use Qualitek-4 for analyzing it.

The term DYNAMIC is associated with data only when the response of the system you are studying is set up as dynamic as opposed to static. A dynamic system differs from the static system in two ways. It has a signal factor, and that the response in the same trial condition is expected to vary in proportion (linearly) to the strength of the signal. All results in a dynamic system are measurable and numeric.

The book by Glenn Peace is an outstanding reference for dynamic characteristic. I read his book and there is no disagreement. Hope the above comments clarify your concern.

- RKR

Topic /Ref : Attribute Data Analysis (DOE-DG82, April 26, 2002)

Question:

If I'm working with Attibute Data, will those data be divided into 3 characteristic like you mention in your book, A Primer on The Taguchi Method on page 19? (the bigger the better, the smaller the better, and the nominal is the best)

-Madeleine "Laksana Madeleine"

Answer/Comments:

The data in all situations (attribute or numeric) will have one of the three quality characteristics (QC: Bigger, Smaller, or Nominal) for analysis purposes. Of course, as I indicated in my last note, to perform analysis, as you know, you must express all attribute data in terms of number first. The matter of assigning the QC to your data for analysis then becomes an easy task.

Suppose that in a aluminum casting process, in actual production environment, the parts are sorted in two groups: ACCEPTED and REJECTED. While carrying out the experiments in the laboratory environment, you could indeed take the liberty to express these attribute as: 1 for poorly rejected, 2 for rejected, 3 for almost accepted, 4 for accepted, 5 for better than accepted, 6 for superior parts, etc. The idea is that you want to expand the range of your evaluation of experimental parts even if the real production can only use two kinds. Once you have quantified your performance evaluation, it is simple matter to identify the QC they belong. In this case, the QC for your result will be BIGGER IS BETTER for analysis purposes.

For additional discussions on attribute data, read the 29 - 30 in my book (16 Steps… www.nutek-us.com/wp-txt.html).

- RKR

I have a problem accepting attribute "ranking"scales, as in your example. I tried this approach in an injection molding experiment, where we were trying to remove an immeasurable visual defect. I found that, because the numerical ranking data is not, by its nature, normally distributed, as are dimensional data, the analysis was not meaningful and contained mostly noise. In lieu of this, I performed an ordinal regression analysis of the "1", "2", "3", "4" AND "5" ranking data (worst to best). Then, inspection of the resultant regression coefficients pointed me towards the factor that had the greatest effect on the defect with much success. I performed a similar experiment, where the data was Pass/fail only (i.e. 2 categories instead of 5). Here, I performed a binary logistic regression analysis, with the same inspection of regression coefficient approach. Again, the factor with the greatest regression coefficient was the one which caused the greatest probability of occurrence of the binary response.

John Vlahakis,Quality Engineer, Nypro, Inc.

John, Thank you for sharing your experience. It is quite possible that process will contain NOISE and make it difficult for DOE to establish factor effects. Multiple samples in each trial condition and analysis using S/N is expected to be an improvement. Also, other technique may indeed produce better results, as you indicated. – R. Roy

Topic /Ref : S/N Analysis of Attribute Data (DOE-DG81B, May 17, 2002)

Question:

Should the calculation on the Attribute Data only use an Average Method? Could it also be calculated using the the S/N Ratio method?

-Madeleine “Laksana Madeleine”

Answer/Comments:

As recommended earlier, once the attribute data is expressed in quantitative terms, you can analyze it using either average (standard analysis) or S/N ratios of the results, when applicable. Of course, S/N analysis should be used only

when there are more than one samples tested in each of the trial conditions, that is your experiment has more than one column of results.

- RKR

Topic /Ref : Standard Vs. S/N Analysis (DOE-DG82, May 23, 2002)

Question:

Is the Average Method better than the S/N Ratio method? If it is, why?

-Madeleine "Laksana Madeleine"

Answer/Comments:

On the contrary, analysis using the S/N of experimental trial results is more likely to be statistically valid than the one using average of the results. This would generally be the case when there are appreciable variations within the results of samples tested in the same trial condition (sample to sample variation). If the sample to sample variation is absent, like in case of running analytical simulation, testing multiple samples in each trial condition, is not necessary.

As a general guideline, perform standard analysis (average) when you only test one sample per trial condition. In all other case (multiple sample tests), you should rely more on S/N analysis. In all cases, you can perform analysis using both approaches. Use the average for ease of understanding, but make your final recommendations based on the S/N analysis.

Since S/N is a function of average and standard deviation, predictions based on such analysis is more likely to represent real performance.

- RKR
-

The traditional approach to DOE is to analyse only averages. In other words, engineers were concerned with only mean response function. However in modern approach to DOE, you need to analyse both variability and mean. Taguchi's S/N ratio combines both mean and variance as a single performance measure and one may not be able to identify what factors are affecting mean and what are affecting standard deviation separately. The best practice is to learn both approaches aselying on S/N ratio for all problems is risky !!

-Dr Antony

Topic /Ref : Conclusions based on S/N and Standard Analysis (DOE-DG83, June 7, 2002)

Question:

I have studied your case study on parameter study on Die casting process and have a few comments to make regarding the same. Lot of research has been conducted on the Taguchi Signal to noise ratios and I would not get into the specifics, but by now it is a well known fact that the Higher is better and lower is better characteristics of the S/N ratio at best replicate the factors significant for the mean. In your case study also the same happens. The actual

significant factor for reducing variation turns out to be Factor D Die temperature with the best setting at level 1, which was not identified in your analysis at all primarily because factor A is found significant for variation based on S/N primarily because of it is affecting the mean.

Shree Phadnis

Master Black Belt

ASQ Certified Black Belt, ASQ Certified Quality Engineer , ASQ Certified Quality Manager

Answer/Comments:

Your observation about S/N for BIGGER and SMALLER QC is a likely scenario for slight confusion. S/N uses equal weight for MEAN and VARIATION and represents a single measure. A more attractive could be to analyze results separately for MEAN and VARIATION. Dr. Taguchi calls it the TWO STEP OPTIMIZATION method. The identification of optimum can be different depending on the approach you follow.

- RKR

Topic /Ref : Experiment with Six Factors and Sample Size (DOE-DG84, June 18, 2002)

Question:

I want to design an experiment using Taguchi methods for steel process.

the objective is to minimize scrap that causes internal crack (the measurement of scrap is weight on kg) the experiment has 6 factors (A B C D E F) no interaction and no noise factor. It includes attribute characteristics or measurable characteristics? Is it ok if I have 1 repetition or just 1 sample for my experiment, as the cost of experiment is very high.

"Rida Alfadiah"

Answer/Comments:

For your experiment involving six 2-level factor, you should design an experiment with an L-8 array. If you want, you may also want to study interaction between two factors. Since there are 6x(6-1)/2 = 15 possible interactions, it would be a guess on your part as to which one to study. But, since it does not cost any extra experiment it is always better to make provision for thi study (leave col. 3 for interaction between factors in col. 1 & 2). For the quality characteristic, the measurable scraps in Kg. sounds like a good choice.

On your other question about number of samples, prefer to test as many samples in each trial as you can. Of course cost is always a concern. But remember that unless you test multiple samples (more than one) in each trial condition, you will not learn about the variability within a trial. If you are hoping to determine an optimum condition that is not only close to the target (or bigger/better), but also produce least variation around it, testing single sample per trial condition may not produce it. So try to draw a balance. For costly test samples, I generally recommend testing 3 or 4 samples in each trial condition.

Once you carry out multiple samples in each trial, you will be able to analyze the results by looking at the mean as well as the standard deviation. Or you could trust the S/N analysis to tell you the optimum condition which is likely to produce the most robust design.

- RKR

I would like to add some comments as for interactions. As Dr. Roy said, there is no obstacle to involve interaction to the study. You have 1 column (say 3) empty and it is quite not effective. This column should be utilized for interaction. In addition, an interaction in appropriate column does not change trial conditions.

You work with interaction only in analysis. How to select 1 interaction from 15? You can use simply knowledge from previous experiment or previous process , etc. But it is sometimes difficult. If so, you can follow this approach: a) From 15 interactions exclude those, which cannot appear in reality (example: color of vehicle x vehicle speed). b) Remaining interactions (say 11) compare by means of "pair comparison". It means, create all pairs, i.e. 1-2,1-3,1-4,.....10-11. For each pair determine preferences, example 1-2.. interaction 1 is more important, 1-3 interaction 1 is more important, 1-4 interaction 4 is more important, etc. Finally, count number of preferences for each interaction. Interaction with the highest number of preferences involve to the study.

-Pavel Blecharz, Ph.D., P.E.(System. Engg.)

Topic /Ref : Pooled Factors in Confirmation Test (DOE-DG85, July 9, 2002)

Question:

After some parameters are pooled, it was determined the optimum condition. When the confirmation test will be performed, do the factors pooled include the confirmation test.

