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Improved Requirement Elicitation Process for Tactical Modules: A Case Study

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Abstract: In defence sector, developing a tactical module is a very challenging task due to limited availability of domain knowledge. Owing to highly sensitive and confidential nature, very less data and information is available on the internet. It is observed that lack of knowledge often leads to large number of defects during user trial (due to incomplete or misunderstood requirements) or less customer satisfaction (due to missed requirements). Cost of fixing defects found in later stages is more as compared to cost of fixing defects detected in earlier stages of the development lifecycle. In our paper, issues related to newly incepted requirements of a tactical modules are captured and a case study on three tactical modules is done to derive an approach for process modification that can be implemented to development life cycle. This will lead to reduced number of defects in delivered product, resulting in cost reduction and raising customer satisfaction to improve reputation and brand value of the organization. Quality function deployment (QFD) is used to determine what is required by a customer, how to gather more information and apply it into our development process. This paper aims at achieving reduced number of defects by use of subject matter expert (SME) as concluded in case study in which QFD is used.
Keywords: QFD- Quality function deployment, HoQ- House of quality, SME – Subject matter expert

I. INTRODUCTION

Due to highly confidential nature and security required for defence forces, development of tactical module becomes difficult task. Limited availability of information becomes major challenge to requirement gathering and understanding. Lack of proper understanding of wants of user may lead to increased number of defects. To study the impact of this problem and to figure out a solution, a case study of three tactical modules was done. Quality function deployment (QFD) was used to map 'what' and 'how' related to requirement capturing of tactical modules. In this paper, we will be bringing out importance of subject matter expert by observing impact on performance of three modules considered in case study.

QFD is derived from Japanese kanji characters "Hin Shitsu Ki No Ten Kai" [1]. It was first conceptualized in 1966 [2]. In 1972, Dr. Shigeru Mizuno and Yoji Akao developed detailed quality deployment methods, commonly known as quality function deployment or QFD. It was introduced to America and Europe in 1983. QFD acknowledge the need to understand customer requirements before design phase and design requirements before production phase so that final designed product is able to satisfy customer needs. The main purpose of QFD is to lay more attention to what customer needs in order to build a product that will meet customer satisfaction. QFD primary objective is to ensure that voice of customer is heard at all stages of development life cycle [2] [3].

QFD aims at maximizing customer satisfaction level. It is a proactive approach rather than reactive approach [1]. Hence QFD brings out many benefits such as [2] [3]

1) Improved focus on voice of customer
2) Improved quality
3) Less ambiguity in requirements
4) Graphical presentation of data
5) Analysis of competitive market
6) Organizing requirements on basis of importance
7) Reduced number of defects due to requirements
8) Coming on agreed upon situation between what customer wants and what company can deliver
9) Categorizing customer needs in basic, expected and delighted needs.

All of the above collaboratively leads to customer satisfaction.

Paper has been further organized in following sections. Section 'II. Literature Survey' will contain literature survey done to show how QFD has been applied to various fields. It will also indicate new area where QFD can be applied. Section 'III Conventional System Model (Four phase approach)' will describe how a traditional four phase approach works. This section illustrates steps of manufacturing industries.

Section 'IV Proposed four phase approach model for improved requirement elicitation process for tactical modules: a case study' will contain use of QFD to derive 'how' based of 'what' while developing a tactical module. Section 'V Results and discussion' will explain results obtained in each phase of four phase approach and root cause analysis done on basis of defect data and brainstorming session with developers and testers. This section will also contain a comparative study of three tactical modules under consideration. Section 'VI Conclusion' will infer importance of domain expertise and its impact on reduction of number of defects. Section 'VII Future scope' will contain extended scope of work done for this paper.

II. LITERATURE SURVEY

QFD is a technique to identify and prioritize requirements based on various parameters. Many papers are available reflecting use of this technique in various fields, predominantly for product. QFD can be extensively applied to product design and other areas for meeting and exceeding customer expectation. Being a promising technique, QFD has been used by many organizations like AT&T for broad range of projects e.g. submarine system strategic-business unit , Network systems , its development organization for the R&D UNIX operating system, Documentation board etc. [4]. QFD has also been applied in service industry, basically hotel and hospitality industry, for achieving customer satisfaction in an increasingly competitive marketplace [5]. QFD has also been used to determine selection criteria for students for industrial training based on based on employers' feedback [6].

