CHAPTER 4

THE PROPOSED QUALITY ASSURANCE SYSTEM

4. The Proposed Quality Assurance System

In order to supply the distributed control system to the customers and make them satisfied, it is necessary to review and assess the current DCS project execution in the company and to collect the past data of the previous projects. These data are, then, analysed in a systematic manner with the engineering techniques called the failure mode and effect analysis (FMEA) and the fault tree analysis (FTA). The details of the analysis are discussed as following.

4.1 The Analysis of the Current DCS Project Execution Processes

As stated earlier in the previous chapter that there are fourteen steps in the DCS project execution in ABC. Here below are the discussions of each process of the project execution in detail. Note that there are some abbreviations in the table and their meanings are as follows.

SE = Sales Engineer
EDM = Engineering Department Manager
PM = Project Manager
E = Engineers
AE = Assistant Engineers
CUST = Customer
OHL = Order Handling Department
Admin Dept = Administration Department
ABC (Sing) = ABC Company at Singapore
H/W = DCS hardware
S/W = DCS software
KOM = Kick Off Meeting
FAT = Factory Acceptance Test

4.1.1 Step 1: The Internal Kick Off Meeting (Internal KOM) Process

S/ No.	Input Interface	Input	Work Process	Work Procedure	Work Instruction	Party	Output	Output Interface
1	(1.1)	- Request for meeting - Awarded contract - DCS system config. - Process's type - Special requirements	Start Job request from Sales	- To inform the contract's award - To describe the detail of the DCS job		SE		
	(1.2)	- Input of (1.1)	Data study	- To study the requirements of the job & select the project members		EDM		
	(1.3)	- Input of (1.1)	Formation of project team	- To inform selected project members of the job & project organisation		EDM		
	(1.4) SE	- Quotation - Letter of Intend (LOI) - Purchase Order (PO) - Customer Requisition spec and/or Invitation to Bid (ITB) - Proposed project schedule - Commercial terms & conditions - Price sheet - Explanation of the scope	Internal KOM	- To conduct the internal KOM		SE	- Internal KOM Review Checklist	
			Internal KOM review? N Y	- To attend the meeting and review related technical/ commercial matters transferred from sales to engineering department	Internal KOM Review Checklist	PM/E		
	(1.5)	- Input of (1.1) & (1.4)	Comprehension of requisition proposal contract 2	- To understand clearly ABC's scope of supply		PM/E		

Table 4.1 Internal KOM Process

The DCS project is firstly initiated from the sales department. After a sales engineer has sold the distributed control system to a customer, the sales engineer will inform to the engineering department manager about the contract's award. This information is usually informed to the engineering department manager (EDM) in speech rather than in writing. The sales engineer will also describe the detail of the DCS project, the DCS system configuration, type of the process control, and request for an internal meeting between sales and engineering department. After the EDM has studied the information receiving from sales, he forms a project team, which consists of a project manager and system engineers. The necessary information has also been transferred by the EDM to the project manager for his study as well.

The internal kick off meeting (internal KOM) is held within the company between the project team and the EDM of the engineering department and the sales engineer from the sales department. The purpose of the meeting is to transfer all customer information from the sales to the engineering department. After the meeting, the project team starts studying the project information such as the project contract and its scope of work.

4.1.2 Step 2: The Customer Kick Off Meeting (Customer KOM) Process

After the internal KOM, the project manager and system engineers in the project team prepare the KOM document and submit to the customer via the sales engineer. The sales engineer, then, arranges the KOM appointment with the customer.

The customer KOM is usually held at the customer's place. The purpose of the meeting is to introduce the project team to the customer, to confirm the corresponding route between the customer and the project team, and to confirm the scope of work of the company ABC. The customer may also submit the engineering information to the project team. The details of the meeting are recorded in the document called the KOM minutes of meeting.

S/ No.	Input Interface	Input	Work Process	Work Procedure	Work Instruction	Party	Output	Output Interface
2	(2.1)	- Input of (1.5)	② Preparation of document for customer KOM	- To prepare relevant KOM document under output of (2.1)		PM/E	KOM document	CUST (via SE)
	(2.2)		Set up appointment with customer	- To arrange the KOM appointment with the customer		SE		
	(2.3) CUST	- Output of (2.1) - P&ID, equivalent document containing tag no.input/output types, and ranges - Operation philosophy	Customer KOM	- To use the KOM document as the basis for discussion		PM/E SE CUST	- Revised KOM document	
	(2.4)	- Input & output of (2.3)	Review data/document after KOM ③	- To study the customer document		PM/E	- Updated KOM document - KOM minutes of meeting (MOM) - Transmittal of MOM	CUST

Table 4.2 Customer KOM Process

4.1.3 Step 3: DCS Hardware Specification Design and Approval Process

S/No.	Input Interface	Input	Work Process	Work Procedure	Work Instruction	Party	Output	Output Interface
3	(3.1) CUST	- Revised P&ID - Revised instrument data sheet - Revised document containing tag no, input/output types, and ranges	③ Technical Meeting Does question occur? Y N	- To clarify and confirm input/output lists including types and ranges - To confirm the model of the DCS hardware - To clarify the technical questions and answers by fax		PM/E CUST	- FAX in/out - Updated bill of material - Overall signal flow diagram* - System cable routing* - Updated system configuration - Updated I/O lists - MOM - Transmittal of MOM * Only if applicable	CUST
	(3.2)	- Input & output of (3.1)	Hardware spec design	- To prepare the DCS h/w manufacturing specification		PM/E	- DCS h/w manufacturing specification	
	(3.3)	- Output of (3.2)	Submission of specification for approval	- To submit DCS h/w manufacturing specification for approval		PM/E	- Transmittal of DCS h/w spec - DCS h/w manufacturing specification for approval	CUST
	(3.4)	- Output of (3.3)	Approval of specification	- To return approved specification with comments (if any)		CUST	- Approved DCS hardware manufacturing specificaiton	PM/E
	(3.5)	- Output of (3.4)	Review of the approved specification ④	- To check for customer comments and discrepancies - To submit for re-approval (if necessary)		PM/E	- Finalised DCS hardware manufacturing specification	
	(3.6)	- Output of (3.5)	Prepare document for h/w ordering	- To prepare the purchase order requisition form		PM	- Purchase order requisition - Finalised DCS h/w manu spec - Revised bill of material	OHL
	(3.7)	- Output of (3.6) DCS hardware	Purchase order to Singapore DCS h/w Manufacturing DCS h/w delivered from Singapore to Thailand ⑦	- To prepae purchase order sheets		OHL ABC (Sing)	- Purchase order sheets - DCS hardware	ABC (Singapore)

Table 4.3 Hardware Specification Design and Approval Process

After the customer KOM, there are several technical meetings between the project team and the customer. The meetings are held to clarify and confirm number of the input to and the output from the distributed control system. The types of DCS input whether they are measured to the DCS in current or voltage form and the types of DCS output are also confirmed in these meetings. The types of input and output are confirmed in order to make sure that the models of the DCS hardware to be ordered are right.

When the project team have clear information about the input and output of the DCS, they start designing the DCS hardware manufacturing specification, which includes the detail of all equipment of the DCS hardware. The designing process takes around one month. The specification is, then, submitted to the customer for approval.

The customer checks the specification and returns the document to the project team. The comments, if any, may also be added to the specification by the customer. The project team reviews and corrects the document again before proceeding the DCS hardware ordering to the company ABC at Singapore. The DCS hardware usually arrives at ABC during the debugging stage.

4.1.4 Step 4: DCS Software Specification Design and Approval Process

After the DCS hardware has been approved, there are several technical meetings with the customer to discuss about the process control and operating concept for writing the DCS software application specification. The customer prepares their requirements in the form of the engineering document such as their loop diagram, logic diagram, sequence control, interlock sequence, graphic interface, logging report, and man machine interface.

The engineers in the project team study the customer's requirements and discuss about the unclear points with the customer. The meetings are held several times until the engineers have no questions about the requirements. Then the project team prepares the software specification according to the customer's requirements and submits to the customer for approval. After the customer's approval, the engineers review and check the customer's comments and discrepancies. Resubmission of the software specification after the customer's approval may be required, if the customer requests the team to submit again.

