Orthogonal Array Testing to Reduce Cycle Time

Emerging Trends

[CT324]

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1. Abstract

Today, testing market is trying to comment and clarify issues related to determine sample size of test requirements and how Design of Experiment (DOE) enables cycle time reduction. The primary objective of any business is to minimize cycle time without losing *quality* and *functional coverage*. An outcome of DOE's methodology proposes to find the maximum number of critical factors at various levels for the smallest number of experimental runs. This can indicate *reduced cycle* time and *test effort*.

Orthogonal Arrays (OA) is a scientific methodology that designs effective test cases as well as analyzes results for quality software. Implementation of OA based testing can help improving not only productivity & defect identification but also defect free product creation with quality code coverage. This paper delineates practical application of OA based testing and its benefit to reduce cycle time compared to conventional approach.

Keywords: Factors, levels, Degree of freedom, Cycle time, Design of Experiment

2. Highlights

Terms	Reference
DOE	Design of Experiments
OA	Orthogonal Array
DR	Defect Report
TQM	Total Quality Management
SME	Subject matter expert (Business Analyst)
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3. Introduction

Today's IT market software products cater to various domains which differ in their nature, complexity, need for performance and availability among other things. Lots of complex tasks can be encountered during day-to-day work pattern. Due to complex design of software product/application hosted in varied domain makes software tester's task difficult. Also seeking to discover the maximum number of potential errors under generally steady deadlines is not enough, to say successful testing.

Testing such distinctive software products/applications, 'efficiently & effectively', is not an easy task as there are few approaches that facilitate easy understanding of product behavior under various conditions. A software product/application can have unexpected behavior depending on multiple factors extending to a failure in software build. This makes the test design & result analysis, defect reporting and analysis, inefficient. The end result extends to make use of more number of resources to complete testing task with better approach which leads organization to spend as much on testing as that of product development. When DOE is used for software testing, there is a large amount of savings in testing time and cost.

This is where Orthogonal Arrays has been introduced in software testing. Orthogonal arrays were originally discovered as a numerical curiosity.

Walkthrough of paper is organized as follows; "Section 4" details out Orthogonal Array and its techniques, "Section 5" depicts practical implementation of Orthogonal Array – explaining in form of case study, "Section 6" conveys benefits of Orthogonal Array and "Section 7" concludes with conclusion of white paper.

4. About Orthogonal Arrays

Before we start talking about Orthogonal Arrays, it would be profitable to have an overview of Six Sigma.

'What is Six Sigma' is that it is a management philosophy. Six Sigma is a customer based approach realizing that defects are expensive. Six Sigma processes will produce less than 3.4 defects or mistakes per million opportunities. Many successful Six Sigma projects do not achieve a defect rate of 3.4 defects per million opportunities (dpm) or less. That just indicates that there is still opportunity. The Six Sigma process is Define, Measure, Analyze, Improve, and Control (DMAIC**)**.

4.1 What is an Orthogonal Array

Orthogonal Array is a method of choosing a set of tests from a universe of tests, to make the testing efficient and effective. It is based on creating Parameters (Control Variables) and Levels (Values) for the parameters, which are the inputs to testable functions. Orthogonal arrays are two dimensional arrays of numbers which possess the interesting quality that by choosing any two columns in the array you receive an even distribution of all the pair-wise combinations of values in the array. It is based on creating control factors and levels (values) for the factors, which are inputs to testable functions. Quality engineering methods of Dr. Taguchi, employing Design of Experiments (DOE), is one of the most important statistical tools of Total Quality Management (TQM) for designing high quality systems at reduced cost. Taguchi's method provides an efficient and systematic way to optimize software designs for performance, quality, and cost.

Orthogonal array testing is a systematic, statistical way of testing, method of defining parameters that convert test areas into factors and levels. Test design using Orthogonal Array creates an efficient and concise test suite with fewer test cases without compromising test coverage. Orthogonal arrays could be applied in user interface testing, system & regression testing, configuration and performance testing.

Using orthogonal arrays is an efficient way to study the effect of several control factors simultaneously. The factor effects thus obtained are valid over the test region and it provides a way to test for the interactions of the factors. The test effort needed is much smaller when compared to other methods of experimentation, such as trial and error, one factor at a time, and full factorial methodologies.