In software industry also, QFD has been used for broad spectrum of work ranging from system or enterprise design to capturing non-functional requirements to documentation. For development of enterprise architecture, QFD has been useful in determining traceability between business drivers and architectural decisions. It works as a tool to ensure quality of design such that both functional and non-functional requirements are catered [7]. QFD is an effective tool in determining methods of improvement for non-functional requirements such as quality and reliability of product. QFD can be combined with failure mode, effects and criticality analysis (FMECA) and Plan-Do-Check-Act (PDCA) cycle where statistical data is studied to determine failure modes and causes , improvement strategy is implemented for enhanced quality and impact is studied [8]. QFD can be used in improving model or standard of documents, such as Software requirements specification (SRS) to make it more specific for a specific domain [9].

As per literature survey, it is majorly deduced that QFD is a strategy which can be applied to any field by slightly customizing it as per requirement of its application. QFD has been largely used for improving quality and reliability of product or services. But, four phase approach of QFD can also be used for improving process of requirement elicitation which largely impact development of a tactical module. Thus, in this paper, experimental case study has been done by applying QFD to improve a process related to requirement gathering of a tactical module. Improvement in requirement gathering phase will in turn lead to less number of defects and reduced rework for later stages.

III.CONVENTIONAL SYSTEM MODEL (FOUR PHASE APPROACH)

There are various approaches to apply QFD namely four phase approach, matrix of matrices and comprehensive QFD [10]. In this section, four phase approach used in manufacturing industries [10] [11] is described and depicted in Figure 1. In a production process, this 4 phase approach typically works as following [12] [13]:

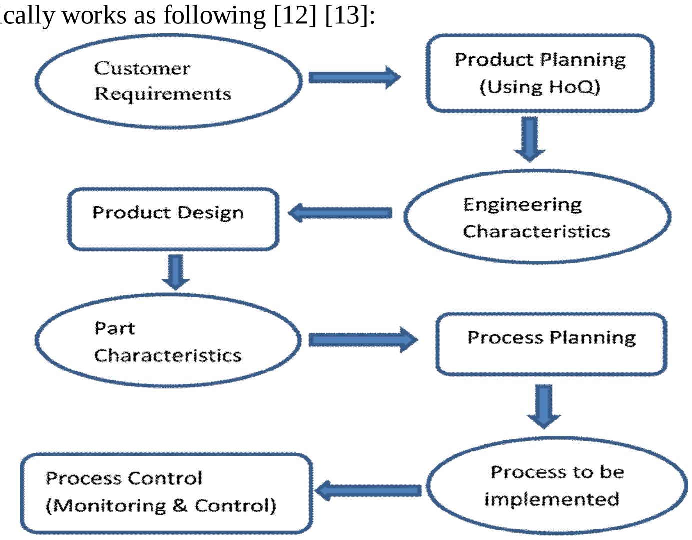

Fig. 1 Four phase approach for manufacturing industry

1) *Product Planning:* In this phase, customer requirements are translated into engineering characteristics. This is mainly done by using HoQ [14] [15] [16]where customer requirements are gathered and assigned an importance value. These are transformed into engineering characteristics which are also assigned an importance factor and target values.
2) *Product Design:* The most important engineering characteristics obtained from previous phase, are translated into part characteristics. This phase is responsibility of engineering department. This phase results in generating ideas for part characteristics of product design. Most important characteristics are moved forward to next phase [17] [18].
3) *Process Planning:* This phase is prime responsibility of manufacturing department. In this phase, process is established for achieving design characteristics of previous phase. Flowcharts are drawn for implementing planned process.
4) *Process Control:* To control planned process, we need to monitor it. So performance monitors are implemented at various points to bring out any deviation, risk or opportunities in the process. This is mainly done by quality department. Any deviation, risk or opportunity is analysed for any corrective or improvement actions.