S/ No.	Input Interface	Input	Work Process	Work Procedure	Work Instruction	Party	Output	Output Interface
4	(4.1) CUST	- Input of (3.1) - Operation manual and concept - Sequence or batch control requirements - Shutdown interlock requirements - Graphic requirements - Logging report requirements - Man machine interface requirements - Loop diagrams - Logic diagrams	(4) Technical Meeting Does question occur? Y N	- To clarify and confirm the detail of DCS control and interface functions - To clarify the technical questions and answers by fax		PM/E CUST	- FAX in/out - MOM - Transmittal of MOM	
	(4.2)	- Input & output of (4.1)	Software spec design	- To prepare the DCS s/w functional specification		E	- DCS software functional specification	
	(4.3)	- Output of (4.2)	Submission of specification for approval	- To submit DCS s/w functional specification for approval		PM/E	- Transmittal of DCS s/w spec - DCS s/w functional specification for approval	CUST
	(4.4)	- Output of (4.3)	Approval of specification	- To return approved specification with comments (if any)		CUST	- Approved DCS software functional specificaiton	PM/E
	(4.5)	- Output of (4.4)	Review of approved specification (5)	- To check for customer comments and discrepancies - To submit for re-approval (if necessary)		PM/E	- Finalised DCS software functional specification	

Table 4.4 Software Specification and Approval Process

4.1.5 Step 5: DCS Software Design Process

After the customer has approved the software specification, the system engineers of the team start designing the application software according to the approved specification. The software is designed in the paper called DCS worksheet. The application software may be divided into several parts based on the process name of the plant. Each engineer designs each software part. The total application software is, then, integrated at the final phase of the software design process.

During the design process, the project manager monitors the project progress. The project manager may advise the team about the design techniques or process control. Each month till the project's end, the project manager prepares a monthly progress report for submitting to the customer and reports to the technical division manager of the ABC.

When the design process steps to the final phase, this means the system engineers almost finish their design work. The project manager requests for the DCS in-house machines to the EDM. These machines are used for the software generation.

S/ No.	Input Interface	Input	Work Process	Work Procedure	Work Instruction	Party	Output	Output Interface
5	(5.1)	- Output of (4.5)	⑤ ↓ DCS software design ↓	- To design the DCS software - To fill in the DCS worksheet		E	- DCS worksheet for generation	
	(5.2)		Monitoring of the project ↓	- To monitor the progress of the project		PM	- Monthly progress report (every month till the project's end)	CUST
	(5.3)		Application of staging area ↓ ⑥	- To request for the DCS inhouse machine for generation		PM EDM	- Verbal	EDM

Table 4.5 Software Design Process

4.1.6 Step 6: DCS Software Generation Process

S/ No.	Input Interface	Input	Work Process	Work Procedure	Work Instruction	Party	Output	Output Interface
6	(6.1)	- Output of (5.1)	⑥ ↓ Software generation ↓	- To generate the DCS software		E/AE	- DCS software source file	
	(6.2)	- Output of (6.1)	Check the generated s/w ↓ ⑦	- To check the generated s/w (Visual check from printing paper or monitor screen)		AE	- Checked DCS software source file	

Table 4.6 Software Generation Process

The output of the previous step is the DCS worksheets. These worksheets are generated to the DCS hardware to make the DCS software source file. The engineers or the assistant engineers complete this work. The generated software is checked by the assistant engineers. This to ensure that software is generated correctly and there is no software bugs due to the typing mistakes.

4.1.7 Step 7: DCS Software Debugging Process

After the DCS worksheets have already been generated to the DCS hardware, the process of detecting errors, or bugs, in the DCS application software starts. The engineers check the application software based on the customer approved software specification. The errors due to the typing or design mistakes are corrected during this process. In addition, the DCS hardware of the customer is also used in the debugging process, if the hardware is delivered to ABC during this period.

During the software debugging process, the team also prepares the inspection test procedure document, called factory acceptance test procedure or FAT procedure document. This document is submitted to the customer for his/her study prior to start the inspection period.

S/ No.	Input Interface	Input	Work Process	Work Procedure	Work Instruction	Party	Output	Output Interface
7	(7.1)	- Output of (6.2) and (4.5)	(7) DCS Software debugging	- To debug software		PM/E	- Debugged s/w	
	(7.2)	- Project scope of supply and customer requirement	Preparation of the FAT procedure	- To prepare FAT procedure based on scope of supply and customer requirement		PM/E	- FAT procedure document	
	(7.3)	- Output of (7.2)	Submission of FAT procedure document (8)	- To submit the FAT procedure to customer for information		PM	- FAT procedure document - Transmittal of FAT procedure document	CUST

Table 4.7 Software Debugging Process

4.1.8 Step 8: Factory Acceptance Test (FAT) Process

The factory acceptance test is the inspection period before shipping the distributed control system to the customer's factory. The customer visits the ABC for checking both the DCS hardware and software. For hardware inspection, the customer checks the correctness of the model and the normality of the functions of all DCS equipment. For software inspection, the engineers conduct the testing process according to the approved software specification and the FAT procedure document.

During this process, the customer may request to add some additional control functions into the application software or they may find some software bugs. These additional requests or software bugs are recorded into the document called the FAT record or punch lists.

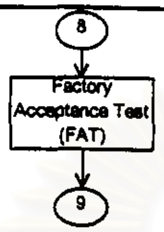
S/ No.	Input Interface	Input	Work Process	Work Procedure	Work Instruction	Party	Output	Output Interface
8	(8.1)	- Output of (3.5) (4.5) and (7.2)		- To conduct the customer FAT for h/w and s/w according to the FAT procedure document		PM/E CUST	- FAT record/ punch list	

Table 4.8 Factory Acceptance Test Process

4.1.9 Step 9: Recovery Work Process

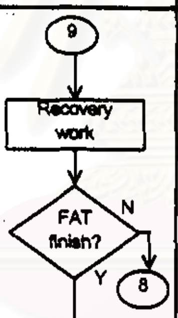
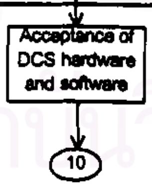
S/ No.	Input Interface	Input	Work Process	Work Procedure	Work Instruction	Party	Output	Output Interface
9	(9.1)	- Output of (8.1)		- To correct any s/w bugs or h/w problems		PM/E CUST	- Acknowledgement of the outstanding items in the FAT record	
	(9.2)			- To accept the DCS h/w and s/w if there is no major nonconformities to the FAT procedure is found		CUST	- Signed customer FAT acceptance certificate	

Table 4.9 Recovery Work Process

The recovery work process is the process to correct the software bugs or hardware problems, which were found during the FAT period and recorded in the punch lists. The project team corrects these problems in the evening of each day of the FAT period so that the customer can check the corrected items on the next day. If there is no major nonconformity to the FAT procedure is found, the customer accepts the DCS hardware and software and signs on the FAT acceptance certificate. This means that the customer accepts to deliver the DCS to the customer's factory.

4.1.10 Step 10: Delivery the Distributed Control System Process

At this process, the project team prepares the distributed control system for delivery. This work includes completing the FAT punch items, completing the final save for software, and keeping the DCS hardware in the boxes or containers.

The project manager makes an interoffice memo to the administration department to deliver the distributed control system to the customer's factory. When the DCS has been delivered to the customer's factory completely, the project manager informs to the sales engineer to submit the invoice to the customer.

S/ No.	Input Interface	Input	Work Process	Work Procedure	Work Instruction	Party	Output	Output Interface
10	(10.1)		(10) Prepare DCS for delivery	- Completion of FAT punch items - Completion of final save for software - Keep DCS h/w in boxes		PM/E	- DCS h/w and s/w for delivery	
	(10.2)	- Output of (10.1)	Handover of h/w & s/w to Administration department for delivery	- To inform the administration department for the DCS delivery		PM	- Interoffice memo	Admin Dept
	(10.3)	- Output of (10.1) - Delivery order (From Administration department)	Delivery to site (customer's factory)	- To deliver the DCS h/w and s/w to the customer's factory		Admin Dept	- Receipt acknowledgement on the delivery order by customer	PM/E
	(10.4)	- Output of (9.2) and (10.3)	Inform SE about shipment completion	- To inform SE about the DCS shipment completion		PM	- FAT acceptance certificate	SE
			Submit external invoice (11)			SE	- Invoice	CUST

Table 4.10 Delivery the DCS Process

4.1.11 Step 11: Final Document Preparation Process

After the shipment of the distributed control system, the engineers prepare the final document according to the contract agreement and submit to the customer. This document may consist of the revised hardware manufacturing specification, revised software specification, and the self-document. The self-document includes all details of the source code of the application software.