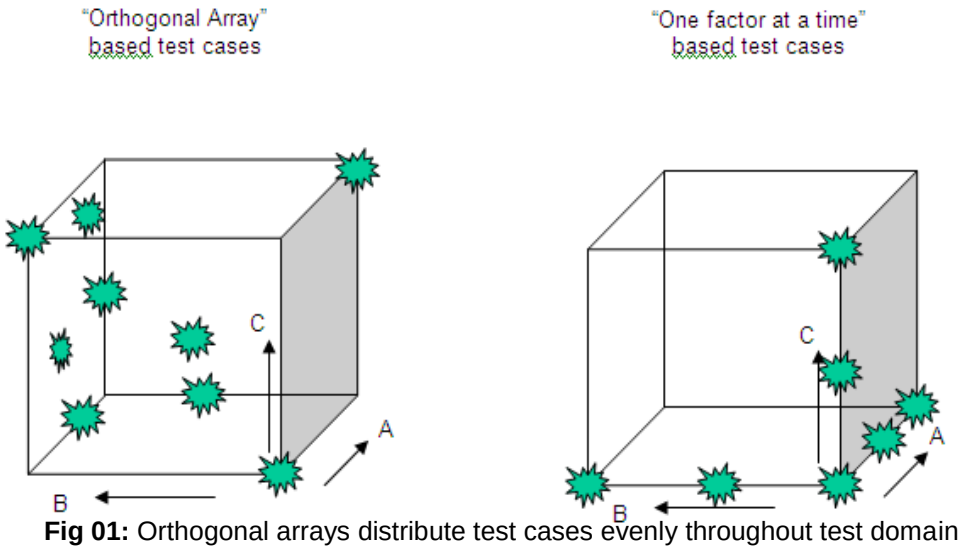

Fig 01: Orthogonal arrays distribute test cases evenly throughout test domain

All orthogonal vectors exhibit Orthogonality. Orthogonal vectors exhibit the following properties:

- Each of the vectors conveys information different from any other vector in the sequence, i.e., each vector conveys unique information therefore avoiding redundancy.
- On a linear addition, the signals may be separated easily.
- Each of the vectors is statistically independent from each other.

When linearly added, the resultant is the arithmetic sum of the individual components.

The Taguchi Approach

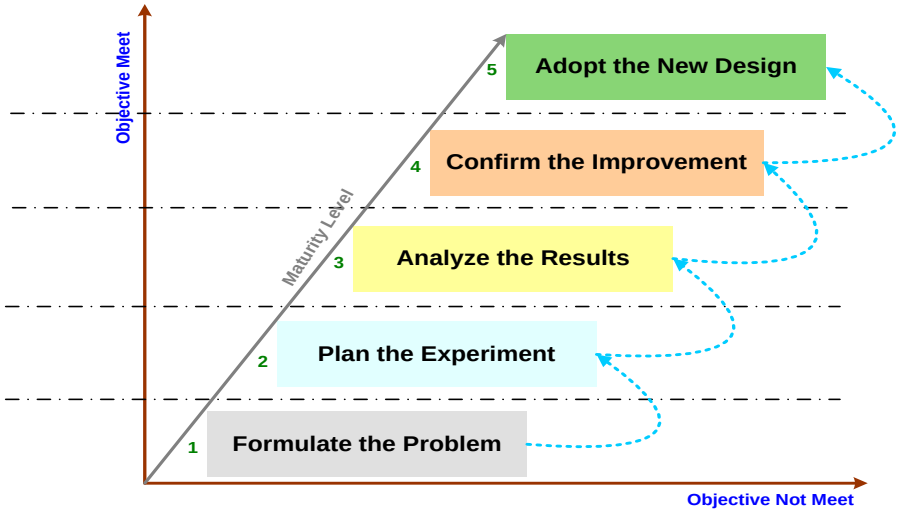

Fig 02: Stages in Taguchi's approach

Dr Taguchi suggests five major steps in the designing process. These steps would help test team in creating a good test design and refining it consequently.

- **Formulate the problem** – Vital step required for test design engineer to evaluate the entire system in terms of parameters that decide the outcome.
- **Plan the experiment** – Planning the experiment focuses on designing test cases, using concept called as Matrix (using OA). It is an efficient way to study the effect of several factors simultaneously for an entire software product/application.
- **Analyze the results** – Analysing the test results after test execution.
- **Confirm the experiment** – Once the results are achieved as per expected behavior, test team confirms the experiment.
- **Adopt the new design** – Start adopting the experimental approach throughout the project cycle.