IV. PROPOSED FOUR PHASE APPROACH MODEL FOR IMPROVED REQUIREMENT ELICITATION PROCESS FOR TACTICAL MODULES: A CASE STUDY

QFD, as mentioned in literature survey, has been largely used for product related requirement capturing. Through this paper, we propose use of four phase approach to modify and improve a process rather than a product. Process targeted in this paper is requirement elicitation. Requirement elicitation process is a very important process in any software development as it is a practice of requirement gathering and understanding of a system from customers, stakeholders and direct users [19].

In this paper, a case study was done on three tactical modules to understand how they performed with respect to development and testing phase and their test reports were studied to conclude what were areas in which they lacked. Tactical modules refer to CSCIs that consists of complex geometrical solutions using mathematical formulations and algorithms. First module, Module 1, was related to providing navigation commands to airborne aircrafts. Second module, Module 2, was used for guiding aircraft back to airbase. Third module, Module 3, was used for weapon allocation. Design constraints for all three modules were same as mentioned in their software architecture description (SAD) documents. These constraints were derived from system architecture and resource allocation document (SARAD) of project. Risk involved with development of these modules was mainly on domain knowledge of teams, although skill set level of all teams was same. Tactical modules were of similar difficulty level but their development teams were having varying domain level expertise. Module 1 team had good skill set but no experience in C4I systems. Module 2 team had good skill set and development experience by working in projects of similar nature. Module 3 team has both skill and more expertise as compared to other two modules. Table I shows comparison between three modules based on number of requirements, number of test cases to be tested in SQT and team size.

Table I. Three modules under consideration

	Module 1	Module 2	Module 3
Requirements	25	17	16
Test cases	113	48	60
Team Size	5	4	4

As described in Section III, the current system model of 4 phase approach implemented four phases to gather and prioritize features of product. In our proposed approach, all phases of four phase approach will be slightly modified to apply QFD for process improvement as depicted in figure 2.

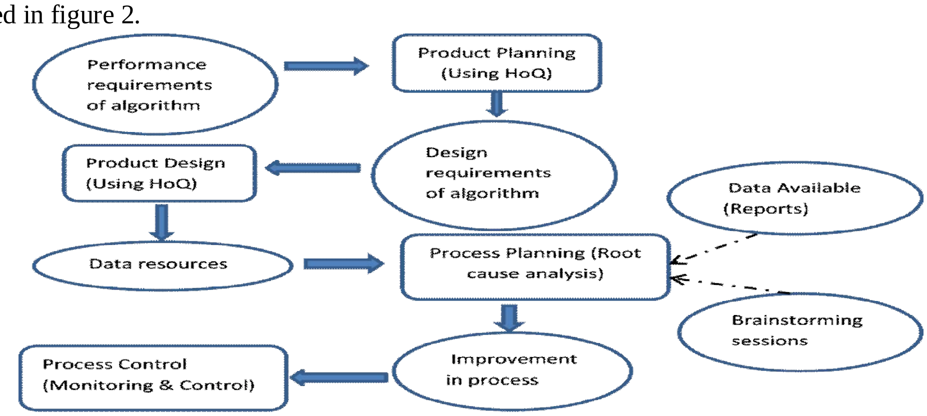

Fig. 2 Proposed use of four phase approach for process improvement

A. Product Planning

In development of any tactical module, main focus of the customer is on following seven requirements:

1) *Accuracy:* A tactical module must perform desired functions correctly, within precision boundaries.
2) *Responsiveness:* Faster response by module is always an add-on for facilitating customer satisfaction
3) *Comprehensibility:* Since actual implementation or coding of tactics might not be available for customer to look into, effective display of solution e.g. GUI can enhance understanding of solution by customer.
4) *Error Handling:* Ability of modules to efficiently handle abnormal inputs or situations increases robustness of algorithm
5) *Cycle Time:* Cycle time is a measurement of the amount of calendar time it takes to perform a process from start to completion. In case of development of algorithm, schedule starting from requirement capturing to acceptance from customer should not be delayed.
6) *Defects:* A zero defect product must be targeted to ensure quality of product.
7) *Cost:* Lower the cost of product, higher the satisfaction level of customer.