-Sinan "Hýnýslýoðlu"

Answer/Comments:

The factors are pooled only when they are FOUND insignificant. Whether a factor is insignificant or not, is determined either arbitrarily by the analyst, or by testing for significance. Understand that the test of significance can only be done when the degrees of freedom (DOF) of the error term (ANOVA table) is non-zero. Obviously, there are times when factors are pooled arbitrarily by judgment. Regardless of the method employed in pooling a factor, once pooled the factors are considered insignificant. The pooled factors offer you opportunities to save cost without incurring additional expense.

While running confirmation test, or in actual production process, you will have earned the rights to set the pooled factor to any level you desire (or economical). As a general practice, it is a good idea to select the levels for the pooled factor you intend to specify for production, and use the same for confirmation test.

If you are using the confirmation test results to compare and confirm your prediction of optimum performance, be sure to use the same factors that you used to calculate the confidence interval (C.I.). For example, if your experiment studied 7 factors, but three were pooled, and you used four factors to make the optimum performance prediction, hen you should use only those factors to confirm your prediction.

- RKR

Topic /Ref : Three-level Factor Interactions (DOE-DG86, July 15, 2002)

We are trying to design experiments in order to optimize process parameters

to get good surface finish in resin transfer molding process. We have 3 level factors and wish to study their interactions.

I have not found any thing in your book and software as far as 3 level interactions are concerned.

Is this the limitation of the Taguchi Method ? If yes then what other method can we use to study 3 level interactions ?

If not then could you suggest us any book or research paper which address 3 level interactions ?

Can you suggest some general books on Taguchi and design of experiments?

I am waiting for your reply in this regard. Thank you very much for your time and patience.

Sincerely yours,

Mohsan Raja

Graduate Student, McGill University

Answer/Comments:

Interactions among 3-level factors (two ore more) are much complicated to analyze and interpret. This is why I decided not to include this topic in by books. Unfortunately, I have not come across any books on the Taguchi technique that describes the methods of handling 3-level factor interactions well, and cannot suggest you with a reference.

There are two reasons for most authors not to describe this topic. First, as indicated earlier, it is much more difficult to make logical determination of presence of interaction and interpret its effect. Second, the methodologies are similar to that for the 2-level factors and can be easy extrapolation by the practioners.

This is not to say that Dr. Taguchi has not treated this subject. Indeed, he offers Triangular Tables (TT) for 2-level, 3-level, and 4-level factors to be used along with his orthogonal arrays. The TT of course, offers you the information about columns to be reserved for interaction studies. (You can find TT in most books on Taguchi approach). For example, when you want to study, interaction between two 3-level factors (A & B) using an L-9 array, the TT will indicate that you put these factors in column 1 & 2, and leave columns 3 & 4 for interactions. This much should be obvious to you when you read any book on the subject. What no one gets into is how to analyze such interactions. This is because, for two 3-level factors, the interaction plot will be determined from plots of three lines with two straight-line segments in each. This means that now you need to look for the angle between 8 pairs of line segments as opposed to only one ONE pair of lines in case of interaction between two 2-level factors.

I recommend you read and understand interaction between two 2-level factors well. Then extending this concept to 3-level factors will be an easy task for you when you want it.

- RKR

Topic /Ref : S/N Analysis with OEC Results (DOE-DG87, Aug. 19, 2002)

Question:

Is only The Standard analysis used in OEC?

I have reviewed the problem in your site under case studies, and see that all the numeric values were calculated according to Standard Analysis for this example. For example ANOVA Table is calculated according to Standard Analysis.

Can S/N used in OEC?

-Dr.Sinan HINISLIOGLU

Answer/Comments:

I'm glad that the case study involving OEC in our site was helpful to you.

Yes. The S/N analysis can be performed with OEC.

The idea of combining multiple criteria of evaluations into a single index such as OEC (Overall Evaluation Criteria), is only for reducing the results of a sample into a single number. Once you have transformed your originally recorded evaluations into OEC's, you are free to decide whether to perform standard or S/N analysis based on your desire. Obviously, you will only decide to perform S/N analysis only when there are more than one column of OEC's, i.e., when you test multiple samples in each trial condition.

Remember that if you performed S/N with OEC of results, you will need to back-transform optimum performance from S/N to OEC to relate to your expected OEC from the confirmation test samples.

- RKR

Topic /Ref : Duplicate Trial Results (DOE-DG88, Aug. 29, 2002)

Question:

In my L-8 Array for Laser Metal Deposition, the control factors are:

- Laser power
- Powder feed rate
- Table feed rate
- Stand off of nozzle from base plate
- Inner gas pressure which directs the powder on to molten metal pool and
- outer gas pressure which shields the metal pool.

I am looking for a better microstructure and hardness profile; i want to optimize the parameters and also want to know the effect of each parameter on the result. Problem is in some trial conditions i am not getting a deposit to test for 4 out of the 8 conditions. Should I just put the hardness profile and microstructure results for these conditions to a minimum value and proceed?

-Reddy "Mallareddy, Bhimanapati (UMR-Student)"

Answer/Comments:

Calculation of DOE results produce meaningful outcome only when the results are different from each other. In situations like yours, where more than one trial results appear to be the same or forced to have the same value, the power of analysis is diminished.

I suggest, you look into the following options:
1. Adjust the factor levels (redefine, widen the range) such that different trials produce the desired characteristics (hardness & presence of microstructure), at different degree.

2. Find ways to measure differences in hardness and microstructure at very low levels.

2. If the above was not possible, select other characteristics that have direct bearing on hardness and microstructure, but are easily measurable and distinguishable from each other.

- RKR

Process knowledge is the prerequisite to applying Taguchi Method/DOE.One should establish the metal deposition process, in this case, in terms of the quality characteristic(s) when any control factor is varied. If there is no such previous knowledge, it is not possible to fix levels.
When we prepare a cup of tea we know for sure that adding five spoonfuls of sugar makes no sense. This is because, it is an established fact. Similar is the case when my wife prepares curry. She cannot add a cupful of salt since she knows for sure that it would be a foolish thing to do that. That trial would be a wasted effort. In my experiment with Electrical Discharge Machine wire cutting. I considered wire tension as one of the parameters. When tried with one value of the tension, the wire broke. That was because I did not know anything previously about the effect of wire tension. I made few trials with varying tension values and fixed up two levels within which the wire did not break. I had to establish that knowledge first. That would be a kind of research which is essential. Thus, if any one is conducting research by varying one parameter while keeping all other known parameters constant, it would essentially lead to generating know-how on the process. That could be a kind of research for which research degrees would be awarded in schools for example. In plastics injection molding process, if choose blindly two levels, perhaps at the higher level the material would degrade or evaporate and at lower one the material would just not enter into the mould cavity even at the highest possible injection pressure the machine is capable of. Thus, at some of the values of laser power, e.g., there may not be any deposition. DOE is not just the answer when one wants to get the optimum result without any process knowledge gained from the data base if any gathered from earlier researchers.
Process knowledge as a prerequisite to using DOE has been emphasized in Dr. Roy's Primer on Taguchi Methods.

Rajesham "Dr. SWARGAM RAJESHAM"

Topic /Ref : Factors Incompatibility (DOE-DG89, August 29, 2002)

Question:

I have a question that came up during a discussion on the DOE using multiple environmental factors at two levels. After I set up the array it became obvious that certain test were not possible because they can not physically occur. Example: temperature at 100 and 0 degrees with snow and rain as another factor. Obviously it cannot snow at 100 degrees. How this is dealt with?

-John "Wazenski, John"

Answer/Comments:

Often, in your DOE plan, you will encounter factor levels that are not compatible. When one or more levels of one factor do not go (exist together for availability, business or other reasons) with all levels of the other factors, you will not be able to run tests for all trial conditions. This creates a problem as you want results from all trial conditions before analyzing results. Yours is a good example of such incompatible situation.

The most common way to avoid such situation is to identify the factors involved and redefine them as a new factor. For example, instead of calling TEMPERATURE (0 degrees & 100 degrees) and MOISTURE CONTENT (rain & snow) as two separate factors, define a new factor by combining the two 2-level factors and call it, say, WEATHER CONDITION. This new factor can now have four levels: (1) 0 degree with rain, (2) 100 degree with rain, (3) 0 degree with snow, and (4) 100 degree with snow. Assuming that 100 degree with snow is not possible to test (or too expensive to test), you can discard this level and let the new factor, WEATHER CONDITION, have the remaining three levels only. Your experiment design, now, will have one 3-level factor along with other factors at various levels as were included in the study.

To learn more about factor combination read Step 10, page 319 in my book (16 Steps… www.nutek-us.com/wp-txt.html).