S/ No.	Input Interface	Input	Work Process	Work Procedure	Work Instruction	Party	Output	Output Interface
11	11.1	- Software backup	11 Final document preparation	- To prepare final document in accordance with contract requirement		E	- Final document	
	11.2	- Output of 11.1	Submission of final document 12	- To submit the final document to customer		E	- Final document - Transmittal of the final document	CUST

Table 4.11 Final document Preparation Process

4.1.12 Step 12: Installation, Startup and Commissioning Process

This step is to install the equipment such as valves, pumps, and transmitters and connect them to the distributed control system. This work is usually performed by the contractor and is not the scope of work of the ABC. After the installation work is complete, the total loop check begins. This is to ensure that the distributed control system and the equipment installed outside are connected correctly. Then the plant is started up and it starts the commercial running. Note that during this process, the engineers of ABC may be requested to stay at site for correcting some problems or making some additional software.

S/ No.	Input Interface	Input	Work Process	Work Procedure	Work Instruction	Party	Output	Output Interface
12	12.1		12 Installation, startup and commissioning 13					

Table 4.12 Installation, Startup, and Commissioning Process

4.1.13 Step 13: Project Review Process

The project manager and the engineers in the team review the project and make the job summary records. The records include the system configuration of the project, process type and detail, special application in the project, and the project summary. The records are then kept in the engineering department for further use in the future.

S/ No.	Input Interface	Input	Work Process	Work Procedure	Work Instruction	Party	Output	Output Interface
13	13.1		13 Project review 14	- To review the project		PM/E	- Job summary records	

Table 4.13 Project Review Process

4.1.14 Step 14: As Built Document Preparation Process

This process is similar to the step 11, the final document preparation process. The engineers prepare the updated hardware manufacturing specification, updated software specification, and the self-document. The as built document is prepared and submitted to the customer before the project's end once again because there may be some changes occurring during the plant startup and commissioning process. Therefore, the submission of the as built document is to ensure that the customer will have the documents that represent his distributed control system correctly.

S/ No.	Input Interface	Input	Work Process	Work Procedure	Work Instruction	Party	Output	Output Interface
14	14.1	- Software backup	14 As built document preparation	- To prepare the as built document in accordance with contract requirement		E	- As built document	
	14.2	- Output of 14.1	Submission of the as built document Project Closure	- To submit the as built document to the customer		E	- As built document - Transmittal of the as built document	CUST

Table 4.14 As Built Document Preparation Process

4.1.15 Average Time for DCS Project Execution

The figure below illustrates the average time for major processes of the DCS project execution based on the average working time data of the past DCS projects in ABC.

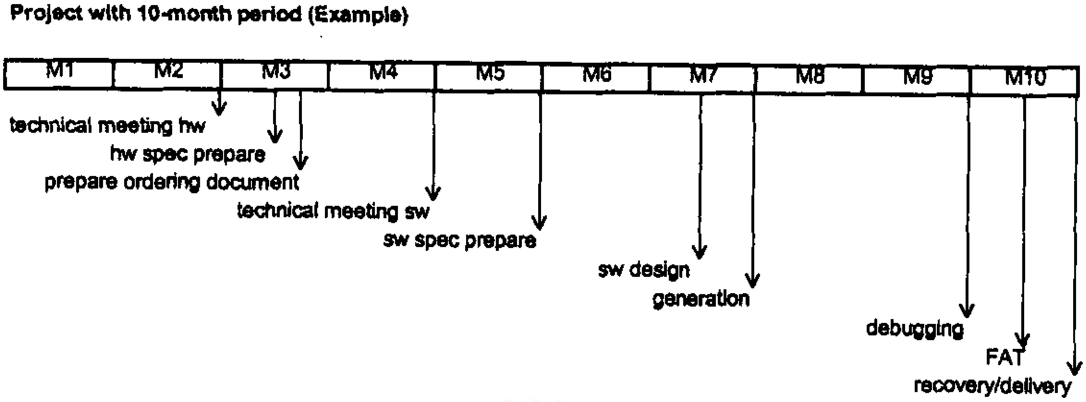


Figure 4.1 Average Time for Major Processes in DCS Project

A DCS project usually needs executing time ranging from 8 to 12 months. For the 10-month project as shown above, each major process requires the working time as below.

Major Processes	Average time (wks)*	Percent of total project (%)**
technical meeting hw	8	20
hw spec preparation	2	5
ordering document preparation	1	2.5
technical meeting sw	8	20
sw spec preparation	4	10
sw design	6	15
generation	2	5
debugging	8	20
FAT	2	5
recovery/delivery	2	5

* Average time based on the 10-month project

** Estimated time percentage for general DCS project

Table 4.15 Average Time of Major Processes in Percentage for General DCS Project

From the table, the technical meeting for hardware requires 20% of the total project period or 8 weeks for the 10-month project. The average time in percentage will be used further in the next section when we compare the average time with the actual time spent in each project. For example, if the total project time is one year, the estimated time for major processes is as follow.

Major Processes	Average time (wks)	Percent of total project (%)
technical meeting hw	9.6	20
hw spec preparation	2.4	5
ordering document preparation	1.2	2.5
technical meeting sw	9.6	20
sw spec preparation	4.8	10
sw design	7.2	15
generation	2.4	5
debugging	9.6	20
FAT	2.4	5
recovery/delivery	2.4	5

Table 4.16 Average Time of Major Processes for 12-month DCS Project

4.2 Past Data Collection of the Previous DCS Projects

The data of projects executed during the past two years have been collected, starting from 1996 to 1997. It is important to note that each project has its own characteristics. This is because each distributed control system is supplied to different customers. Therefore, the technical characteristics, such as the project's size, types of the distributed control system, system configuration, types of the process control, functional specifications and hardware specifications, and especially the application software, of each project are so different. However, we can use the data collected from each project as the guideline for comparing whether the proposed quality assurance system improves the ways to execute the DCS project.

Since each project has its own characteristics, I have firstly explained some background information of the projects being discussed prior to discuss about the collected data. There are three projects to be discussed. The first of these is the 'RCA Project'. This is for the chemical company producing the chemical gas at Rayong province. The second project is the 'AIT Project' for the plastic customer at Rayong province. The third project is the 'TRC Project' for the customer producing rayon at Ang Thong province.

4.2.1 RCA Project

This DCS project was for the customer (end user) located at the Eastern Industrial Seaboard in Map Ta Phut, Rayong province. This plant produces the chemical gas such as hydrogen and chlorine gas. The project started at the beginning of 1996 and the delivery date must be within 12 months from the project starting date.

The customer selected a 'middle size' distributed control system for his plant. In ABC, there are three different sizes of distributed control system, ranging from the small size, middle size, to the large size. The small and middle size uses rather old technology whereas the large size uses a new technology to develop the software application.

ABC got this order from the main contractor of this plant, not from the end user. Therefore, the technical information such as the detail of the process control and instrument requirement was received from this main contractor only.

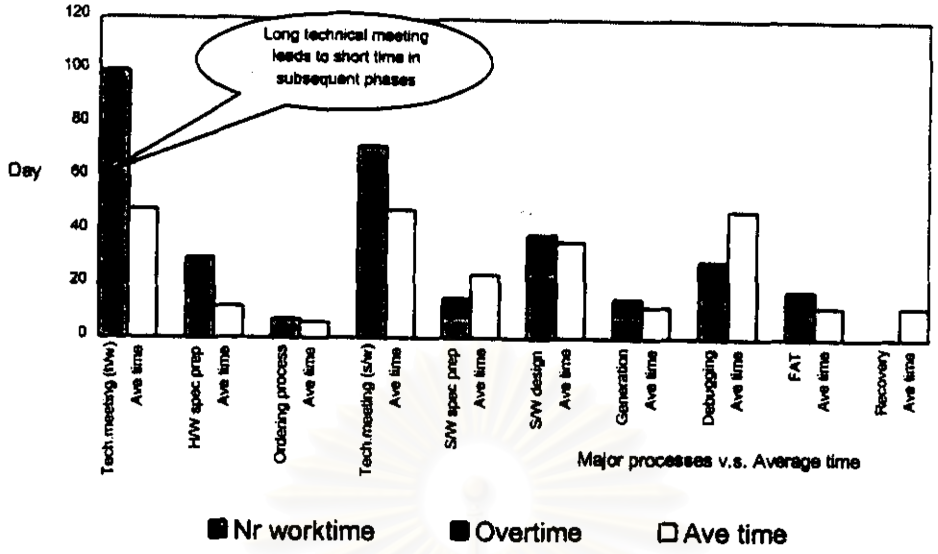


Figure 4.2 Time Used in Major Processes of RCA Project

Source: Data of the ABC Company

A. Technical Aspect

Since the engineers of the main contractor (Japanese-Thai company) were quite new with the distributed control system of ABC, the ABC project team had to coach them to understand the various functions of the DCS and help them to define the control functions of the plant. As a result, the information received from them is less during the beginning to the middle of the project period and the software functional specification for approval could be issued after the project was already passed nine months. In other words, this meant that the DCS software design work for this project could be started only after the project has passed for nine months. Therefore, the software design, generation, and debugging process were done in hurry and overtime in order to meet the target delivery date.