To implement customer requirements, these requirements can be translated into following design requirements from developer point of view:

a) *Problem Definition:* Problem definition must be complete, correct and consistent. It has been observed that well define problems usually takes less amount of rework.
b) *Tactical Knowledge:* While developing tactical module, developers must possess tactical knowledge. This knowledge may be attained by previous experience of similar module, consultation from a domain expert and relevant study material.
c) *Testability:* If an algorithm is highly testable, chances of latent defects or field defects are considerably reduced.
d) *GUI:* Use of graphical user interface enables customer to understand what is being done by algorithm. GUI increases understanding of developed solution.
e) *Alerts:* Abnormal inputs and situations can be dealt by algorithm by generating alerts for such situation so that user is made aware of the situation.
f) *Development Effort:* Development effort of any algorithm mainly depends on its complexity and skill set possessed by developer. Major impact for development efforts comes from rework done owning to defects found.

In first phase of Product Planning, we considered performance parameters required of a tactical module as WHAT of HoQ. HOW to achieve WHATs was determined from developer's point of view and a House of Quality (HoQ) was established to bring out correlation between them. To construct House of Quality [12], requirements from user's perspective (customer / developer) are mentioned as WHATs for developing HoQ. These requirements are assigned a value on the basis of importance or value to user on a scale of 1 to 5, 5 being the highest. Percentage importance value of each requirement is calculated. Requirements identified to achieve WHATs of HoQ are mentioned as HOWs for same HoQ. Correlation between various HOWs is determined and depicted as correlation matrix on top of the house. This correlation may vary from strongly negative to strongly positive. Along with it, direction of improvement is shown for HOWs. Direction of improvement indicates whether we want to increase or decrease stated parameter. Association between WHATs requirement and HOWs requirements are shown at centre in terms of number (9, 3, 1). This association can be negative as well as positive. Absolute importance of each HOW requirement is calculated as summation of product of association value of each WHAT requirement and its percentage importance. Finally, percentage importance of all design requirements was calculated [20]:

$$PD = (I / \sum I) * 100 \qquad (1)$$

Where PD = Percentage distribution;
I = Importance value of a customer requirement;

$$\text{Using (1), Abs Imp} = \sum (AV * PD) \qquad (2)$$

Where Abs Imp = Absolute Importance of each design requirement;
AV = Association value of design requirement with customer requirement;

$$\text{Using (2), } PI = (\text{Abs Imp} / \sum \text{Abs Imp})*100; \qquad (3)$$

Where PI = Percentage importance of each design requirement

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B. Product Design

In product design phase, factors that impact high priority HOWs of first HoQ were considered. In HoQ developed in product planning phase, design requirements are given a value indicating how important these design requirements are. Based on this value, high priority design requirements were considered [21] as WHATs for HoQ to be developed in this phase. HOWs for second HoQ were resources that impacted high priority design requirements. They are listed below:

1) *Complete Requirement:* A requirement must be complete in terms of its understanding by both customer and developer.
2) *Ambiguous Requirement:* A requirement must be clearly stated.
3) *Study Material:* Study material relevant to problem statement can be helpful in development of solution.
4) *Domain Knowledge:* Since tactical modules may involve strategic knowledge that is not readily available on internet, it requires experienced personnel.
5) *Skill Set:* Skill set constituting development platform, programming and technical knowledge can play a major role in impacting development efforts.
6) *Data Availability:* Data availability for verification of algorithm implementation is a major concern when it comes to defence related projects.
7) *Rework:* Major impact for development efforts comes from rework done owning to defects found or change of requirements.

HoQ was developed for this phase considering WHATs and HOWs as mentioned above.

C. Process Planning

In Process Planning phase, a comparative case study of three modules under consideration was done, based on high priority HOWs derived from HoQ in product design phase. In this phase, code quality reports [22]of each module were analysed for quality factors e.g. maintainability, clarity etc. and SQT [23] reports were analysed for causes of defects. Comparative performance of these three modules based on various parameters is summarized in Table II and III.

Table II
Code quality reports of three modules under consideration

Parameters	Module 1	Module 2	Module 3
Code Clarity	*79%*	*84%*	*92%*
Code Maintainability	*78%*	*88%*	*91%*
Code Testability	*78%*	*86%*	*88%*

These figures in Table 2 were taken from code quality report are generated by LDRA (Liverpool Data Research Associates) tool.