4.2 Why to make use of OA technique

Test case design is an interesting and creative problem for the software test professional.

- Systematic & statistical method of testing pair-wise combinations of selected factors/variables across their levels

- Creates an optimized test suite with lesser test cases
- Detects all single mode and double mode faults
- Increases confidence levels in the system by executing a concise set of tests and uncovering most of the bugs.

4.3 How to Use OA technique

Simple and straightforward steps has been detail out below

- Decide how many independent variables will be tested for interaction. This will map to the Factors of the array.

  Number of factors to be studied = A factor is a variable under study; an input that can be controlled. As an example, in a data entry form, one of the fields may constitute a factor. A factor can be either quantitative (measured in a continuous scale; example: CPU utilization) or qualitative (measured in an integral scale example: input fields).

- Decide the maximum number of values that each independent variable will take on. This will map to the Levels of the array.

  Number of levels for each factor = A level is a value that a factor can assume when used in an experiment. In the example of a data entry form cited above, levels can be the possible values for the field. Although the field accepts many different values, we will take only a minimal, representative number of values as levels.

- Count the Degrees of Freedom = Number of degrees of freedom associated with a factor is equal to one less than the number of levels for that factor. This gives the minimum number of test case to be executed based on the factors and levels.

  Degree of Freedom (for the case study) = $1 + df_2 + df_3 + df_4 + df_5$
  Where df_n = degree of freedom of n-level factor

- Find a suitable orthogonal array with the smallest number of Runs. A suitable array is one that has at least as many Factors as needed from Step 1 and has at least as many levels for each of those factors as decided in Step 2.

- Map the Factors and values onto the array.

- Choose values for any "left over" Levels.

- Transcribe the Runs into test cases, adding any particularly suspicious combinations that aren't generated.

5. Practical Implementation of OA

5.1 Business problem

Today's IT business demands to release software product/application in shorter timeframe to push the software product/application go live way ahead of their competitors. One of the largest logistic provider organisation had the similar problem to release their software product/application go live to their customers. But at the same time the objective was to have complete coverage by minimizing testing efforts. The problem is to identify the minimal set of experiments/test cases to be executed as part of the regression test bed for an existing software product/application. Implementation of a new test approach wherein test design cycle time can be reduced but with 100% test coverage.

5.2 Solution

To overcome the above business problem, test team has arrived at the best way of optimizing "Test Design" technique, reducing test cycle time without losing the test coverage and quality of software product/application.

Test team has introduced implementation of Orthogonal Array testing approach from DOE to execute test execution.