- RKR

Topic /Ref : Two-Step Optimization (DOE-DG90, Sept. 12, 2002)

Question:

On p. 372 of your recent book, "Design of Experiments Using the Taguchi
Approach", you say that Taguchi now recommends a 2-step process for maximizing a signal-to-noise ratio. Can you point me to a publication that describes Taguchi's latest thinking on signal-to-noise ratios, including this 2-step process? If that is not easily done, can you tell me how this "2-step" process compares with the standard advice in the literature on this issue, namely: (1) model mean and log(standard deviation) separately, and (2) maximize the signal-to-noise ratio analytically using these models?

Thanks for your time and for your very interesting book.

-Spencer Graves

Answer/Comments:

Your best source for getting recent publications on Dr. Taguchi's latest thinking will be from the American Supplier Institute (ASI), an organization he helped formed in the early 80's. Please visit and request their publications.
http://www.amsup.com/taguchi_methods/index.htm
I became familiar with his 2-step optimization recommendation while teaching Robust Design course for Ford Fairlane Training Center in Dearborn, Michigan a few years ago. This particular course was developed by Ford in collaboration with ASI for their training program.

The two-step optimization method is a common sense way to determine the optimum condition to reduce variability and mean. It does what the S/N ratio and MSD do without including any new concepts (like calculating MSD and transforming results into Log coordinate). In this approach, the factor levels are first adjusted to reduce variability (which is always smaller is better), then, the remaining factors are adjusted to make type mean move toward the goal (nominal, smaller, or bigger). In case of any conflicting demand on the same factor, as it may have influence on both mean and variability, the variability is always prioritized. For variability, a separate analysis is performed by taking standard deviation (just as done using the mean) of the results of each trail condition. Analyses using S/N ration are likely to produce the same results as by two-step optimization with equal priority (50%weight) on mean and variability.

- RKR

Topic /Ref : Miscellaneous Questions (DOE-DG91, Sept. 19, 2002)

Question:

Would you please clarify a few points about the Taguchi technique.

1. IS Taguchi principle only for main effects?
2. Noise factors are uncontrollable factors. Then, how can I choose levels for noise factors?
3. Are signal factors controllable or uncontrollable? How can I find the effect of signal factors?
4. If the no. of levels for a particular factor is more, can we get more accurate solution than with less no. of factors?
5. How can I choose the no. of samples per trial? Is there any standard technique available? If the sample size is large, will it lead to more accurate solution than with small sample size?

-vijila glitus evelin

Answer/Comments:

Is Taguchi principle only for main effects?
No. Interaction effects between two factors are easily investigated by the Taguchi orthogonal arrays. To design experiments to investigate suspected interactions, appropriate columns of the array are left empty. To help with such experiment design, Dr. Taguchi created the TRIANGULAR TABLES. There are separate tables for 2, 3, and 4 level array/columns.

The common perception, however, is that Taguchi technique looks only at main effects. This is because, in the Taguchi technique, study of factor effect and robustness are prioritized over interaction effects.

How can I choose levels for the uncontrollable noise factors?
Noise factors are included in the outer array of the experiment. Since they are considered to be uncontrollable in real life application, they are never treated along side the control factors in the inner array. Since they are uncontrollable, you would never specify them for the final design. However, for the purposes of running your experiment with the outer

array, you need to be able to set/hold the levels of the noise factors under the laboratory/test condition.

Are signal factors controllable or uncontrollable?
This question is difficult to answer in short in this forum. For all your static design (which is what most experiments are), the signal factor is assumed/kept fixed. Read materials under DYNAMIC CHARACTERISTICS wherever you can find (www.nutek-us.com/wp-doe.html , serach engines,).

Is it possible to get more accurate solution with factors and higher levels than with greater number of factors?

The levels of the factors and the number of factors included in the study are determined by separate considerations and rationale. The number of levels a factor to have should strictly be decided by the need to study nonlinear influence of the factor. If there is no prior knowledge about nonlinearity, two levels for a factor should be the choice. The number of factors to be included in the study, on the other hand, is decide by the size of the array your time and money available for the project. Of course, here, you face the need to compromise between factors and the interactions you wish to study. These decisions are not guided by science, rather your experience rationale for the project.

How can I choose the number of samples per trial?
There is no special recommendation for sample size. One is minimum, but, it is always the more the better. If you design experiment with an outer array, the size of the array will dictate the number of sample. If not, it will be your subjective choice. In my training, I recommend to keep this number between 3 –10. Go for a smaller sample when the cost of sample is higher and expected variability is low. Go for a higher number when the variability is high and the cost of sample is affordable.

- RKR

Is Taguchi principle only for main effects?

(1) Let;'s do a simple experiment.

Consider the famous time period of oscillation of a body with weight W and
spring constant k,

T = f(W, k) = 2*Pi*sqrt(W/(g*k)) where g is the gravitational
constant.

Let's ask our engineering friends if W and k 'interact' on influencing T, i.e. is there a 2-factor interaction effect?

Based on my own experience from teaching DOE, most of them would say NO because both factors have a clear and separate role on T. For those of us who knows the definition of 2-factor interactions and Taylor series approximation would answer YES. Therefore, asking experimenters to whether two factors interact in influencing a response as prior evidence in planning an experimental design is dangerous. That is, they don't even know if their interpretation of interaction the same as the statistical definition of interaction.

Most of us should have no problem describing quadratic effect but not many of us can describe the 2-factor interaction effect as in the context of DOE.

(2) Taguchi technique not only chooses main effect over interaction effect, he chooses quadratic effect over interaction

effect.

Quadratic effect X1(superscript: 2)is just a special case of X1*X2. It is 'logical indefensible' when one concerns quadratic effect while assuming interaction effect is zero. For example, using L9 to investigate 4 factors. Interpreting the marginal mean plot can be misleading due to the presence of 2-factor interactions. Also, in Taylor series approximation to any analytical function, X1*X2 appears before X1(superscript: 2), X2(superscript: 2)

Based on my reading of Taguchi books, 2-factor interaction plot is hard used to analyze the data, i.e. how to visualize 2-factor interaction is not taught. Also, when using L8 to investigate 7 factors, the readers are never warned that the results could be misleading if there is any sizeable
2-factor interactions.

For more details, see articles:
Let's All Beware The Latin Square by J.S. Hunter, Quality Engineering, 1(4), p. 453-465, 1998
Interactions: Ignore them at your own risk by Paul Hurley, Quality Engineering, 6(3), 451-457, 1994
Why three-level designs are not so useful for technological experiments by Soren Bisgaard, 9(3), p. 545-550, 1997

Aldous Wong
Senior CI Specialist, Imperial Oil Resources

The point that Dennsi Craggs (below) has brought out is a real good one. It is indeed one of the two main reasons why Dr. Taguchi recommended transforming trial results into S/N ratios, which is Log (to the base 10) of mean squared deviation (MSD). The transformation liberalizes all influence function and validates the assumption of additivity in the predictive equation for the optimum performance.
- Forwarded by R. Roy, Nutek, Inc. www.nutek-us.com

This is a very interesting topic. Here the physical principles are well known, but the equation is nonlinear. One approach is to transform the equation with the objective of obtaining a linear equation. In the spring mass oscillation problem, the equation can be linearized by taking the log of both sides of the equation, i.e.:

log(T) = log(2*Pi) + 0.5*log(W) - 0.5*log(g) - 0.5*log(k)

After transforming the data, should be able to perform a DOE. The analysis can determine if there are any interactions between log(W), log(g) and log(k) that affect log(T). The simple physics model does not consider these secondary effects. For instance, if a two level experiment is desired, the levels for the spring constant k can be separated as wide as possible. If a three level experiment is desired, the spring constant (k) factor levels spacing will be equal in the log(k) scale, but unequal in the k measurement scale.

-Dennis L Craggs

I could not respond to your mail before as I was suffering from Chicken Pox. Anyway, I will begin to respond to some of

the questions soon. I have seen some great explanations below from Dr Roy, however, I thought that I have to add my views and opinions as well.

Q1: This is a common query from many industrial engineers in organisations. Can we study interactions using OAs? Answer is YES !! Taguchi Methods are not same as Taguchi's original work in the field of Experimental design. The idea of Taguchi Methods is to minimise the effect of interactions by selecting the right Quality Characteristics. This is not the case always in industrial experiments. The emphasis is on main effects in Taguchi Methods. However this does not imply that you cannot analyse interaction effects. As long as you have sufficient degrees of freedom for analysing the interaction effects, why not?? Please do bear in mind that many Taguchi experiments are saturated designs where your objective is to identify the vital few process variables or design parameters from the trivial many, as opposed to analysing the interactions among the design parameters or process variables. The use of linear graphs along with Interaction tables would assist you with the analysis of interactions and of course to understand the confounding pattern of interactions.

Q2: The levels of noise factors should be kept minimum (2-levels) as it will increase the size of the experiment and hence costs associated with the experiment. The objective of including noise factors for the experiment is to achieve robustness. The idea of robustness is to minimise the impact of noise factors by determining the best levels of control factors. In order to minimise the size of the experiment, people are currently employing the so called Combined-Array strategy rather than Inner-Outer array or Product-array Strategy. So it is worth investigating the difference in these strategies prior to carrying out the experiment.