Table III
Defect statistics of three modules under consideration

Module	Total Internal defects (SQT and review)	SQT DD
Module 1	*1804*	*0.166*
Module 2	*1024*	*0.005*
Module 3	*458*	*0.062*

These figures in Table 3 were taken from Monthly Progress Review sheet [3] of project.
Further, a brainstorming session was conducted to understand reasons behind causes of defects. This session included developers and testers. Root cause analysis [24] was done to come out with a strategy to resolve identified causes.

D. Process Control

In process control phase, planned strategy was implemented and results achieved by application of planned process were compared to conclude impact (positive/negative) of our suggested strategy on process. For this purpose, results of these three modules from SQT and Pre FAT [23] were compared to conclude the impact of proposed modification in requirement elicitation process.

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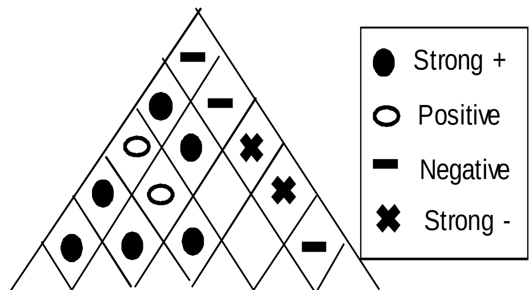
V. RESULTS AND DISCUSSION

A. Process Planning

HoQ for Process planning was built considering requirements mentioned in section 'IV Proposed four phase approach model for improved requirement elicitation process for tactical modules: a case study'. Percentage importance was calculated for all design requirements using formulae (1), (2) and (3). It can be concluded from the Figure 3 that most important design considerations were Problem Definition (21%), tactical knowledge (27%) and development efforts (22%). Problem definition and tactical knowledge are positively correlated and development effort has negative correlation with the other two. Hence improvement in problem definition and tactical knowledge will result in reduction of development effort, as represented in direction of improvement in HoQ in Figure 3.



	Direction of Improvement			↑	↑	↑	↑	↑	↓	Module Rating		
Customer Requirements (What)	Design Requirements (How) (Focus Area)	Importance (1-5)	% Distribution	Problem definition	Tactical knowledge	Testability	GUI	Alerts	Developement effort	Module 1	Module 2	Module 3
Improve	Accuracy	5	22	9	9		1	9	3	1	4	4
	Responsiveness	3	13	3	9			1	3	1	3	3
	Comprehensibility	3	13	3	3	9	9		9	3	3	2
	Error Handling	4	17	3	9			9	9	1	3	4
Reduce	Cycle time	1	4	9	9	1	3	3	9	5	2	3
	Defects	5	22	9	9	9			9	5	3	3
	Cost	2	9	9	9	3	3	3	9	5	3	3
Total		23	100									
Absolute Importance				642	822	346	178	403	690			
% Importance				**21%**	**27%**	11%	6%	13%	**22%**			

9 High
3 Medium
1 Low

1 -> 5 increasing order

Fig. 3 House of quality for product planning

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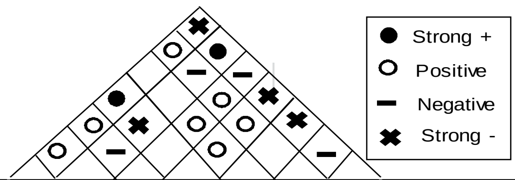
B. Product Design

HoQ of Product design phase was built by converting high priority HOWs achieved from HoQ of product planning phase as WHATs. Based on percentage importance derived from HoQ in figure 4, focus areas to be considered were Complete requirement (23%), Ambiguous requirement (23%), Domain Knowledge (23%) and Rework (14%). It can be observed from HoQ in figure 4 that complete requirement and domain knowledge were inversely related to Ambiguous requirement and rework. Thus improvement in domain knowledge will result in reduction of ambiguous requirements and rework.