5.3 Traditional Approach followed

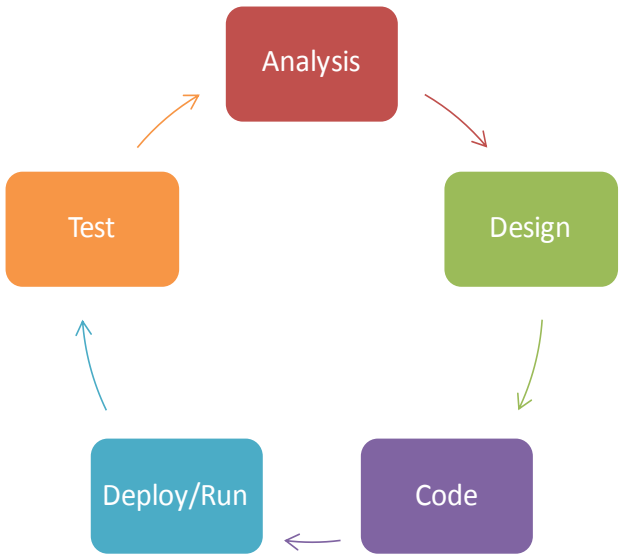

Fig 03: Traditional approach

5.4 How OA techniques been used

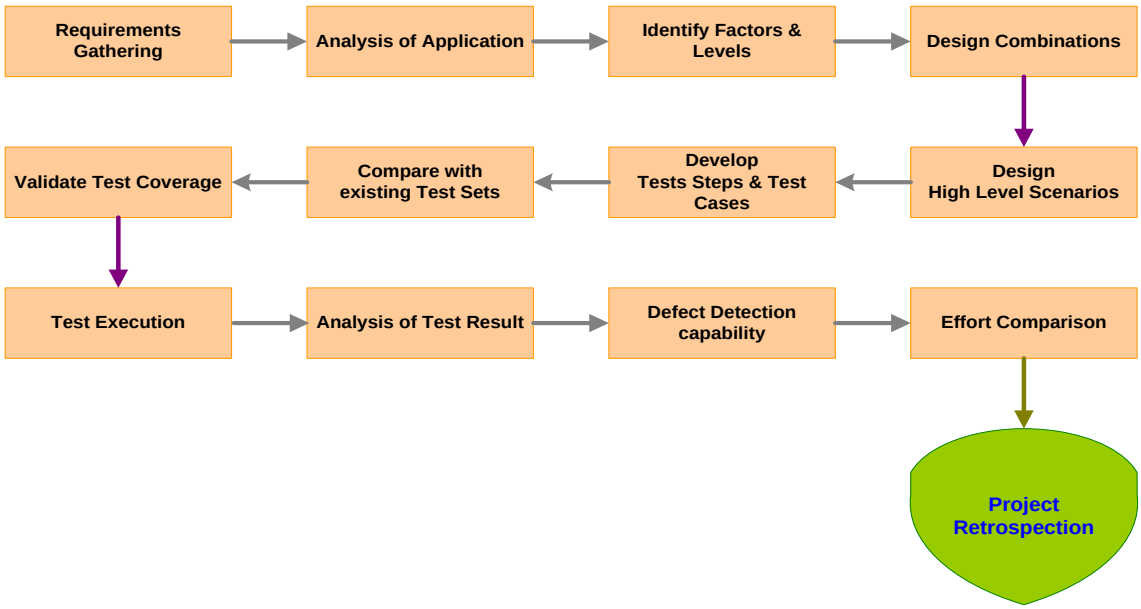

Fig 04: OA test approach

5.5 Implementation from OA technique

Based on the domain knowledge, understanding of the business process and customer usage conditions, the following factors with their levels (values) as shown in below table were recognized.

Below are sample “Parameters” and “Levels” considered for logistic application –

Table 1 - Parameters and Levels for OA

Sr. No.	Parameters	Values	
A	Shipment	New 1. Create a new Sender Information & update details	Existing (Open an existing Sender based on Logistic Tracking Number / Reference Number / Shipment Reference Number -text / label) 1. with Shipment Status at Open 2. with Shipment Status at Template 3. with Shipment Status at Printed 4. with Shipment Status
B	Recipient Info with Routing & Export Documentation	Single 1. Routed (requires validation of Postal code) a. With Export Documents (all 27) b. Without Export Documents 2. Non-routed (does not require validation of postal code) a. With Export Documents (all 27) b. Without Export Documents	Group 1. Routed (requires validation of Postal code) a. With Export Documents (all 27) b. Without Export Documents 2. Non-routed (does not require validation of postal code) a. With Export Documents (all 27) b. Without Export Documents
C	Recipient Info Availability to	Default - Mygroup / Myself	Changed 1. from Mygroup/Myself to All

Sr. No.	Parameters	Values	
			Users 2. from Mygroup/Myself to Logistic User 3. from Mygroup/Myself to fdx User 4. from Mygroup/Myself to CTS User 5. from Mygroup/Myself to Super User
D	Shipping Date and Pickup	Current Date 1. With Pickup a) Weight <=> 69 kg/150 lbs b) with /without Ship Alert 2. Without Pickup a) Weight <=> 69 kg/150 lbs b) with/without Ship Alert	Future Date 1. With Pickup a) Weight <=> 69 kg/150 lbs b) with /without Ship Alert 2. Without Pickup a) Weight <=> 69 kg/150 lbs b) with/without Ship Alert
E	Packaging 1. Service Type / Recipient's Country 2. Number of Packages 3. Packaging done by	As per Sender's Packaging - (update Package dimensions & Weight) 1. with Number of Packages => 1 a) Based on Recipient country - choose the Service Type	Logistic Packaging (choose one of the Six Types and Update weight of Packaging) 1. with Number of Packages => 1 a) Based on Recipient country - choose the Service Type
F	Shipment Content	Documents a) with Special Handling b) Without Special Handling	Commodities 1. Existing (from the Commodities Tab) a) with Special Handling b) Without Special Handling 2. New (create a new commodity) - update country of manufacture & commodity description a) with Special Handling b) Without Special Handling
G	Commercial Invoice & Billing Details	CI - Required with Print Layout - default/changed 1. BD / Commercial Invoice sent to Sender 2. BD / CI sent to Recipient 3. BD / CI sent to III Party	CI - Not Required with Print Layout - default / changed 1. BD to be sent to Sender 2. BD to be sent to Recipient 3. BD to be sent to III Party