Q3: Signal factors do not have or have little influence on variability but have major impact on mean response or quality characteristic. For static experiments, the signal factor is kept fixed or constant and for Dynamic experiments, you need to vary the levels of Signal factors for achieving greater optimisation. For many experiments, they can be controllable and it is important to understand at what level the signal factor should be kept for maximising the process performance.

Q4: This depends on the objective of your experiment. As Dr Roy highlighted in his response if you know that the effect of factors on the response is non-linear, you can study factors at 2-levels. On the other hand, if non-linearity is suspected (this is the case for many engineering systems), it is advisable to study factors at 3-levels. Bear in mind, the interactions among factors at 3-levels is rather more complicated than that at 2-levels.

Q5: Much has been done on sample size calculations for Taguchi Experiments. One classic book for this issue can be obtained from 'Understanding Industrial designed Experiments' by Schmidt and Launsby, Air Academy Press. You should understand the relationship between the sample size and the risk of not detecting an effect of either factor/interaction for industrial experiments.

-Dr Antony

Suitable transformation can indeed linearize or simplify (eliminate the need of interaction term) the surrogate model. However, there are responses

that can not be linearized via transformation, otherwise, there won't be any need for 3 level design for quantitative factors.

-Aldous Wong

Topic /Ref : OEC Characteristics (DOE-DG92, Sept. 25, 2002)

Question:

(Follow up questions)

In the Overall Evaluation Criteria (OEC) how can I find the best and worst value for the criteria? Is there any formulae/technique available for finding these values?

-"vijila glitus evelin"

Answer/Comments:

The OEC formulation (www.nutek-us.com/wp-oec.html) uses the best and the worst values of the observed results. These extreme values are picked up from the observed/collected results after all the experiments are carried out. During the discussion during the planning session, i.e., before the experiments are carried out, you may assume some expected ranges. However, they must be replaced by the actual results after the experiments are conducted.

How can I give weighting to the various criteria?

The relative weights of the individual criteria of evaluations (in case of multiple criteria/objectives) are determined by the consensus of the team members participating in the planning session. This and many such items are subjectively determined in the planning session. As most parishioners of DOE are well aware, it is the planning of the experiment (Brainstorming) that will make the experiment more effective. The planning discussions is a logical process, not a scientific one. Like the weighting for OEC, the decisions about how many factors to include, which interaction to study, whether to go for robust designs, etc. are all decided in the planning session by group consensus and scope of the project.

In ANOVA, what is the use of pooling? If, we don't pool the insignificant factors, what is the effect?

Pooling is a process where insignificant factors are discarded from the group of factors studied. The primary rationale for pooling is to reduce the probability of incurring BETA error, which is to call something important while it is not. It is customary to use only the unpooled factors to calculate the expected performance at the optimum condition. Using the unpooled factors (significant) only for estimating the expected performance, will allow you to predict performance which is more conservative and more likely to be reproducible. You should definitely pool factors (for larger experiments) when the degrees of freedom (DOF) of the error term is zero or small. The DOF of the pooled factors increases the DOF for the error term, which strengthens the power of test of significance of the factor influences.

- RKR

Topic /Ref : Signal-to-Noise Ratio (S/N) (DOE-DG93, October 15, 2002)

Last month I bought your book 'Design of experiments using the Taguchi Approach',more recently I had occasion to read Dr. Taguchi's 'Introduction to Quality Engineering'.

Now I have two problems:

1. If I am right the MSD is the sum of a signal and a noise factor. Then I fail to see that the log of MSD is a S/N ratio.

2. Dr.Taguchi mentioned the expansion by orthogonal polynomials and tabulates their coefficients. Alas he does not give a derivation of these coefficients. Looking up Chebyshev polynomials in a Handbook of mathematical functions does not help.

Can you enlighten me? Thank you in advance,

J.G.Lever

Answer/Comments:

You raised a good point about usage of the term S/N ratios. There are rooms for some confusion. Let me try and clarify a few things.

1. The term signal-to-noise ratio literally represents the ratio of response due to signal factor (control factor in most cases) to that due to the noise factor. And, of course, you would always want to maximize S/N. This is how it has all along being used in electrical and electronics engineering. The same concept has also been extended to the analysis of experimental results, as there are similarities. Unfortunately, the common definition of S/N from MSD does not show that, nor do you require the principle of such ratios for formulation of S/N based on MSD. Formulation of S/N shown in page 372 in my book for nominal case and description in Dr. Taguchi's System of Experimental Designs somewhat explains (www.nutek-us.com/wp-txt.html) the rational for the ratio concept.

The reason MSD is used for evaluation of multiple sample results is because it makes sense to evaluate it in terms of something that is closer to the target and that has less variation around the target. The transformation of MSD into Log scale, however, is strictly a matter of convenience as Log offers linearity and ability to handle wider ranging data. It need not have been called S/N. But since, MSD also looks for results that higher response due to factor and/or lower response due to noise, and because it is in the Log scale, the term S/N is introduced. But, you definitely have the right to be misled when you try to extract the ratio of the two responses (signal and noise) directly from the MSD expression. Particularly, it is difficult to apply the concept in case of static experiments (as opposed to dynamic response/system) where signal factor is fixed.

2. No comments. Please share your research findings in future communications.

(Ref. S/N Step 12, page 373 *in* 16 Steps… www.nutek-us.com/wp-txt.html).

- RKR

To answer your second question.....to find the i-th coefficient, c(i), of an expansion of function g(x) in terms of any set of orthogonal functions f(i,x) you need to integrate g(x) * f(i,x) *w(i,x)* dx over your domain and divide it by the integral of f(i,x)^2*w(i,x)*dx over over the domain. The function w(i,x) is a weight function, which is different for each set of orthogonal functions. The weight function may be the identity function (w(i,x)=1) for Chebyshev polynomials. The summation of c(i)*f(i,x) then approximates g(x). For smooth functions g(x), the approximation error decreases rapidly with increasing number of terms in the summation.

-W. Joseph Mantle, Ph.D.

Ford Motor Company

Topic /Ref : Severity Index (DOE-DG94, Oct. 24, 2002)

Question:

1. How can I find the severity index and contribution?

2. Is there any formulae available for that?

3. Why we multiply with different weightings in OEC instead of multiply with percentage values? For example, if I have two criteria, each with 50%, why I multiply each criteria with 0.5 instead of 50?

4. How can I find F-value in confidence interval. In Qualitek software, I think the value is different from ordinary table values. What is the reason for that?

"vijila glitus evelin"

Answer/Comments:

1. The severity index (SI) can be calculated from the interaction plot for the pair of factors concerned. The strength of presence of interaction is measured n terms of a numerical quantity (Severity Index) which measures the angle between the two lines. The Severity Index is formed such that it is 100% when the lines are perpendicular and 0% when the lines are parallel.

2. The formula for SI can be found at page 265 of Step 8 in my book: 16 Steps…. You can also see how the SI calculated in the "automatic Interaction " option from Main Effect screen of Qualitek-4 software (You can see this in DEMO also, www.nutek-us.com/wp-q4w.html).

3. Your analysis would not change whether you multiple the OEC formula with, say 50 for 50% or by 0.50. By multiplying by 50 for 50%, you assure that the OEC value is normalized to be within 0 – 100. On the other hand, if you use 0.50, the resulting OEC will be constrained within 0 -1.0. This however, will not change the conclusions you derive from analysis.

4. Your observation about the F-value is correct.. Qualitek-4 uses the original formula for calculation of F values instead of using a look-up table. It iterates to get solution must close to the book value. But, because for certain combination of degrees of freedom (error and the factor), the calculated F value is highly nonlinear (unstable). This makes the solution very difficult and different from the book value, which should be considered as exact solution. When in doubt, therefore, the book value should be preferred. Be assured, however, that the values calculated by the software is within sufficient accuracy for the purpose it is used.

To learn more about *interaction effect* read Step8, page 241 *in* 16 Steps… www.nutek-us.com/wp-txt.html).

- RKR

Topic /Ref : DOE for Banking Service Study (DOE-DG95, Nov. 26, 2002)

Question:

I want to ask you how the Taguchi method can be applied for banking services. I remember that you have answered this question through the discussion group a long time ago in which you have introduced some factors as examples

which can be examined. Please send me the email and let me know if there are any case studies or experiences in this way.

-Younes Leysi-Derilou,MSc

Answer/Comments:

I believe we had some discussions on related subject, but it is worth asking about it again. I do not have a specific case study on banking service to refer to you. Wonder if any of our members can help.

Members, please help Younes with any case studies in the service industry, if not one specifically in the banking service. Forward your response directly to Younes and to me so that I may distribute to all members.