Design Requirements (What)	Process Planning (How)	Importance (1-5)	% Distribution	Completeness	Ambiguity	Study Material	Domain Knowledge	Skill Set	Data Availability	Rework	Module 1	Module 2	Module 3
Direction of Improvement				↑	↓	↑	↑	↑	↑	↓	Module Rating		
Improve	Problem definition	5	38	9	9		9			9	1	4	4
Improve	Tactical knowledge	5	38	9	9	3	9	1	1	3	1	3	3
Reduce	Development effort	3	24	9	9	1	9	9	9	3	5	3	3
Total		13	100								1 -> 5 increasing order		
Absolute Importance				900	900	138	900	254	254	528			
% Importance				**23%**	**23%**	4%	**23%**	6.5%	6.5%	14%			

9 High
3 Medium
1 Low

Fig. 4 House of quality for product design

C. Process Planning

Code quality reports and SQT reports of all three modules under consideration were studied. It was observed from Figure 3 that performance of Module 1 module was low and its defects, cost and cycle time were high as compared to Module 3 module. The reason behind this, as seen from HoQ in Figure 4, was that team's knowledge of domain and understanding of problem statement was not as good as other modules, which resulted in higher defects and development efforts. Separate brainstorming sessions were conducted for development teams of each module and testing team to discuss defects found. Values assigned to modules as seen in Figure 3 and 4 are after brainstorming session with development and testing teams. In this session, code quality reports were discussed to understand type of rules violated resulting in percentage obtained by module and their causes. SQT and review reports were also studied for categorizing reasons behind defects. Main reasons and their percentage contribution in total number of defects are depicted in figure 5.

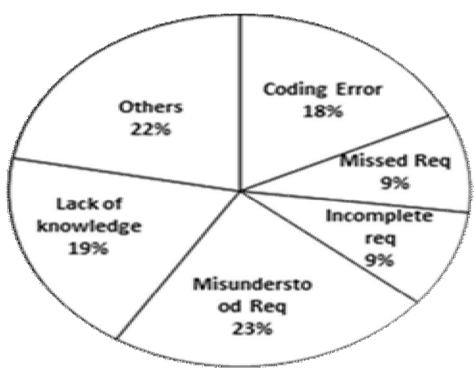


Fig. 5 Percentage of defects

These reasons were discussed with developers to understand their point of view on factors leading to them. A cause and effect analysis was done for defects using information gathered in brainstorming session and a fishbone diagram [25] was generated as shown in Figure 6. It can be concluded from figure 6 that most of these causes were directly or indirectly related to lack of domain knowledge. Domain knowledge is basically tacit in nature, residing in the minds of people either with past experience of developing similar modules or projects or with user who actually operates such modules on field or target environment. As defence based projects are highly confidential in nature, availability of related information on internet regarding such modules is very limited. There are two ways of gathering knowledge [26] for such modules:

Experience based: Knowledge can be acquired by working in similar types of projects where experience is gained while development as well as on field trials, where many situations are encountered which are missed out during requirement gathering. Field knowledge is highly beneficial in defence.

++ related projects.

Domain Expert or SME: If previous experience is not present, like in our first module, domain expert is an appropriate choice for gathering knowledge. In this case, obtaining important information and feedback from domain expert starting from requirement elicitation phase should be encouraged. Cost of fixing defects found later in the cycle rises exponentially [2].