During the factory acceptance test (FAT), there were three parties joining the inspection test. These included the engineers of the main contractor, engineers of the end user, and ABC engineers. Unfortunately, the FAT could not finish within the specified time because of the design changes during the inspection period made by the end user who first time saw the control functions for his plant. The end user complained that some process controls did not meet their requirements. This meant that the ABC engineers had to redesign and reprogramme the system. Even the FAT was not complete at the specified date, the customer agreed to allow the ABC to deliver the system to the factory and requested for another FAT at site. This was because the customer needed the DCS hardware in order to keep the main project schedule: they wanted to connect the control cable from equipment outside control rooms to the DCS hardware.

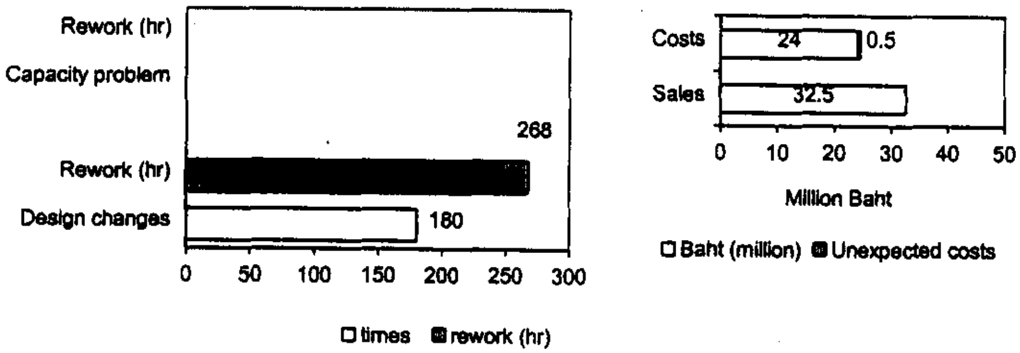


Figure 4.3 Technical and Financial Aspects of RCA Project

Source: Data of the ABC Company

B. Financial Aspect

The delay in the technical meeting leaded to the shorten time for further processes of the DCS project: software design, generation, and debugging process. Moreover, the changes occurred during the FAT process also caused the ABC engineers spending overtime to complete their jobs. These cost the company a lot of overtime payments and high cost of reworking. Since the Re-FAT was required at the factory, the cost of travel and accommodation for the project team also cost the company a lot of money. The profit made was much less than was expected.

C. Customer Aspect

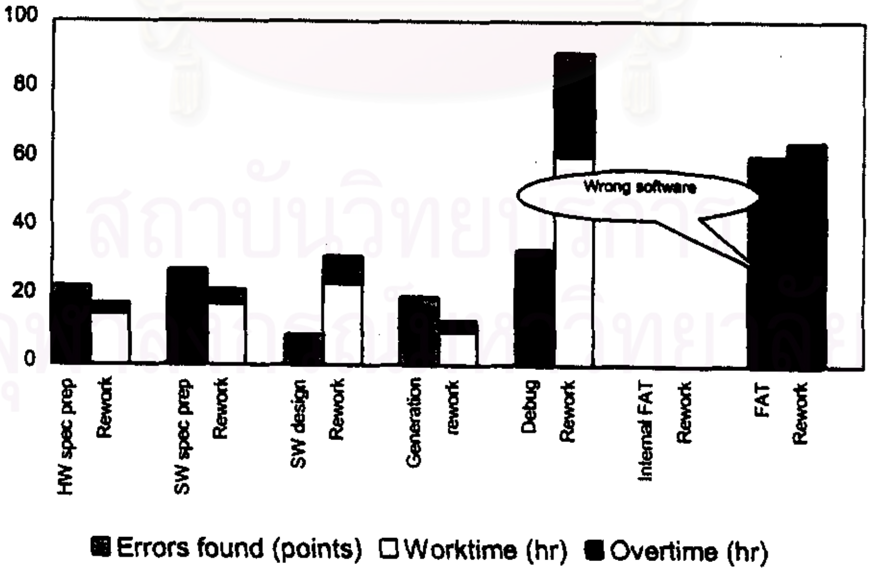


Figure 4.4 Errors Detected and Rework of RCA Project

Source: Data of the ABC Company

There were many software errors due to ABC's mistakes and design changes in this project. The customer was not so happy with the results. However, ABC promised to the customer that there would have another FAT setting at the factory. Therefore, the customer thought that all errors could finally be solved before the plant startup with ABC's support. The delivery was not the problem of this project because the customer allowed delivering the product even the software application still was not complete.

4.2.2 AIT Project

The customer of this project was the factory located at the Eastern Industrial Seaboard in Map Ta Phut, Rayong province. This plant produces plastics in the forms of powder and pellet. The project started in February of 1997 and the delivery date was in November of the same year.

The distributed control system of this factory was the 'large size' of DCS which used the new technology to develop the software application. ABC got this order from the Japanese contractor of this plant. Similar to the previous project, the technical information such as the detail of the process control and instrument requirement was received from this contractor only.

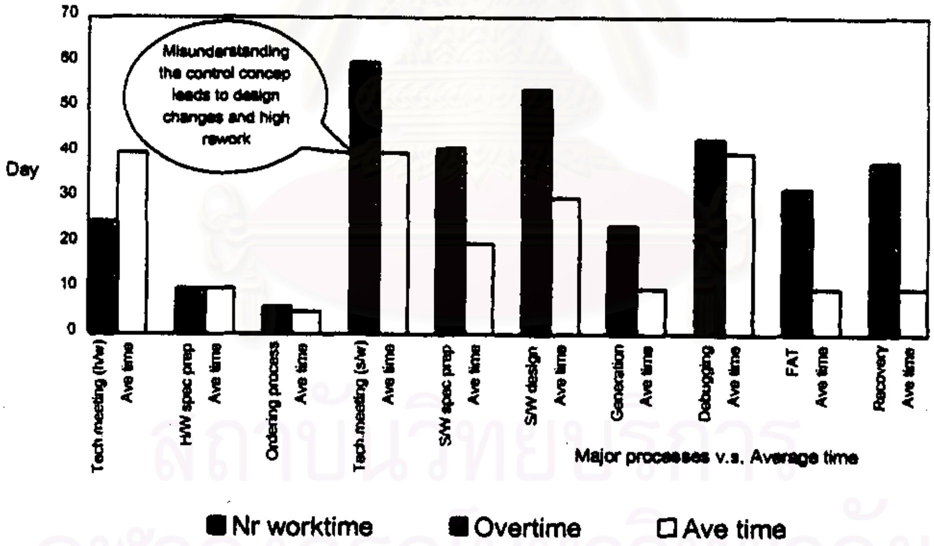


Figure 4.5 Time Used in Major Processes of AIT Project

Source: Data of the ABC Company

A. Technical Aspect

The process know-how was from another Japanese company, so the contractor had to have several technical meetings with this Japanese-know-how-company to get enough engineering information before translating to ABC's project team. The information given to the project team was rather late from the project schedule. In addition, there are very few technical meetings between the contractor and the project team during the project execution because of the location's difference (Japan and Thailand).

The control requirement and the report function given to the project team were very simple. However, if the project team concentrated on this control requirement in much detail, they would have seen that there were several unclear points found in the document and they would have seen that, in fact, the requirements were very complex.

There were three engineers with one project manager executing this project. These three engineers were freshmen at that time and all of them had no experiences in designing the DCS application software. Since there was no senior engineer to guide these engineers during preparing the software functional specification, the first revision of the functional specification, supposed to be submitted to the customer, was resulted in scrap. This was because project manager did not approve it and did not allow submitting to the customer for approval.