Calculation:

Total Number of Factors: **7**

No of 2-Level Degree Factors: **7**

By Using the “Degrees of Freedom” formula = 1 + df2 + df3 + df4 + df5

Dfn = No. of N level factors * (n-1)

Where dfn = degree of freedom of n-level factor

“Degrees of Freedom” implemented in case study: 1 + 7 * (2-1) = **8**.

As per “Degree of Freedom” calculation we arrived at total number of **8** test cases need to be designed.

Based on the above calculation the Test Case design for logistic application has been detailed out using OA technique. –

Table 2 – Designed test cases using OA techniques

TC1	New 1. Create a new Sender Information & update details	Single 1. Routed (requires validation of Postal code) a. With Export Documents (all 27)	Default - Mygroup / Myself	Current Date 1. With Pickup a) Weight < 220 kg b) With Ship Alert	As per Sender's Packaging - (update Package dimensions & Weight) 1. with Number of Packages => 1 a) Based on Recipient country - choose the Service Type	Documents a) with Special Handling	CI - Required with Print Layout - default 1. BD / Commercial Invoice sent to Sender
TC2	New 1. Create a new Sender Information & update details	Single 1. Routed (requires validation of Postal code) b. Without Export Documents	Default - Mygroup / Myself	Future Date 1. With Pickup a) Weight < 220 kg b) Without Ship Alert	Logistic Packaging (choose one of the Six Types and Update weight of Packaging) 1. with Number of Packages => 1 a) Based on Recipient country - choose the Service Type	Commodities 1. Existing (from the Commodities Tab) a) with Special Handling	CI - Not Required with Print Layout - default 1. BD to be sent to Sender
TC3	New 1. Create a new Sender Information & update details	Group 1. Routed (requires validation of Postal code) a. With Export Documents (all 27)	Changed 1. from Mygroup/Myself to All Users	Current Date 1. With Pickup a) Weight = 220 kg b) Without Ship Alert	As per Sender's Packaging - (update Package dimensions & Weight) 1. with Number of Packages => 1 a) Based on Recipient country - choose the Service Type	Commodities 1. Existing (from the Commodities Tab) a) Without Special Handling	CI - Not Required with Print Layout - changed 2. BD to be sent to Recipient
TC 4	New 1. Create a new Sender Information & update details	Group 1. Routed (requires validation of Postal code) b. Without Export Documents	Changed 2. from Mygroup/Myself to Logistic User	Future Date 1. With Pickup a) Weight = 220 kg b) Without Ship Alert	Logistic Packaging (choose one of the Six Types and Update weight of Packaging) 1. with Number of Packages => 1 a) Based on Recipient country -	Documents a) with Special Handling	CI - Required with Print Layout - changed 2. BD / CI sent to Recipient

					choose the Service Type		
TC 5	Existing (Open an existing Sender based on Logistic Tracking Number / Reference Number / Shipment Reference Number -text / label) 1. with Shipment Status at Open	Single 2. Non-routed (does not require validation of postal code) a. With Export Documents (all 27)	Changed 4. from Mygroup/ Myself to CTS User	Current Date 2. Without Pickup a) Weight <220 kg b) With Ship Alert	Logistic Packaging (choose one of the Six Types and Update weight of Packaging) 1. with Number of Packages => 1 a) Based on Recipient country - choose the Service Type	Documents a) Without Special Handling	CI - Not Required with Print Layout - default 3. BD to be sent to III Party
TC 6	Existing (Open an existing Sender based on Logistic Tracking Number / Reference Number / Shipment Reference Number -text / label) 1. with Shipment Status at Template	Single 2. Non-routed (does not require validation of postal code) b. Without Export Documents	Changed 5. from Mygroup/ Myself to Super User	Future Date 2. Without Pickup a) Weight <220 kg b) With Ship Alert	As per Sender's Packaging - (update Package dimensions & Weight) 1. with Number of Packages => 1 a) Based on Recipient country - choose the Service Type	Commodities 2. New (create a new commodity) - update country of manufacture & commodity description a) with Special Handling	CI - Required with Print Layout - default 3. BD / CI sent to III Party
TC 7	Existing (Open an existing Sender based on Logistic Tracking Number / Reference Number / Shipment Reference Number -text /	Group 2. Non-routed (does not require validation of postal code) a. With	Default - Mygroup / Myself	Current Date 2. Without Pickup a) Weight = 220 kg b) Without Ship Alert	Logistic Packaging (choose one of the Six Types and Update weight of Packagi	Commodities 2. New (create a new commodity) - update country of manufacture &	CI - Required with Print Layout - changed 3. BD / CI sent to III Party