Lately, I have been asked by many in fields other than traditional engineering application areas, about the application of DOE. The other day, a US Air Force maintenance and service specialist called me asking for case studies in maintenance service and if I knew how to get hold of them. I didn't know of any. An attendee in my recent seminar told me his reason for attending the seminar was to apply the Taguchi approach to study social behavior of certain population segment as part of his graduate research. Perhaps some day will see some documentation/publications on such special applications.
Good luck to you, and please share your finding (case study in banking) when completed.

- RKR

Some DOE examples in non-manufacturing settings:
(1) Boost Your Marketing ROI with Experimental Design by Eric Almquist and
G. Wyner, Harvard Business Review, Oct 2001
(2) Experimental Design with Applications in Management, Engineering, and
the Sciences, by P. Berger and Rob Maurer, Duxbury 2002

-Aldous Wong, Senior CI Specialist

The application of DOE/Taguchi in Service Industry is not a common practice. However, there are few case studies published in Journals. One case study published in the International Journal of Quality and Reliability management is about the application of Taguchi methods in improving service performance in a shipping company. The response of interest was the time to deliver the service and time to respond to customer complaints. Experiments are also used for improving recruitment effectiveness and I have come across this case study few years ago.

In service industries, DOE is applied under a different name called ' Conjoint Analysis'. This technique is used to understand the key attributes which are most appealing to consumers and at what levels they should be used to optimise the service performance characteristic. I was quite intrigued by the work of Prof. Gusafsson who looked at the integrated approach of QFD and Conjoint Analysis for his PhD research. There are many applications of Conjoint Analysis in Service Industry which uses Orthogonal Arrays as part of the optimisation strategy and of course identifying the key attributes of service.

Hope this is a great start for you. Any queries, please do not hesitate to contact me.

-Dr Jiju Antony, University of Warwick

Topic /Ref : Optimum Condition – Is it Absolute Best (DOE-DG97, March 7, 2003)

Question:

I have just been reading your very informative book "Design of Experiments using the Taguchi Approach" but one issue troubles me. May be I've missed it but it isn't clear to me whether the Optimal value is (a) the best possible value, or (b) the best possible value from all permutations of selected levels and factors e.g. one of the 8 permutations if using a L-4 (2^3) array. From your book I would assume (b) to be the answer whereas a colleague of mine who attended a Taguchi course some years back assures me that (a) is the correct answer.

……

Chris Watts, Director of R&D Programs

3Dlabs Ltd, Meadlake Place, Thorpe Lea Road

Egham, Surrey, TW20 8HE, UK

Answer/Comments:

The optimum condition determined by analysis of results from DOE is always the most desirable condition from among all possible combinations. If you are studying THREE factors at TWO levels each, and you designed this experiment using an L-4 array, there are EIGHT (2^3) possible conditions recognized by the DOE model. Even though you only run FOUR experiments, the optimum selected is the most desirable among the EIGHT. In case you study SEVEN factors using an L-8 array, the optimum is the most desirable among the theoretically possible 128 conditions.

Let's clarify the term "best or absolute possible". One needs to be careful about this statement as it may mean different things at different context. Suppose that some of the factor among the ones studied are of 'continuous' type (thickness, temperature, pressure, etc are of this type). That means that these factors may assume (in real life) many other values between the two extreme levels included in the study. Having studied only two levels of the factor, we make the DOE math model see the response as truly linear. It means that the end points are truly the highest or lowest points. Indeed there can be no other point higher or lower/higher than the end points when the response line is straight line. Theoretically this is correct. However, in real life behavior, the response to this factor may be non-linear, and there can be points, between the end points, that are lower or higher than the end points. Unfortunately, the DOE predictive model (Y-optimum) is unaware of it and cannot identify such possibilities. This is true in all types of DOE, including the full factorial studies.

Does this sound scary to you? Let this not be a deterrent to your project studies. It is the reason why you would always run CONFIRMATION tests. So that you can find out how good your prediction is. If your confirmation test results (mean) fall within the confidence interval, you can trust the results as acceptable even though you may not have climbed "Mount Everest", but you reached a peak close to it. The confirmation test also validates your DOE prediction in spite of the fact that you may not have corrected for all kinds of interactions that might have been present.

- RKR

Very good question indeed.

When there is 2-factor interaction, L4 may not locate the true optimum result!

Attached are couple examples from my inhouse DOE (Design Of Experiments)

workshop to illustrate the potential risk of stopping after screening design such as L4. Validation experiments would not detect the problem. I am in the process of writing a paper based on these examples. [Contact Aldous if you want more information or ppt files]

The risk of using screening design is well known within statistical DOE community. For additional info, see:

T.P. Ryan, Taguchi's Approach to Experimental Design: Some Concerns, Quality Progress, May 1988.

Paul Hurley, Interactions: Ignore them at your own Quality Engineering, 1994, 6(3), p.451-457

F. Dong and T.N. Goh, Impact of Unspecified Interactions on the effectiveness of Taguchi's parameter design, International Journal of Reliability, Quality and Safety Engineering, Vol 5, no. 4, 1998, 373-382

Aldous Wong

Topic /Ref : Interaction and Noise Effects (DOE-DG98, March 17, 2003)

Question:

I am student of Sepuluh Nopember Institute of Technologi Indonesia. In my Final project, I applied Taguchi with 4 factor and 3-level in tube glass putting using thermal shock. Which OA I must use if I want interactions?

The other problem is how to determinate noise in my experiment. I wish to incorporate condition that influence cutting process (i.e cooling time, tube temperature etc) or condition in costumer environment (i.e environment temperature).

Thanks for attention

-Febrian Mahdi

Answer/Comments:

You should use an L-9 (3^4) orthogonal array to study FOUR 3-level factors that you wish to study. If you also must study some of the interactions between factor, which can be 6 (= 4 x 3 / 2) different kinds, you will need to consider an L-27 (3^13) array and keep two columns for every pair of interaction.

For you and others who have interest in INTERACTION studies, here is my OPINION and recommendations. When it comes to interactions, I recommend that you only study interaction between TWO 2-level factors. Interactions among more factors and that between two 3-level or two 4-level factors are much more COMPLICATED to STUDY and INCORPORATE DESIGN CHANGES. Interaction study is of no use, if you could not satisfactorily make corrections in your optimum designs based on what you find out from the interaction. Bottom line is that interaction study between two 3-level factors would cost you many additional experiments. Do it only when you know what to do with the knowledge of the presence of the interaction (The books that show you how to handle interaction between two 3 or 4-level factors are rare.).

With regard to your question about how to determine the effects of NOISE in your experiment, carefully identify noise factors and study them, if possible, by including an outer array I your experiments. If you were to study four 3-level factors and also wish to study three 2-level noise factors, you will have an L-9 inner array with an L-4 outer array in your experiment.

- RKR

Beyond different experimental strategy proposed in previous e-mails (i.e. 2-levels instead of 3 levels), you may use some way for elimination of interaction(s), (engineering approach in planning phase).

Some ways for elimination of interaction of 2 factors:

- choice of different quality charcteristic

- substitute 2 interacting factors by 1 factor, representing the same procedure (e.g. energy transformation)

- keep 1 of interacting factor in constant value
- use of "sliding levels" (i.e. setting of 1 factor is dependent of another factor value)

-Dr. Pavel Blecharz

How do you justify that you need to all 4 factors at 3 levels? If I were you, I would have started off with factors at 2-levels and add centre points to determine the statistical significance of curvature effect. If my test on curvature is significant, I would then choose three levels. As Ranjit mentioned below, analysis of interactions at 3-levels is rather a complex process. You could have four types of interactions here: linear x linear, linear x quadratic, quadratic x linear and quadratic x quadratic. This would tell you that you need four degrees of freedom for analysing interactions for factors at 3-levels.

If you have to analyse the impact of noise factors, you need to include them using either combined array approach or noise array approach. Combined array is more cost effective if the cost of the samples is high. You need to carry out some research before you select any of these strategies.

-Dr Antony

Topic /Ref : 3-level Factors Interactions (DOE-DG99, March 20, 2003)

Question:

I have to design an experiment using 6 parameters at 3 levels each, using an orthogonal array of strength 2. I would like also to study the interaction between two of these parameters. Which array shuold I choose? And which is the optimum column assignment for evaluating the interaction?

-Marco Severgnini
c/o Science and Biomedical Technology department
University of Milan, Italy

Answer/Comments:

Perhaps you have been following the discussions and comment on the interactions in recent mails. Since interaction is one of the difficult areas to study and derive the needed design changes from it, more discussions on the subject is welcome.

In your situation, you should refrain from worrying about interaction in the first attempt. Simply design the experiment using an L-18 (2^1 3^7) orthogonal array to study the SIX 3-level factors. If you wish, you may also assign an additional 3-level factor and a 2-level factor in the remaining columns of L-18 array. If this is not satisfactory and you wish to study interactions, you will need to go for an L-27 array. Bare in mind that you will need to set aside two 3-level columns to study each interaction (between two 3-level factors) and that there is no way for you to decide which among the 15 (6x5/2) possible interaction to study.