There were so many functions to be tested during the inspection period (FAT). Therefore the contractor requested for an internal FAT between the contractor and the ABC Company. This was to ensure that the application software were written correctly and to assure that the contractor would not lose his face due to many software errors or bugs when the end user and know-how company joined during the actual FAT.

Unfortunately, because of the unclear control requirement given at the beginning of the project and lack of communication between the project team and the contractor, almost 70 percent of the written application software did not meet the contractor's actual requirements. This was only discovered during the internal FAT which was held one month prior to start the actual FAT in November 1997. Almost the design works done previously were resulted in scrap. The project team had to redesign the software and to rectify these problems all day and night in order to finish them before starting the actual FAT.

The actual FAT could start but only some parts of the software could be tested. The project was delayed one month from the project schedule so that the project team could rectify all those pending problems and there was another FAT again in December 1997.

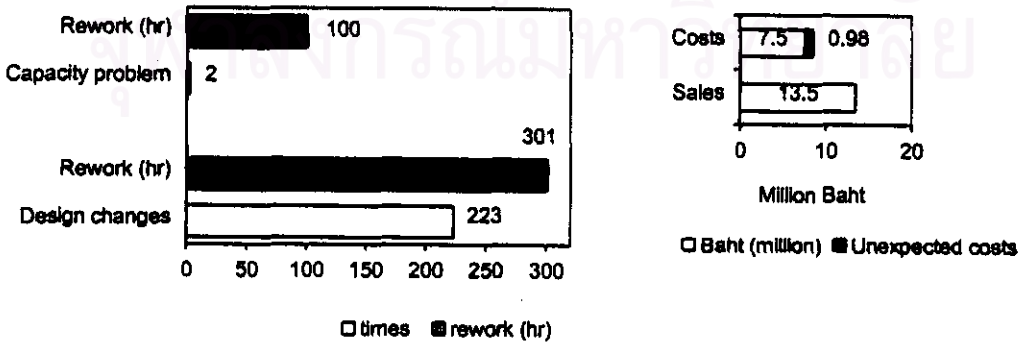


Figure 4.6 Technical and Financial Aspects of AIT Project

Source: Data of the ABC Company

B. Financial Aspect

The overtime payments and costs of reworking for this project were very high because the project team had to redesign almost the software within a very short time. In addition, there was also the cost of Re-FAT in December and the system was eventually delivered one month late.

Due to many software hidden bugs, the errors that could not be found during the FAT, the project team had to travel to the factory to rectify these problems many times and this took eight months after the DCS was delivered to site. The cost of travel and accommodation for the project team was also high. As a result, the ABC Company made profit of this project less than was expected almost 1 million Baht.

C. Customer Aspect

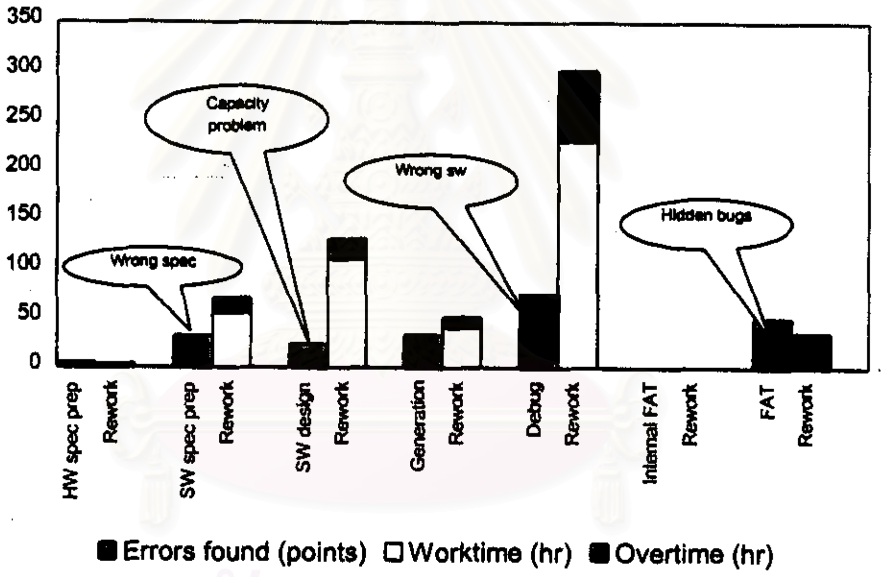


Figure 4.7 Errors Detected and Rework of AIT Project

Source: Data of the ABC Company

The customers (both the contractor and the end user) were not so satisfied with the DCS product because the project was delayed one month from the project schedule and the system could not be delivered completely at the agreed date. In addition, there were so many software bugs because the application software was redesigned in rush time and hurry manner. This was resulted in the customer dissatisfaction.

4.2.3 TRC Project

This project was for the factory producing rayon in Ang Thong province. This was a small modification project. The period of this project was planned as three months. The customer already used the distributed control system, the 'small size' DCS, and he wanted to expand the process's capability. Therefore, some functions were required to implement in the DCS. ABC got this order directly from the customer and the technical information such as the detail of the process control and instrument requirement was received from the customer.

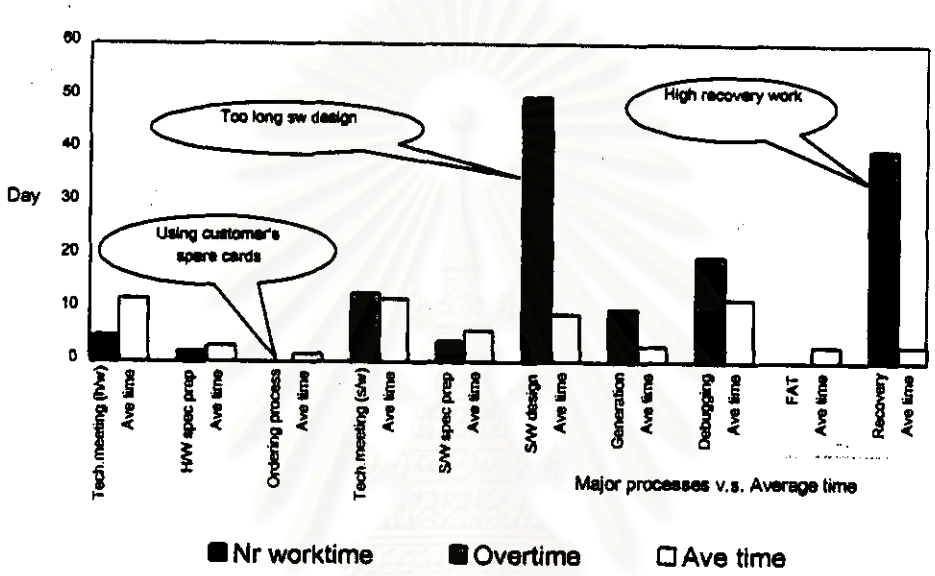


Figure 4.8 Time Used in Major Processes of TRC Project

Source: Data of the ABC Company

A. Technical Aspect

To improve the process capability of the plant, the customer requested two control functions to be implemented in DCS. He required a set of controllers with one built-in calculation to control the acid flow and the other requirement to calculate the temperature-and-pressure-compensated steam flow rate. These requirements, if looking roughly, would be simple and the project team of ABC Company could finish the job within a short period. Actually, the requirements were little but complex and difficult.

This project took long time for the DCS design phase, if comparing to the quantity of requirements (just two required functions). For the first requirement which was to controlling the acid flow, the strong foundation of mathematics is required for solving the complex equation. It took two weeks for solving the complex formula and simplifying it for implementing in the DCS.

The second requirement was to find one formula which was able to calculate the superheated steam flow rate in various pressure and temperature conditions. Since the ABC Company did not have any technical information to support this requirement, so the project team had to contact to the ABC at Singapore and ABC Mother Company and asked for help. Finally, the team could get the results but it took more than two months to get the answer.

There was no FAT to verify the software at ABC. The customer requested for checking the application software at site. To complete the inspection test and finish the job, the engineer had to travel to customer's site and make some software modification several times until the control result was acceptable by the customer. Finally, the project schedule was late from the initial plan two months. That is, the software has been loaded at site after passing 5 months from the beginning of project and it took another 2 months for software recovery at site. The actual project period was 7 months, instead of 3 months as planned.