	label) 1. with Shipment Status at Printed	Export Documents (all 27)			ng) 1. with Number of Packages => 1 a) Based on Recipient country - choose the Service Type	commodity description a) Without Special Handling	
TC 8	Existing (Open an existing Sender based on Logistic Tracking Number / Reference Number / Shipment Reference Number -text / label) 1. with Shipment Status at Upload	Group 2. Non-routed (does not require validation of postal code) b. Without Export Documents	Default - Mygroup / Myself	Future Date 2. Without Pickup a) Weight =220 kg b) Without Ship Alert	As per Sender's Packaging - (update Package dimensions & Weight) 1. with Number of Packages => 1 a) Based on Recipient country - choose the Service Type	Documents a) Without Special Handling	CI - Not Required with Print Layout - changed 3. BD to be sent to III Party

Test Coverage details from these 8 test cases design using OA technique are as followed;

- ✓ Negative test cases covered in the design for major factors
- ✓ For other fields, negative testing is taken care in the test cases steps
- ✓ Mandatory field validations also included in the test steps while creating the test scripts/test cases
- ✓ The user interface test cases are distributed amongst the various test cases to cover them with the functionality, for eg: Export documents, is covered across 3 tests.
- ✓ The development of test cases requires good understanding of complete functionality of the application from end-to-end
- ✓ There is a chance of 10 to 15 % of duplicate steps; these are required to continue with the scenarios.

Detailed test design analysis explaining the coverage of test cases thereafter reducing test design cycle time.

Table 3 – Detailed test design analysis

OA scenarios	Number of Test Steps	Test Case Coverage (No. of Traditional Test Cases)
TC #1	119	246
TC #2	117	275
TC #3	124	175
TC #4	78	164
Total	**438**	**860**

- ✓ 4 newly design OA scenarios covered more than 860 test cases from existing traditional 1700 + test cases of logistic application.
- ✓ 4 scenarios are covering almost 50% of logistic application test cases.
- ✓ Remaining 4 OA scenarios shall cover around more 450 to 470 test steps, completing total test coverage of 1700 + test cases.
- ✓ Total number of test cases would be approximately 900 from newly implemented OA technique.
- ✓ Effort reduction = 45% (approx) in test design and execution

After test execution metric has been draw to estimate cycle time reduction in test design & test execution phase for logistic application using OA technique.

Table 4 – Reduction Metric

Testing Activity	Traditional Approach	OA technique	Improvement
Test Design	1750 Test cases (61 Person days)	8 Test cases (35 Person days)	**42.62%**
Test Execution (Cycle -#1)	10 (Person days)	5.5 (Person days)	**45%**

The above metric shows “Cycle time reduction” in test design & test execution phase after implementation of OA techniques successfully with an effect of complete test coverage.

5.6 Staffing (Resources vs. Skills set)

Implementation of Orthogonal array from DOE, looks very easy but actually requires a lot of effort from a complete team, instead of an individual. OA implementation is not a cup of tea for traditional testing team, not many knows in IT industry that implementation of OA requires skilled, efficient & effective resources like SME, Test engineer and Test Lead to drive the complete OA show. Below picture will depict the required resources and their required skills to implement OA successfully in a project.