When it comes to interaction, Dr. Taguchi asked experimenters to "DIG WIDE, and not DEEP". This profound recommendation stems from the realization that faced with a large number of factors and a corresponding possibility of larger number of interactions, what are you to do when your resources are limited? The strategy to follow will be to

study the factors first. Check to see if you confirm your prediction (Confirmation test within confidence interval). If you do, you are done. It does not, however, mean that the interactions do not exist; it simply means that your design solution is acceptable in spite of the presence of interaction. On the other hand, if you do not confirm, you will know which factors to study and which interaction to be included in your study. Understand also that from your first experiment with factors only, the strength (Called SEVERITY INDEX in Qualitek-4 software) of all possible interactions between two factors can be obtained. This information can be utilized to decide which interaction to include in your repeat study.

- RKR

Topic /Ref : Why do DOE? (DOE-DG100, March 26, 2003)

Question:

Why do DOE?

As practicing engineers, research scientist, or academicians, why should you learn and apply DOE and or Taguchi technique? What benefits have you experience by applying the technique?

-Engineering Management, Manufacturing Industry

Answer/Comments:

I need your help to answer the above questions. I would appreciate it very much if you would take a few minutes of your time and write a few sentences. Please provide your name and organization with your comments (I will not post your e-mail address unless requested. If you do not want your name published, do not add name after your comments.). Selected comments will be posted in our DOE site www.nutek-us.com/wp-doe.html .

I look forward to hearing from you soon.

- RKR

"I use DOE to help my clients optimize processes for value-added products while minimizing production costs. In the manufacturing of wood products like value-added oriented strand board panels and specialty plywood panels, there are several parameters that affect the process. DOE is the tool to deal with processes with so many variables."

- Dr.David Barrett, Professor, Department of Wood Science, Vancouver, BC, Canada.

Imagine the feeling of finding something you really want when it is on sale at a deeply discounted price. A well thought-out experiment allows you to find-out so much for relatively little time and effort; you just can't beat it for economy, efficiency, and effectiveness. And it is so beautiful, watching knowledge unfold like a flower."

- Larry Smith, Manager, "Champion of Quality", Ford Motor Company, Dearborn, Michigan.

"When I need to adjust one thing to improve performance, or when the single source of problem is known, often I can arrive at the solution intuitively. But when I'm dealing with more than one factor, or looking for unknown sources of problem, DOE comes to help."

- DOE Practitioner

"Designed experiments can help untangle the nature of complex and otherwise confusing relationships faster than many of the alternatives. 'Thinking DOE' helps one think more systematically, regardless of the application."

- Paul Selden

Topic /Ref : L-8 Array for three 2-level factors (DOE-DG101, Dec. 11, 2003)

Question:

I am doing project in rapid prototyping technology using Taguchi technique to optimize the process parameters. …..

1. I have 3 factors with 2 levels. So, I use L8 OA. To test the significant factors and all the three 2-factor interactions. i.e A*B, A*C, B*C. But it is same as full factorial experiment. Is anything wrong when I use Taguchi technique i.e L8 array. My friend told me that it was full factorial experiment, so not to use Taguchi technique i.e L8 array. Then what is the benefit by using Taguchi technique rather than full factorial experiment in this case?
2. In OEC, each criteria has different units. if we combine is there any problem occur?
3. What is the advantage of using Taguchi or DOE when compared with other optimization techniques like Artificial neural network, fuzzy logic, generic algorithm etc.
4. How can I confirm the experiment? please explain clearly about the confidence interval (C.I) at predicted mean and predicted at confirmation? How can I compare the results from the confirmation experiment?,

<vijila_glitus@yahoo.co.in>

Answer/Comments:

I would address your first question here.

When you use an L-8 array to study three 2-level factors (say A, B, & C), you have all possible combinations (full factorial) that the three factors create (2^3 = 8). With three factors, you can have three interactions between two factors like, AxB, BxC, and CxA, The same three factors may also have an interaction effect among them, i.e., AxBxC. When you run L-8 experiment, by assigning the factors appropriately (A in col1, B in Col. 2, C in Col. 4, etc.), you will be able to determine effects of the three factors and four interactions from the experimental results.

Is there any benefit by running L-8 instead of the classical full factorial in this case? Not really. They become one the same, and you may chose to follow notations of any one method you are comfortable with.

Perhaps it is worthwhile to mention that, often the reason for preferring Taguchi approach will be to do, not a full-factorial experiment, but a fractional one that has been validated by some one, and the one that is smallest in size. Taguchi orthogonal arrays are indeed the smallest fractional factorial experiments you need to run. The second reason for your selecting Taguchi approach could be your familiarity with the standardized approach of interpretation of results (following some textbook on the topic or practitioners in the field). Of course, remember, unless your experiments involve some of Dr. Taguchi's robust design strategy, loss functions, outer array design philosophies, the classical and the Taguchi DOE's approaches hardly differ.

- RKR

I thought I would give some insights into your questions, especially question 3. There are no advantages of DoE/Taguchi over optimisation strategies using AI (neural networks, algorithms, fuzzy logic, etc.). rather these are very much complimentary to Taguchi/DoE methods.

Using Taguchi methods, you would not be able to determine the real parameter settings, rather it tells you which level is better when you compare two, three or four levels. People use Neural networks to obtain the real values of parameters which optimise the response or output function of interest. The optimal settings is the one which gives you minimum RMSE.

-Dr Antony

Topic /Ref : Interaction Among THREE FACTORS – Part I (DOE-DG102, April 22, 2003)

Question:

We have installed The Qualitek-4 software, licensed to Dr.Frank Liou, in LAMP lab. I am working on it for Taguchi Analysis of laser cladding parameters. I am stuck at a point and want your advice on this. Could you please help.

I am considering using an interaction of 3 control factors, which is very critical for the experiments. But I haven't encountered a case in which interaction of 3 factors is considered, as they seem to be two factor interactions.

The interaction which is being considered is energy intensity with factors laser power, beam diameter and traverse speed. Could you please offer some suggestions?

-Yashodhan Joshi, Research Assistant
Manufacturing Engineering University of Missouri-Rolla

Answer/Comments:

There have been some discussions on interactions in the past. But, since there is much to be said about interaction and since it is one of the difficult area to understand and analyze, I suppose there will be much more discussions to come.

Interaction studies (1) between factors with levels higher than two levels, and that (2) among three or more factors are difficult to design, analyze, and incorporate changes as a result of its presence (Textbooks or reference materials on three-factor interactions are hard to come across). This is why experimenters should refrain from dealing with above two types in their preliminary experiments. Instead, industrial experimenters are strongly recommended to concentrate on interaction between TWO 2-level FACTORS. My recommendation to you is that should you wish to study interactions among three factors, spend a good amount of time learning how the three-factor interactions before proceeding with your experiment. Perhaps the following points will help you understand the complexities that arise.

Assuming that you have all factors at TWO LEVELS, when you have SEVEN such factors, the full factorial arrangement requires 128 conditions. By running all 128 separate experiments the following statistics can be calculated:

Average effect = 1 (one average of all results)
Main effects = 7 (for seven factors, like inL-8 array)
Interaction between two factors = 21 (AxB, AxC, DxE, FxG, etc)
Interaction among three factors = 35 (AxBxC, BxCxD, etc)
.. .. .. four .. = 35 (AxBxCxD, BxCxDxE, etc)

.. .. .. five .. = 21 (AxBxCxDxE, BxCxDxExF, etc)
.. .. .. six .. = 7 (AxBxCxDxExF, BxCxDxExFxG, etc)
.. .. .. seven .. = 1 (AxBxCxDxExFxG)

General combination formula for interaction calculation is n-C-r = n!/[r! (n-r)!], where '!' symbol stands for factorial value. Example: For two-factor interactions when there are seven factors, there will be 7-C-2 = 7x6x5! /[2 x 5!] = 21 interaction pairs.

So what information do you miss when you do an L-8 array experiment with seven 2-level factor? Or, what could you get when you can afford to run all 128 experiments?
Obviously, information about all the above interaction is what will be your answer.

More information sounds attractive, and who wouldn't want it? But, at what cost?
Aside from the time and cost of running much higher number of full-factorial experiments, there are two other hidden reasons to consider: First (a) the difficulty in establishing whether interactions exists or not, and complexities in determining what to do with the information, that is, how to modify the design to correct for the presence of interaction. Second (b) the hierarchy of importance of information. In terms of the absolute magnitude, the main effects tends to be larger than the two-factor interaction, which in tern is tend to be larger than the tree-factor interactions, and so on. (For quantitative variables, the main effects and interactions are similar to the relative importance of the terms in a TAYLOR SERIES EXPANSION of a response function. Ignoring the three-factor interaction is like ignoring the third order term which is usually much smaller than the second order term.)