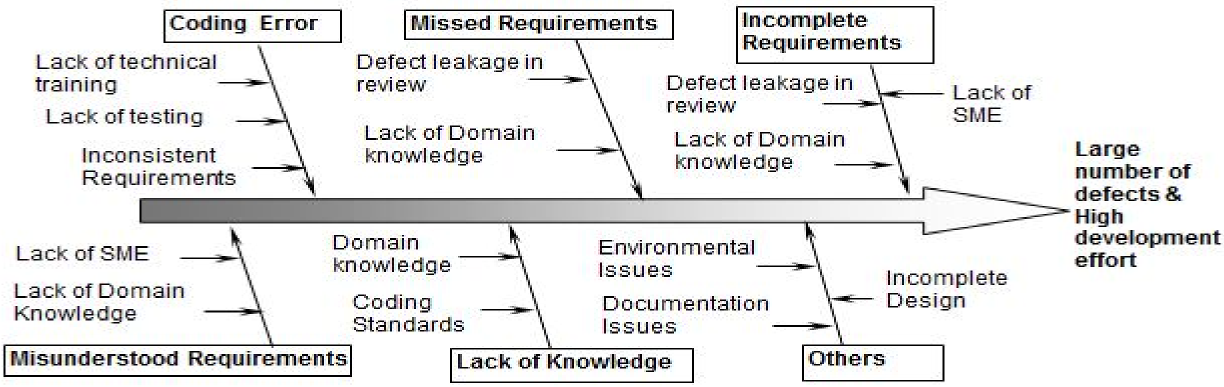


Fig. 6 Cause and effects analysis

D. Process Control

As planned in Process Planning phase, a domain expert was introduced on need basis after SQT. All modules were advised to clarify any doubts regarding requirements and their perceived implementation. All implementation done by team were reviewed and verified by domain expert at development site only. Requirements were made more complete and clear. Owning to this strategy, number of defects was considerably reduced in Pre FAT testing, done by customer. Number of 'Failed' and 'Not Offered' test cases for Module 1, Module 2 and Module 3 were zero. Complete set of test results are depicted in Table IV and V. These values are obtained from SQT and pre FAT reports of three modules under consideration. Comparative results are shown in figure 7.

Table IV
SQT Status (Number of test cases)

Module	Pass	Partially Pass	Fail	Not Offered
Module 1	55	7	39	12
Module 2	34	1	13	0
Module 3	43	6	8	2

Table V
Pre FAT Status (Number of test cases)

Module	Total test cases	Pass	Observations	Pending
Module 1	55	49	3	3
Module 2	35	33	1	1
Module 3	50	49	1	0

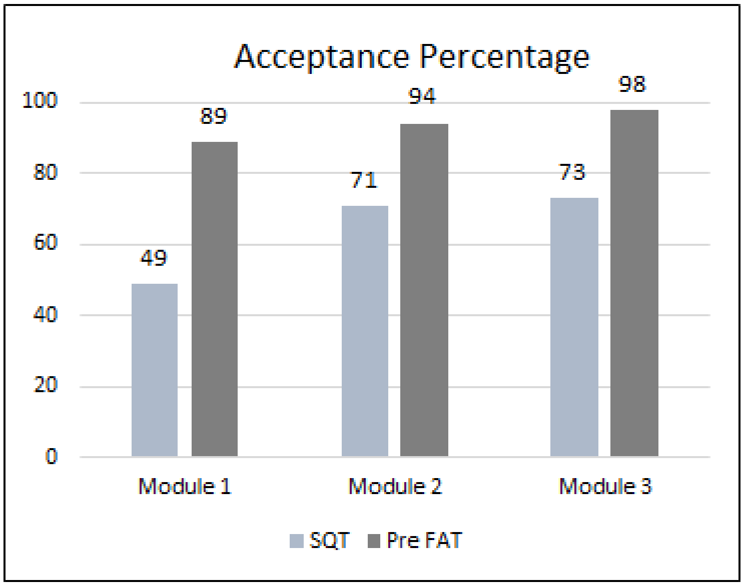


Fig. 7 Comparative results of SQT and Pre FAT

VI. CONCLUSIONS

As observed in results of process control phase, involving a domain expert after SQT has increased pass or acceptance percentage of test cases from SQT to Pre FAT by 83% for Module 1, 33% for Module 2 and 34% for Module 3. There was a considerable average increase (50%) in pass percentage. This is due to the fact that all field experience, inner working environment of module and abnormal circumstances faced are usually tacit, owning to highly sensitive and confidential nature of work. Involvement of a domain expert in requirement elicitation process can help to reduce number of defects arising from incomplete, misunderstood or missing requirements. Lesser the defect leakage from requirement phase, lesser will be number of defects in later stages and their associated rework. As we can see that involving expert after SQT considerably reduced number of defects, this benefit can be reaped from initial stages of module development, resulting in reduced development effort and increased customer satisfaction and brand value.

VII. FUTURE SCOPE

Defects leakage happens in spite of all precautions. Future research can be done on type of observations or defects that can be traced back as originating from requirement elicitation phase and reported from field or customer. Their causal analysis can be done using FMECA [27]and QFD can be used to derive a strategy to prevent them. Similarly, case studies can be done to identify problems occurring during other processes of software life cycle and QFD can be used for identification of preventive strategy.

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