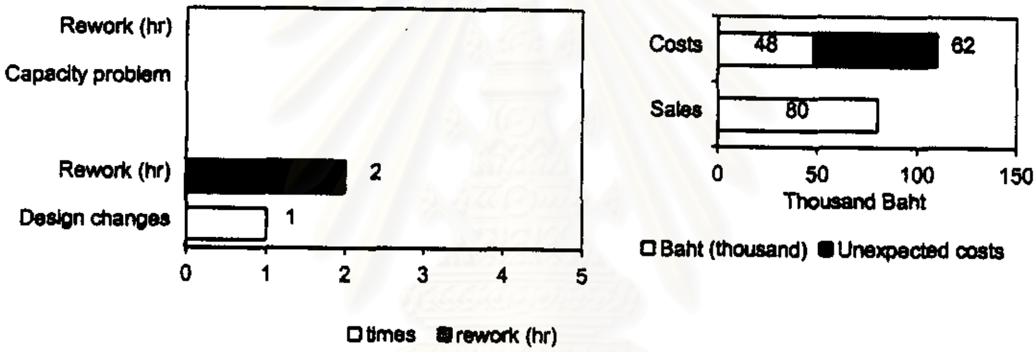


Figure 4.9 Technical and Financial Aspects of TRC Project
Source: Data of the ABC Company

B. Financial Aspect

During the sales negotiation period, the sales staff thought that the requirements were little and the ABC Company could finish it within short time and get high profit margin from this simple job. In fact, the company did not get any profit from this job because the ABC Company did not check the customer's requirements carefully and quoted to the customer with rather cheap price. The costs incurred, due to the technical correspondence between the ABC Company and Mother Company, travelling costs and modification costs during checking the software at site after software loading, were not included into the sales price. This cost the ABC Company about 30,000 Baht.

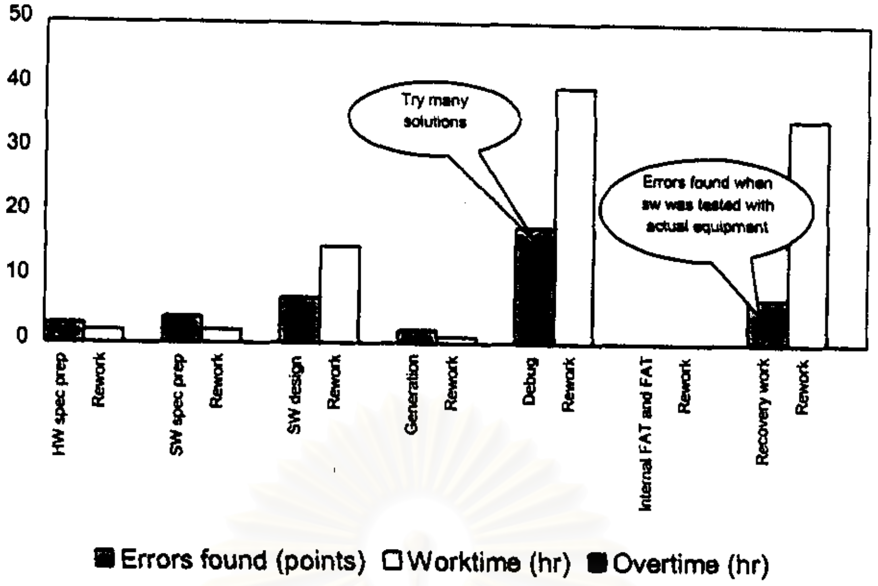


Figure 4.10 Errors Detected and Rework of TRC Project

Source: Data of the ABC Company

C. Customer Aspect

The customer quite understood that the ABC Company needed a period of time to find solutions for the customer's requirements, so he could wait for the results without any complaint. When the application software was verified that it met the customer's requirements, though the project was delayed for 4 months, the customer was still all right with it since his process's capability has been improved as it was expected.

4.3 Problem Analysis Using the FMEA and FTA

As stated earlier in the statement of problems that ABC Company has major problems on the following issues:

- Lack of procedures to control the project execution
- Lack of the document and data control
- Technical problems

This is because the company has no effective quality assurance system. Although the DCS hardware, which was manufactured by ABC Singapore, is good and comparable to any other in the DCS industry, there are major problems with the software quality. The troubles during the DCS project execution should be eliminated and prevented before these troubles reach the customer.

In order to define, identify and eliminate the problems in the DCS project execution in a systematic manner, the failure mode and effect analysis (FMEA) and fault tree analysis (FTA) have been introduced in the ABC Company.

4.3.1 The FMEA Types Selection

There are four types of FMEA: system, design, process, and service FMEA. The DCS project execution in the company has both the design function (software design) and the process function (there are 14 processes of the DCS project execution). Therefore, the design FMEA and the process FMEA have been selected to apply to the company.

4.3.2 The FMEA Team Selection

The FMEA is a team function and cannot be done individually. The FMEA team must also be established for the specific problems, and cannot serve as the company FMEA team who solves all the problems in the company. Therefore the team to solve the problems in the DCS project execution has been established. In order to getting the best analysis of the current DCS project execution, the persons who join the team must be expert at designing software and controlling the DCS project. They also should have good qualification and extensive experiences in the distributed control system. The team consists of five members from the engineering department. Their qualifications are as follows.

1. Mr. Sakchai, aged 34: Assistant Engineering Manager and Project Manager

He graduated from a university in electrical engineering. He has joined with the Company ABC more than six years. He has been trained in Japan in designing DCS software for one year. He has executed and managed 14 DCS projects. Two of them were for foreign customers in Philippine and Vietnam. He is an expert in DCS programming and DCS project management.

2. Mr. Pongsak, aged 38: Assistant Engineering Manager and Project Manager

He graduated from a university in electronics engineering. He has joined with the Company ABC more than six years. He has worked with the Company ABC in Singapore for one year for a project in Indonesia. He has executed and managed 15 DCS projects. Some customers are in foreign countries. He is an expert in DCS programming, panels, and project management.

3. Mr. Sayom, aged 29: Senior Engineer and Project Manager

He graduated from a university in electronics engineering and worked with the company for more than seven years. He has been sent for training in Japan, Singapore, and the Netherlands several times. He has worked with many foreign customers including Japanese, Koreans, Singaporean, and European customers and has executed 12 DCS projects. He is an expert in DCS project management and designing DCS software, especially in chemical batch process and food process.

4. Mr. Suniboon, aged 25: System Engineer

He graduated from a university in control engineering and worked with the company for more than 3 years. He has been sent for DCS training in Japan for several months. He has executed 4 DCS projects as a system engineer designing the software application. He is very talented and he is an expert in DCS programming, especially in petrochemical process.

5. Ms. Sayamol, aged 26: System Engineer

She graduated from a university in control engineering and worked with the company for more than 4 years. She has been sent for DCS training in Singapore for several times. She is very good in DCS programming and has executed 5 DCS projects as a system engineer designing the software application. She is an expert in designing software, especially in chemical process and interlocking system.

4.3.3 The Process of Conducting the FMEA

The flowchart of the fourteen processes of the DCS project execution shown in the section 4.1 has been used during the FMEA meeting. Firstly, the flowchart was explained to the FMEA team in order to make sure that everyone had the same understanding about the project execution. Then the problems associated to each process were identified, understood, and discussed. The team began to collect the data of the failures in each process and categorised them appropriately. The form shown in the figure 2.4 (FMEA format) has been used. Note that the failures identified were the failure modes of the FMEA.

The failures collected from each process were then analysed using the brainstorming technique. The information gained from the analysis was used to fill in the columns of the FMEA form in the relationship of the effects of the failure and the existing controls. The level of Severity, Occurrence, and Detection of each process was also discussed. The number of Severity, Occurrence, and Detection of each process is resulted from the team judgement.

The results of the discussion for the evaluation criteria of the Severity, Occurrence, and Detection of the design and process FMEA are shown on the following two tables. Note that the ranking of 1 to 10 is used because it provides ease of interpretation, accuracy, and precision in the quantification of the ranking (Stamatis, 1995: 35).

The FMEA team quantifies the value of the Severity, Occurrence, and Detection of both the process FMEA and design FMEA. The priority of the problems is then articulated via the RPN (Risk Priority Number). This number is the product of the Severity (S), Occurrence (O), and Detection (D) ranking.

$$RPN = (S) X (O) X (D)$$

The RPN is a measure of process or design risk. This value is only used to rank order the concerns in the process and design of the DCS project execution. Note that this RPN will be between '1' and '1000' and all RPNs have no other value or meaning (Stamatis, 1995: 35).