[Read more about interaction studies in STATISTICS FOR EXPERIMENTERS – Box, Hunter & Hunter, 197, Page 374.] Indeed, it is this later consideration that validates all fractional factorial experiments including experiments using Taguchi orthogonal arrays. When interaction is of interest, and columns can be sacrificed to do so, two-factor interactions must be studied first. Perhaps you should study 10 two-factor interactions before proceeding to study one three-factor interaction. Bottom line, you must do what you can afford (time and number of experiment). When sacrificing factors for interactions, exercise extreme care.

How do you decide which interactions to study, and which factors to discard to make room for interactions?

Look for more discussions in future discussions.

- RKR

Three-factor interactions are relatively small in magnitude as compared to 2-factor or second-order interactions. In Classical DOE, column 7 is theoretically used for studying a three-factor interaction, but practically used for blocking purposes (if you have to consider day-to-day variability, machine-to-variability, shift-to-shift variability, material-to-material variability, etc., where Day, Machine, Shift etc, are treated as a block). Moreover, this column is used for pooling if you have to analyse variability as a separate response.

Can you provide more information to the group as to what are the objectives of your experiment, what do you want to get out of your experiment, what is the problem at hand?

-Jiju Antony

My impression from literature is that three-way interactions, i.e. AxBxC, are relatively rare as compared to two-way interactions, and if present, probably small. This may be part of the reason that one configuration of the Linear Graph for L8 shows when three factors are assigned to columns 1, 2 and 4 respectively the factor for column 7 is shown as

independent .

Therefore if one needs to determine or evaluate the magnitude of a three-way interaction between three factors one could apply the L8 orthogonal array in the Resolution V mode whereby Factor A is assigned to column 1, Factor B to column 2 and Factor C to column 4 - as the Linear Graph suggests. The AxBxC interaction would then be associated with column 7 and can thus be evaluated.

The AxB, the AxC and the BxC interactions would respectively be in columns 3, 5 and 6.

-Dr Wim Richter, MMTek CSIR, Pretoria 0001, South Africa

I will ad some comments, because we have solved similar problem in practice.

All factors you described, have one common thing: They determine amount of energy in process. But, in fact, the last factor (traverse speed) is "time". Set up this factor in accordance with required amount of production, taking into consideration physical constraints. Then keep the factor on constant value and resolve the problem with 2 factors, including their interaction.

-Dr. Pavel Blecharz

Topic /Ref : How to Select Levels of Factors (DOE-DG103, May 16, 2003)

Question:

Please clarify the definition of Levels in DOE. My understanding is that the 3-level nomenclature -1 0 1 usually stand for LOW MID, and HIGH levels, and that they do not have to correspond to any specific value. I have found two "pseudo-standards" in my industry, one where three level designs LOW, MID, HIGH are associated with P10, P50, P90 (percentiles), and a second one where the same three levels are associated with MIN (P0), MEAN (P50) and MAX (P100).

Could you elaborate whether one is correct and not the other, or which one poses more benefits or if neither is better that the other.

My understanding is based more on a physical ground than on a statistical ground, and it tells me that you simply need contrast among the different levels, off course, the physical behavior of process may be complicated and the more levels and the broader the factor range of exploring the better your trends.

-"Mauricio Villegas"

Answer/Comments:

Your question is quite interesting as the answer to this issue may require a good understanding of the process

performance.

The symbol -1, 0, and +1 are used by classical design matrix to designates three levels of a factor. The corresponding definition in Taguchi Approach is 1 , 2, and 3 respectively for the first ,second, and third level of the factor. In deciding which level should have what designation, follow the simples guidelines below:

1. *When the factor is of discrete nature, like machine (Three types), tool (three kinds), operators (three individuals), Knob Settings (three settings), etc., there are no restrictions about which one to assign what level number.*

2. *If the factor is of continuous type, like speed, time, temperature, pressure, etc., you must assign levels in order of the magnitude (1 for smallest level value, 2 for mid level). There is no requirement that level 2 should be a number in the middle of level 1 and level 3. Nor do you have to call a lower valued level as level 1. A general recommendation for three level factor is that you select the mid level (level 2) near the current condition, and select the other two at the 'two extreme ends'. Again, there is no specific requirements as to what makes the extreme; 5%, 10%,or 15% from the current operating condition. None such guidelines. My personal recommendation is that for the two levels (level 1 and level 3) go as far away from current operating condition (level 2) as possible, making sure that these levels does not prevent you from running the experiment and that you can release the design when they are identified as the desirable levels.*

- RKR

Topic /Ref : Working Confidence Level (DOE-DG104, August 18, 2003)

Question:

Please clarify my confusion about when to take the confidence level as 90,%, 95 % and 99%.

-Kantha Babu

Answer/Comments:

When analyzing results of designed experiments, you will commonly use CONFIDENCE LEVEL (CL) values for two purposes. First, to perform test of significance to in ANOVA, and second, to establish confidence interval (C.I.) for the optimum performance. In either case of the applications, you will need to select a value for the CL arbitrarily (subjectively). The important thing is to work with a value you decided for the entire experimental analysis (never change to suit your conclusions conveniently).

Here are some general recommendations:

- *Work with 80%, 85%, 90% or 95% for all general situations. Obviously, use lower CL when influence of the error term is higher. This will keep you confidence interval tighter and find more factors significant.*

- *Use 95% for safety related or critical items.*

- RKR

CI's of 80% stand a 1 in 5 chance of being missed by chance alone. A 95% CI gives a pretty wide range but one would miss it only 1 out of 20 times by chance alone. (If you miss it - there is probably a good reason). One would want to seek a balance here. If it is a confirmation interval, I would go for the 90% or 95% to avoid false positives that sent me off looking for interactions and doing costly prolonged experimentation when the out of CI results could very well be due

to chance alone.

- Dr. Dave Stimley

In Classical DOE, people refer to 90%, 95 and 99% Confidence Levels. In Screening phase, where the objective is to identify the key process or design parameters, it is best to use 90% Confidence level. When you move to the next phase, which is characterization, it is best to stick with 95 or 99% confidence levels. Here the objective is to use only the most significant terms (either main or interaction effects) for the predicted model.

-Dr Antony

Topic /Ref : Orthogonal Array Choices (DOE-DG105, Sept. 4, 2003)

Question:

Where can I best find the orthogonal array choices for experimentation?

(Preferably from the Web.)

-Mike Fox

Answer/Comments:

You can find orthogonal arrays for Taguchi experiments in the appendix section of most books on the subject (www.nutek-us.com/wp-txt.html). You may also search the web (Google or Yahoo) using the key words " Orthogonal Arrays Experiments" to find many references. One search I did came up with 20,000 hits. That's of course a problem to find the right one.

Frankly, just the array source alone will not be of much help. Among the large number of available orthogonal array, you will mostly need L-4, L8, L-12, L-16, L-9, and L-18 arrays. The important thing for any practitioner is to know each of these arrays well, in terms how they look (how many rows and columns, and how are the columns) and what they are used for. Because it is by developing this familiarity, you will know which array to use when. This knowledge about the array is a must before you can lead a group in the planning discussion and determine what the factors to study and how many levels they each should be which you need to proceed with the experiment design.

If you your question relates to confirming which array to use or how to design the experiment given a certain situation (number of factors and their levels), you may find some help in our site on experiment design tips: www.nutek-us.com/wp-tip.html .

- RKR

The near-to-complete library of orthogonal arrays has been collected by N. J. A. Sloane, and can be found on http://www.research.att.com/~njas/oadir/index.html]. I use many of the arrays in market research studies.

In addition to the constructions described on the page, I would like to mention the expansive replacement procedure described in the book "Orthogonal Arrays: Theory and Applications" by A. S. Hedayat, N. J. A. Sloane and John

Stufken" (Springer-Verlag, New York, 1999). The procedure is simple yet very powerful as one can generate many other arrays tailored for the purpose.

-Ludek Broz, NFO AISA (Market Research) Ltd.

Topic /Ref : Test of Significance for Low Error DOF (DOE-DG106, Sept. 4, 2003)

Question:

When the estimates for Confidence Intervals of Tests of significance are unreliable (DOF of error <3) should one use the F tables and manually calculate these values? Seems this would make sense since problem appears to be with how QT4 computes F and other texts such as Ross (1996 now 1988 is out of print) would have you use the tables.

-Dr. L.D. Stimley, Scientific Atlanta

Answer/Comments:

As you observed, calculation of confidence level (CI) in performing test of significance in Qualitek-4 software is unreliable when the error degrees of freedom (DOF) is less than 3. The reason for this is that Qualitek-4 software numerically solves the original Gamma function that relates CI with the F-ratio and error DOF, instead of referring to a look up table. The real time calculation offers computation at any value of the independent variable, but suffers in the accuracy for lower value of error DOF.

In case when you have error 0<DOFY<=3, you should definitely perform manual calculation or computation using other capabilities when you need to. However, be aware that, even the published table values (computed using sophisticated computational routines) are highly nonlinear for lower error DOF and lower DOE of the factor in question (You can observe the numbers on top-left corner of the F-table and see how the F-numbers change).