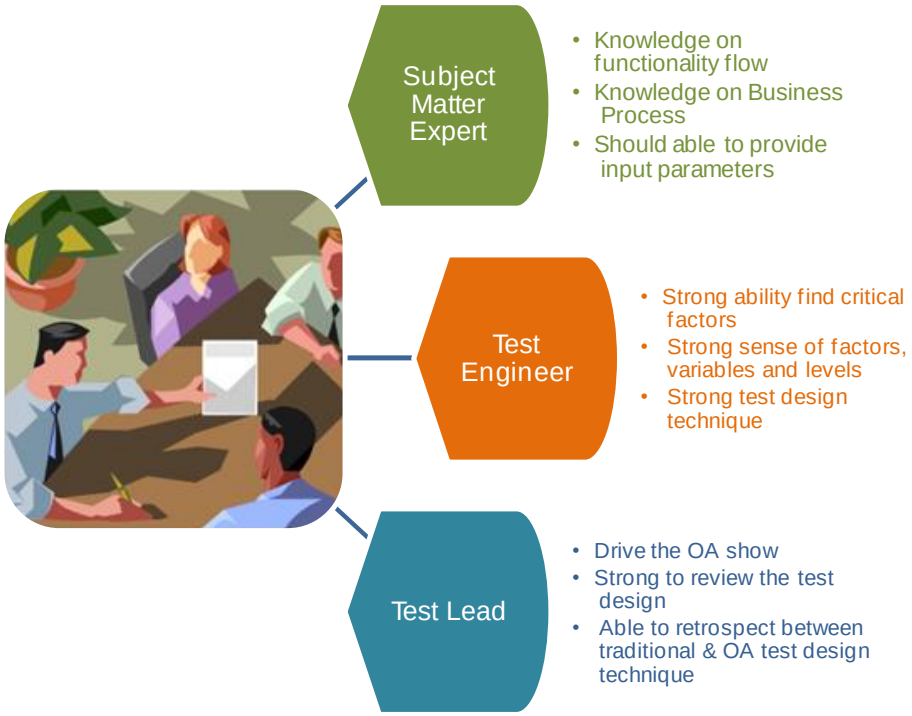

Fig 05: Staffing (Resources vs. Skill)

5.7 Limitation, Benefits and Challenges using OA

Benefits:

- Creates an efficient and concise test bed with fewer test cases than testing all combinations of decision variables
- Creates quality product in shortest time with minimum effort
- Ensure that all the decision variables are simultaneously tested rather than testing them independently - a scientific method to design test cases as well as analyse test results.
- It is simpler to generate and less error prone than test beds created by hand.
- Can be generated easily with different software available.
- Productivity
  - Implementation time is less
  - Execution time is less
  - Result analysis takes less time
- Quality
  - High code coverage (~95%). For the remaining ~5% of the code tests have to be written manually. In this way, close to 100% of the feature code is covered.
  - Efficiency in defect identification

Limitations:

- The domain based test cases shall not be covered by the OA test design
- If any factor is missed during the construction of OA, the whole purpose of the test strategy will be lost, so the utmost care should be taken during the identification of factors

- As per the standard arrays from the Taguchi methods, if a factor is having more than 5 levels is not handled
- As per the standard arrays from the Taguchi methods, the maximum number of test cases for any project can be done with 81 test cases and maximum number of factors are 60

Challenges:

- Availability of Subject Matter Expert for logistic domain
- Deciding factors and levels for test design

5.8 Risks

- Though OA provides uniform test coverage, but no preference has been given to critical path.
- May not be practically possible to define factors and levels for all the functions defined in a software application.
- Adding new test cases later during test execution phase becomes difficult. An analysis has to be first made on how the fix can be put into the existing test cases.

6 Benefits of Orthogonal Arrays

Some of the general business benefits using OA techniques have been keyed down below:

- Helps in productivity improvement with cycle time reduction
- Helps in improving test coverage
- All pair-wise combinations of test set created.
- Orthogonal Array test cases can be customized based on available time and known problems
- Independent of platforms and domains
- Provides uniformly distributed coverage of the test domain.
- Concise test set with fewer test cases is created.
- Arrives at complex combinations of all the variables.
- Simpler to generate and less error prone than test sets created manually.

7 Conclusion

With orthogonal Array Test Design, the number of test cases drastically reduced, at the same time the coverage is increased. As the number of test cases reduced, there will be a lot of effort saving. For this study, the factors and levels identified as per the Taguchi method and mapped to the Standard array.

There are 2 phases of test life cycle management which can benefit by adopting Orthogonal Arrays.

- Test case development for new feature/product
- Re designing the existing test cases

The most critical portion of the adoption process is the understanding the product and modeling its features as Parameters and levels. The care and efforts put in to develop this model will drive the success of the test suite design. IT organizations should start experiencing benefits of Orthogonal Arrays and Six Sigma concepts; it will be worthwhile in OA concept and avail the fruitful benefits using OA in software testing.

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