The FMEA team has selected the threshold of the pursuing failures or problems based on the 90 percent confidence. This meant that 90 percent of all failures must be addressed for a very critical process and design on the guideline scale of 1 to 10. Since the maximum number possible for the RPN is 1000 (10X10X10 from occurrence, severity, and detection), ninety percent of 1000 is 900. Now subtract 1000-900 = 100. Therefore the threshold of examining the failures would be anything equal or greater than a 100 RPN. In other words, the RPN of problems which has the value greater than 100 must be addressed.

Rules to address to the problems are as following. The problem with high RPN will be addressed first. In case that there are more than two failures with the same RPN, then first address the failure with high severity, and then detection. Severity is approached first because it deals with the effects of the failure. Detection is used over the occurrence because it is customer dependent, which is more important than just the frequencies of the failure (Stamatis, 1995: 40).

Severity (S) Evaluation Criteria

Effect	Criteria	Ranking
Hazardous Effect	Hazardous effect. Safety-related -- sudden failure. Noncompliance with government regulation.	10
Serious Effect	Potential hazardous effect. Able to stop product without mishap; safety-related ; time-dependent failure. Disruption to subsequent process operations. Compliance with government regulation is in jeopardy.	9
Extreme Effect	Customer very dissatisfied. Extreme effect on process; equipment damaged. Product inoperable but safe. System inoperable.	8
Major Effect	Customer dissatisfied. Major effect on process; rework/repairs on part necessary. Product/process performance severely affected but functionable and safe. Subsystem inoperable.	7
Significant Effect	Customer experiences discomfort. Product/process performance degraded, but operable and safe. Nonvital part inoperable.	6
Moderate Effect	Customer experiences some dissatisfaction. Moderate effect on product/ process performance. Fault on nonvital part requires repair.	5
Minor Effect	Customer experiences minor nuisance. Minor effect on product/process performance. Fault does not require repair. Nonvital fault always noticed.	4
Slight Effect	Customer slightly annoyed. Slight effect on product or process performance. Nonvital fault noticed most of the time.	3
Very Slight Effect	Customer more likely will not notice the failure. Very slight effect on product/ process performance. Nonvital fault noticed sometimes.	2
No Effect	No effect on product or subsequent processes.	1

Occurrence (O) Evaluation Criteria

Occurrence	Criteria	Ranking
Almost Certain	Failure almost certain. History of failures exists from previous or similar designs.	10
Very High	Very high number of failures likely.	9
High	High number of failures likely.	8
Moderately High	Frequent high number of failures likely.	7
Medium	Moderate number of failures likely.	6
Low	Occasional number of failures likely.	5
Slight	Few failures likely.	4
Very Slight	Very few failures likely.	3
Remote	Rare number of failures likely.	2
Almost never	Failure unlikely. History shows no failures.	1

Detection (D) Evaluation Criteria

Occurrence	Criteria	Ranking
Almost Impossible	No known controls available to detect the failure.	10
Remote	Remote likelihood current controls will detect the failure.	9
Very Slight	Very slight likelihood current controls will detect the failure.	8
Slight	Slight likelihood current controls will detect the failure.	7
Low	Low likelihood current controls will detect the failure.	6
Medium	Medium likelihood current controls will detect the failure.	5
Moderately High	Moderately high likelihood current controls will detect the failure.	4
High	Good likelihood current controls will detect the failure.	3
Very High	Very high likelihood current controls will detect the failure.	2
Almost Certain	Current controls almost always will detect the failure. Reliable detection controls are known and used in similar processes.	1

Table 4.17 Evaluation Criteria Table for the Process FMEA

Severity (S) Evaluation Criteria

Effect	Criteria	Ranking
Hazardous without warning	Very high severity ranking when a potential failure mode affects safe DCS control operation and/or involves noncompliance with government regulation without warning.	10
Hazardous with warning	Very high severity ranking when a potential failure mode affects safe DCS control operation and/or involves noncompliance with government regulation with warning.	9
Very High	DCS control operation inoperable, with loss of primary function.	8
High	DCS control operation operable, but at reduced level of performance. Customer dissatisfied.	7
Moderate	DCS control operation operable, but comfort/convenience item(s) inoperable. Customer experiences discomfort.	6
Low	DCS control operation operable, but comfort/convenience item(s) operable at reduced level of performance. Customer experiences some dissatisfaction.	5
Very Low	Small item does not conform. Defect noticed by most customers.	4
Minor	Small item does not conform. Defect noticed by average customer.	3
Very Minor	Small item does not conform. Defect noticed by discriminating customer.	2
None	No effect.	1

Occurrence (O) Evaluation Criteria

Occurrence	Possible Failure Rates	Ranking
Very High:Failure is almost inevitable	> 1 in 2	10
	1 in 3	9
High:Repeated failures	1 in 8	8
	1in 20	7
Moderate: Occasional failures	1 in 80	6
	1 in 400	5
Low: Relatively few failures	1in 2,000	4
	1 in 15,000	3
Remote: Failure is unlikely	1 in 150,000	2
	< 1 in 1,500,000	1

Detection (D) Evaluation Criteria

Detection	Criteria	Ranking
Absolute Uncertainty	Design control will not and/or can not detect a potential cause/mechanism and subsequent failure mode; or there is no design control.	10
Very Remote	Very remote chance the design control will detect a potential cause/mechanism and subsequent failure mode	9
Remote	Remote chance the design control will detect a potential cause/mechanism and subsequent failure mode.	8
Very Low	Very low chance the design control will detect a potential cause/mechanism and subsequent failure mode.	7
Low	Low chance the design control will detect a potential cause/mechanism and subsequent failure mode.	6
Moderate	Moderate chance the design control will detect a potential cause/mechanism and subsequent failure mode.	5
Moderately High	Moderately high chance the design control will detect a potential cause/mechanism and subsequent failure mode.	4
High	High chance the design control will detect a potential cause/mechanism and subsequent failure mode.	3
Very High	Very high chance the design control will detect a potential cause/mechanism and subsequent failure mode.	2
Almost Certain	Design control will almost certainly detect a potential cause/mechanism and subsequent failure mode.	1

Table 4.18 Evaluation Criteria Table for the Design FMEA

4.3.4 Quantifying Severity, Occurrence, and Detection of Each Process

The FMEA team has quantified the severity, occurrence, and detection of each process of the DCS project execution based on the evaluation criteria table for both process and design FMEA shown on the table 4.17 and 4.18. Since there are many failure modes in the fourteen processes of the project execution, only two of them will be explained how the FMEA team could get the severity, occurrence, and detection value of the failure mode in the process being discussed. This is because the FMEA process to getting the S, O, and D values of the DCS project execution is the same.

4.3.4.1 Internal KOM with a Failure Mode: Deviation between the invitation to bid (ITB) and the contract is not discussed

In the internal kick off meeting process, one of the failure modes in this process is that the deviation between the ITB and the contract is not discussed. When the Company ABC awarded the contract, it is possible that there might be some differences between the scope of work of the company and the ITB. If the deviation between these two documents is not fully discussed and informed to the customer at the beginning of project, the consequence (potential effect) of this failure is that it will lead to the customer dissatisfaction when the customer finds the deviation by himself. Since the company will supply only the items that were specified in the contract, so the customer has to absorb the expenses of the deviation by himself.

The Company ABC has experienced with this kind of problem and the customer was very dissatisfied. The customer may not select the Company ABC again for his next DCS project. Therefore, the severity level is ranked to the score of 8. The score cannot be set to either 9 or 10 because this problem does not concern with the government regulation. Since there is no formal procedure to detect this failure from reoccurring, only few engineers who know this experience will check the deviation first. Therefore, the occurrence and detection level is ranked to the score of 9 (very high occurrence) and 10 (almost impossible), respectively. As a result, the RPN score is equal to 8 X 9 X 10 = 720, which is the highest RPN score because this failure will lead to company's loss order for the next DCS project.

4.3.4.2 Internal KOM with a Failure Mode: Verbal commitments are not fully discussed

During the sales negotiation before getting a DCS contract from the customer, sales staff may verbally commit to the customer that the Company ABC will supply some items (e.g. free one-year service support, warranty, training, or some engineering document), if the company awards the contract. If these verbal commitments are not fully discussed during the internal K.O.M., the project team does not know these commitments and does not supply them to the customer. This leads to the customer dissatisfaction. The consequence of this failure is that the customer experiences some dissatisfaction. However, after the customer informs the project team about the sales verbal commitment once again, the team will check with the sales staffs whether it is true or not. If it is true, the company always supplies the committed items to the customer. Therefore, the severity of this failure is at moderate level and is ranked to the score of 5.