- RKR

Topic /Ref : Interpretation of S/N (DOE-DG107, Sept. 5, 2003)

Question:

Sorry if my english is not good.

i have read your book "design of experiments using the taguchi approach" and i still don't know how to interpret s/n.

if in linear model y=b0+b1x, we can interpret b1: y will increace b1 unit if x increace 1 unit.

how to interpret 10 db, 20db,18db,....?

-effendy jimmy

Answer/Comments:

The best way to look at S/N (read as signal-to-noise ratio) is that it is the mean squared deviation (MSD) transformed in the logarithmic scale. So to see how S/N is affected, is to see what MSD is made up of. MSD depends on two quantities; the performance average and the standard deviation. If you could momentarily assume that the performance is on target, that is the average of the population performance is on target (nominal, if present), then, MSD is directly proportional to the square of the standard deviation. So, S/N is also is dependent on the standard deviation of performance, except, taking log (to the base 10), changes the relationship slightly.

To develop a "feel' for S/N, understand that changes in S/N (- or +) is more useful to you, the absolute value of it is not that meaningful. A change of S/N by 6 points represents a 50% reduction in the standard deviation (doubling Cpk, at fixed mean). This means that if S/N increases from – 21 to – 15 (6 points gain) or from 12 to 18, the standard deviation of performance is been reduced to half of the original value (say from 4 to 2).

You can verify the S/N to standard deviation relation by compute S/N for two values of standard deviation (say 4 and 2) while keeping the average at nominal value.

To learn more about interaction effect read Step 12, page 371 - 372 in the 16 Steps… www.nutek-us.com/wp-txt.html).

- RKR

Topic /Ref : Confidence Levels (DOE-DG08)

Question:

I have been approached by a Six Sigma practitioner recently with the following question and I need opinions and suggestions from the expert panel members. I am forwarding this question to the panel so that I will have good and stimulating responses.

QUESTION: Why do we stick with 90% confidence level or 10% significance level for many screening designs and 95% or 99% for fractional factorial designs?? We will have a wider confidence interval for higher confidence levels. The purpose of the screening is to select the most important ones and at the same time reject the unimportant ones from further rounds of experimentation.

Comments please.

-Dr Jiju Antony, Glasgow Caledonian University

Answer/Comments:

?? (Discussions lost)

- RKR

Topic /Ref : Mixed Level Factor Design (DOE-DG110, Dec. 5, 2003)

Question:

Is it possible to use L-16 for 5 factors(4 LEVELS FOR 3 FACTORS, 2 LEVELS FOR 2 FACTORS) like 4 LEVELS FOR 5 FACTORS using L-16. If it is not possible please give some detailed information. According to your notes and software it is not right to use such array because

I think there will be a orthogonality problem.

-Sinan "Hýnýslýoðlu"

Answer/Comments:

You can indeed use the L-16 (4^5) [called modified L-16] to design experiments with THREE 4-level factors and TWO 2-level factors. Since the modified L-16 comes with FIVE 4-level columns, you will need to dummy treat (downgrade levels) two columns of this array by first reducing 4 levels to 3, then, 3 levels to 2. You can proceed to do so directly by replacing all 3 levels by 1 and 4 levels by 2 in the two selected columns.

Although, the two downgraded columns will be internally balanced, all columns of the downgraded array are not necessarily balanced between each other. Of course, in the process, you will loose the orhogonality as is always the case with dummy treatment.

This and many other special design situations may not be covered in our web site on experiment design tip (www.nutek-us.com/wp-tip.html). Also, designs of this and many other similar ones may not be handled (programmed to handle only about 500 design situations) by the AUTOMATIC DESIGN features of Qualitek-4 software. In these cases you must utilize the knowledge of column level upgrading/downgrading and combination designs to alter the array.

- RKR

Topic /Ref : OEC Formulation (DOE-DG111, Dec. 18, 2003)

Question:

Can Qualitek software handle a somewhat large number of response variables (5-10) at one time?

-George Nelsen

Answer/Comments:

Qualitek-4 can handle up to NINE evaluation criteria (response characteristics) at a time. Of course, following the strategy described in my textbook and that used in the software, you can create your own math model to combine unlimited number of characteristics (results). There is no restriction on the number of criteria that can be combined.

To see how the software formulates a single index, called the Overall Evaluation Criteria (OEC), you can review POUND.Q4W example in the demo program (assuming that you have downloaded the demo program (www.nutek-us.com). Run this file then, select OEC from the EDIT menu (in the Experiment Configuration screen) to review OEC formulation. Also, be sure to read about the theory and background on how to combine multiple criteria in an Overall Evaluation Criterion in the textbook or by visiting www.nutek-us.com/wp-oec.html .

In cases where you have multiple criteria, a recommended way to analyze the results is to carry out separate analysis for each criterion (Characteristic) of evaluation before performing analysis using the combined index (like OEC). This way, you would be able to see the optimum condition identified by the different analyses. After all, if the optimum combination is the same from all such analyses, there would be not much benefit by conducting analysis using the OEC.

- RKR

Topic /Ref : Error DOF (DOE-DG113, February 11, 2004)

Question:

I would appreciate very much your answer for the following question.

In the process of pooling control factors in ANOVA (standard analysis) the degree of freedom is transferred to the error. This allows us to calculate the f values of the other factors. But, I think, this is not appropriated because the variance of error would be explaining only part of the experimental error. For instance, in the orthogonal array L(8)2(7) if anybody pool one factor, this means that 1 DOF is transferred to the error. If we look at the critic f value this correspond to 161.4. With this result is practically impossible to reject H0.

-Dr. Mario Villarroel

Answer/Comments:

I'm not sure I fully understand your question. Also, it is difficult to be specific without looking at the ANOVA table. However, I will forward a few general comments about pooling and the error degrees of freedom (DOF)

The Error Terms (DOF & % Influence) in ANOVA shows combined effects of THREE items (not just experimental error): 1. Factors not included in the study, 2. Uncontrollable (Noise) factors, and 3. Experimental errors such as wrong data or improper set up. Unfortunately, unless the Error DOF is non-zero (greater than 3 for Qualitek-4 software), you cannot have a reliable indications of this influences.

How to decide when to pool (ignore) a factor? You pool factor only when you determine that the factor is insignificant. To determine if a factor is significant or not, you must perform the test of significant first which can be performed only when the error DOF is non-zero.

How do you get non-zero error DOF?
If you perform standard analysis and have multiple sample results in each trial condition, you automatically start with a larger number for error DOF. In this situation, you can POOL factor only after testing for significance, and if it is found to be insignificant. Pooling factor should be arbitrary (start with factors with least variance/sums of squares) only when you have many factors and the error DOF is zero to start with.

To learn more about interaction effect read Step 7, page 207 in my book (16 Steps… www.nutek-us.com/wp-txt.html).

- RKR

Topic /Ref : Experiment Size (DOE-DG114, March 11, 2004)

Question:

I am PhD, 2nd year student in University of Southampton. I am planning to do several experiments in my tribology field using 4-levels (material combinations) and 40 factors (different lubrications). If possible, please give me suggestions/improvements for my experiments as soon as possible.

-Ramkumar Penchaliah, Surface Engineering & Tribology Group, School of Engineering Sciences
University of Southampton, Southampton, SO17 1BJ, UK

Answer/Comments:

I'm happy to learn that you are planning to conduct many structured experiments for your research. I'm sure you would find good applications of the DOE techniques in many areas of research involving different lubrication, design, and application factors.

Since you mentioned about possible size of your experiment involving 40 factors, I felt it would be beneficial for you and others in your situation to keep the following points in mind.

- *Keep the experiments as small as possible by selecting a smaller number of factors and studying them at TWO levels when possible.*
- *When you brainstorm and identify a large number of factors, use Pareto principle to arrange them in descending order of importance (perceived, before test). This way you will be able to select the number of factors you can study from the top. Try to keep your experiment of the size that utilizes arrays between L-8 to L-18.*
- *Unless you have prior knowledge or strong conviction about a factor, study them at 2 levels. Consider treating them at 3 levels if non-linearity is a concern. Studying factors at 3 or 4 levels will make your experiment larger.*
- *Bottom line, decide upon the size (L-8, L-16, etc,.) of your experiment based on what time and budget will allow, not what you wish to study. Once the size of the array is settled, include the factors for your study from the top of your list.*

As you can see sizing the experiment and selection of the factors to study (or whether interaction and how many to study) are very subjective; it not science, it is compromise. Feel strongly about making good judgment, but attempt to do it objectively, and with group consensus when working as a team.

To learn more about experiment planning in my book (16 Steps… www.nutek-us.com/wp-txt.html).

- RKR

Topic /Ref : Topic/xx (DOE-DGxx)

Question:

xx

Answer/Comments:

Xx

- RKR