Since the sales staffs do not take the commitments seriously, the sales staffs may forget to inform all of these commitments to the project team. Some of them are informed but some are not. Therefore, the occurrence is ranked to medium or the score of 6. For the existing process control, the company uses the internal K.O.M. review checklist but the checklist does not focus this matter clearly. The project team may get or may not get the commitment information from the sales staff. Therefore, the detection is ranked to medium or the score of 5. As a result, the RPN score is equal to 5 X 6 X 5 = 150.

Note that the RPN of the first failure is much higher than that of the second failure. This is because the first failure, if it occurs, will lead to the customer dissatisfaction and the customer has to absorb the deviation expenses. Consequently, the customer will not trust the Company ABC, and finally the Company ABC will lose order from this customer in the future. While the second failure, if it occurs, will lead to the customer dissatisfaction at a lower level. This is because the customer still can get the committed items at the project end with the expense of the Company ABC.

4.3.5 Results of Conducting the FMEA

Item	S/No.	Process	Potential Failure Mode	RPN
1	1.1	Job Request from Sales	Insufficient information receiving from sales	140
2	1.4	Internal KOM	Deviation bet. ITB and contract is not discussed	720
3	1.4	Internal KOM	Verbal commitments are not fully discussed	150
4	2.4	Review Data/Document after KOM	Failure to check the cust. data/doc completely	350
5	2.4	Review Data/Document after KOM	Not revise the project execution plan	300
6	3.2	Hardware spec design	Failure to finish the h/w spec design on time	210
7	3.6	Prepare document for h/w ordering	Send wrong format document to order handling	120
8	4.1	Tech. meeting (S/W Requirement)	Misunderstanding the cust. control concept	400
9	4.2	Software spec design	No relationship of switch used between pages	480
10	4.2	Software spec design	Command used in flowchart is machine code	560
11	4.2	Software spec design	Abbreviation used have no explanation	480
12	4.2	Software spec design	Inconsistency bet. s/w spec of each project	400
13	5.1	Software design	Poor software structure	420
14	5.1	Software design	Using wrong buffer for sending data	320
15	5.1	Software design	Not fulfil the customer's requirements	400
16	5.1	Software design	Customer changes the approved spec	400
17	5.2	Monitoring of the project	Poor monitoring	448
18	7.1	DCS software debugging	Not enough time to debug all software	392
19	8.1	Factory Acceptance Test	Failure to conduct the test to finish on time	108
20	8.1	Factory Acceptance Test	Incomplete software	336
21	9.2	Acceptance of H/W and S/W	Customer do not accept the h/w and s/w	560
22	10.1	Prepare DCS for delivery	Some h/w items are forgotten to deliver to site	120
23	10.1	Prepare DCS for delivery	Do not complete the FAT punch items	210

Table 4.19 High-Risk Areas of the DCS Project Execution

The results of conducting the FMEA are shown on the appendix II. There are two forms of the FMEA, the process FMEA and the design FMEA. Note that the FTA (Fault Tree Analysis) was also used during conducting the design FMEA of the software specification design and application software design. All failures resulted from the fault tree analysis are then recorded in the design FMEA form for analysing the cause of failure, and evaluating the severity, occurrence, detection, and the RPN value of each failure.

From the FMEA meeting, we can highlight the high-risk areas of the DCS project execution where its RPN is greater than 100 as shown on the above table. From the table, there are 23 items that the RPN of the process exceeds 100. These items are then ranked in order from the highest to the lowest as shown on the following figure. The internal KOM (S/No. is 1.4) has the highest risk and should be addressed first because it may lead to the high customer dissatisfaction. This means, the deviation between the ITB (Invitation To Bid) and the ABC contract should be discussed within the company prior to inform to the customer during the KOM. This is to ensure that the scope of work of ABC is clear before the project starts.

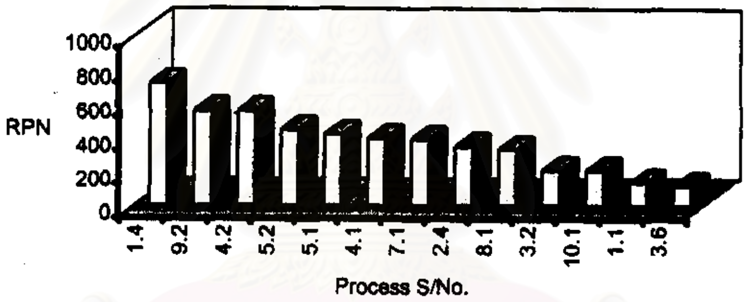


Figure 4.11 The RPN of the High-Risk Area Ranked in Order

After the discussion within the FMEA team, the recommended actions are set and recorded in the FMEA process and design form. The FMEA team concluded that the procedures of the DCS project execution must be improved. In addition, the tools and checklists to prevent errors in the processes should also be established. The table 4.20 illustrates the document and tool required. All documents to be established are shown on the appendix III and the detail of the Engineering Database Pool (EDP) for keeping database is shown on the appendix IV.

Item	Description	Process	FMEA*note	RPN
1	Job Request Form and Doc required (D1)	Job Request from Sales	P/1 of 16	140
2	Internal KOM Review Checklist (D2)	Internal KOM	P/2,3 of 16	720
3	Basic Design Review Checklist (D3)	Review Data/Doc after KOM	P/4 of 16	350
4	Walkthrough List Procedure and Form (D4)	KOM and H/W Spec Design	P/5 of 16	210
		S/W Spec Design	D/1 of 2	560
		DCS Software Design	D/2 of 2	420
		Generation and Debugging	P/12 of 16	392
5	H/W Spec Design Planning Sheet (D5)	H/W Spec Design	P/5 of 16	210
6	Input Engineering Doc Checklist for H/W Spec Design (D6)	H/W Spec Design	P/5 of 16	210
7	H/W Spec Design Review Checklist (D7)	H/W Spec Design	P/5 of 16	210
8	Ordering Procedure and List of Document Required (D8)	Prep Doc for H/W Ordering	P/7 of 16	120
9	S/W Spec Design Planning Sheet (D9)	S/W Spec Design	D/1 of 2	560
10	Input Engineering Doc Checklist for S/W Spec Design (D10)	S/W Spec Design	D/1 of 2	560
11	Standard S/W Spec for System Engineering Guideline (D11)	S/W Spec Design	D/1 of 2	560
12	S/W Spec Design Review Checklist (D12)	S/W Spec Design	D/1 of 2	560
13	S/W Design Planning Sheet (D13)	DCS Software Design	D/2 of 2	420
14	Input Engineering Doc Checklist for DCS S/W Design (D14)	DCS Software Design	D/2 of 2	420
15	Engineering Database Pool S/W for keeping database	DCS Software Design	D/2 of 2	420
16	Change Order Form (D15)	DCS Software Design	D/2 of 2	420
17	S/W Design Review Checklist (D16)	DCS Software Design	D/2 of 2	420
18	S/W Media Handling Procedure (D17)	Generation and Debugging	P/10-13of16	392
19	Punch List Form (D18)	Debugging	P/12 of 16	392
20	Debugging Review Checklist (D19)	Debugging	P/12-13of16	392
21	Punch List Form (D18) & Internal Inspection Records (D20)	Internal FAT	P/14 of 16	336
22	Punch List Form (D18)	FAT and Recovery Work	P/13-14of16	108
23	Certificate of the FAT Completion (D21)	Acceptance of H/W and S/W	P/14 of 16	560
24	Pre-Delivery Review Checklist (D22) and Final Save Procedure (D23)	Prepare DCS for Delivery	P/14 of 16	120
25	Document&Data Control System (D24), and Document Schedule (D25)	Overall Project	P/1-16of16 D/1-2of2	448
26	Example of Detail Project Schedule (D26)	Monitoring of the Project	P/9 of 16	448
27	Example of Project Progress Monthly Report (D27)	Monitoring of the Project	P/9 of 16	448
28	Notice of Job Milestone (D28)	Monitoring of the Project	P/9 of 16	448

Note: P = Process FMEA and D = Design FMEA
P/1 of 16 means Process FMEA reference page 1 of 16 in Appendix I
D/1 of 2 means Design FMEA reference page 1 of 2 in Appendix I
P/12-13of16 means Process FMEA reference page 12 and 13 in Appendix I

Table 4.20 Document and Tool Required for DCS Project Execution