KEY CONSIDERATIONS IN THE UPGRADE OF MEASUREMENT AND CONTROL SYSTEMS ON LEGACY ASSETS

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I would also like to acknowledge the patience of my wife Anna while I dedicated time to the work.

Abstract

Upgrades to legacy instrumentation and control systems provide operators with solutions to end of life problems and alignment with evolving mandatory compliances. Upgrades may enable further improvements such as centralized operations, expansion of the extent of automation and introduction of advanced process control.

Whilst ample discussion on the design and implementation of automation systems and related project management is available in trade books and journals, due to the complexity within the challenges that project teams face, the outcomes of upgrades often fall short of the expectation of successful implementation of a fit for purpose automation system.

This thesis firstly examines the vulnerabilities within a project organisation that have the potential to contribute towards negative outcomes, then develops additional tools and techniques to guide the decision making of the project team towards achieving desirable outcomes on future upgrades. These tools and techniques are then applied on a couple of small automation upgrade projects to examine their effectiveness and identify any areas for improvement.

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Chapter 1
Introduction

1.1 Objective

In the author's experience spanning 25 years it has become apparent that automation upgrades to legacy assets on brownfield projects can be blighted by poor performances. The objective within this thesis is to devise a means to guide the thinking within project teams towards achievement of a fit for purpose automation system delivered on time and within budget.

1.2 Background

Instrument and automation systems measure and control the process variables of pressure, temperature, level, flow, electrical energy and analytical values using a range of sensors, actuators and controllers and initiates alarms and trip actions on processes reaching an undesirable or dangerous state.

The ratio of manual to automated operation on a process facility is reflected in a statistic known as the extent of automation that has risen in stages over the last century from 0% to virtually 100%.

100 years ago measurement consisted of visual observation of the variables and control achieved typically by manually starting and stopping a pump or turning a hand valve. Thus, 100 years ago the extent of automation was close to 0%.

Today, process is measured and controlled via an automation system with minimal human intervention thus today the extent of automation is virtually 100%.

"*Over the years, automation technology has advanced along with various other technologies. The main driving and enabling technologies are information, communication, networking, and electronics* [14]"

The earlier automated measurement and control systems were fully pneumatic. This has changed with the introduction of electronic and digital instrumentation that now limited the application of pneumatics to final control elements.

Table 1 below summarizes evolution of automation over the past decades

1940 – 1960	Pneumatic
1960 – 2000	Analogue
1980 – 1990	Digital (Proprietary Protocols)
2000 onward	Digital (Open (Protocols)

Table 1

Source: Erickson [1]

The evolution of instrument and automation systems exerts an influence over stakeholders to initiate projects that will increase the extent of automation and upgrade existing systems. Thus, evolving technologies, changing market environment and new regulatory compliances will combine to place challenges on engineers and project managers in the actions of performing the design, installation and commissioning of instrument upgrades and in the risk management of the change out between the old and new systems.

1.3 Purpose of the Study

The purpose of the study is to analyze the causes of historic poor performances on upgrades, then from the causal factors develop techniques that will guide the thinking within present day project teams towards better outcomes.

1.4 Research Plan

1.4.1 Overview

"*Research Approaches are plans and the procedures for research that span the steps from broad assumptions to detailed methods of data collection, analysis and interpretation* [10]" The Research Approach or Plan embraces three components of Philosophical Worldview, Designs and Research Methods as presented in Fig. 1 below.

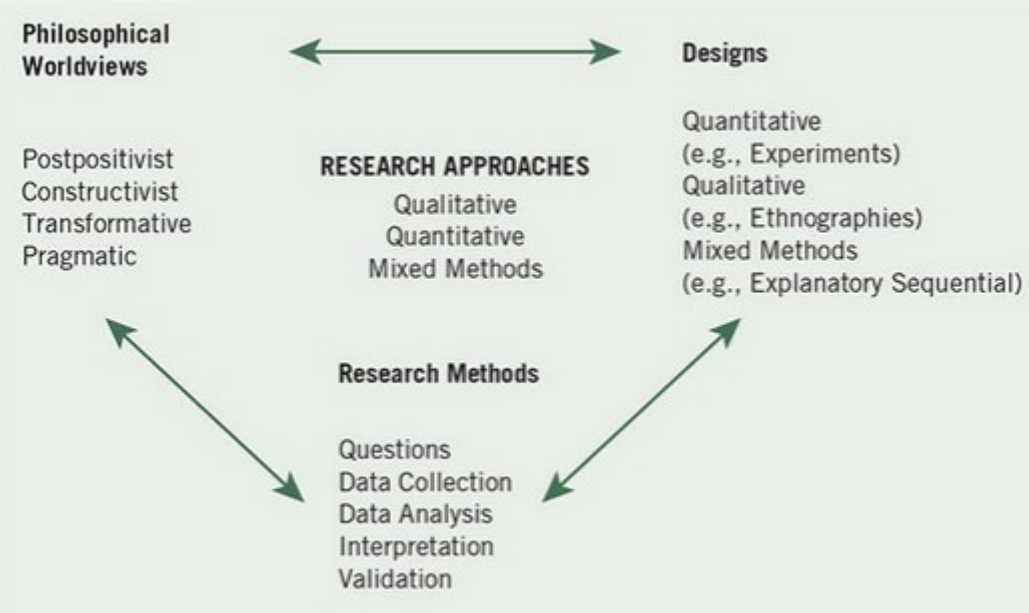


Fig 1: Research Framework

Source: J W Cresswell and J D Cresswell [10]

1.4.2 Worldview

Worldview is a basic set of beliefs of ideas that guide action and the type of belief held by an individual researcher will lead to the choice between a qualitative, quantitative or mixed methods approach. There are four worldview categories of post positivist, constructivist, transformative and pragmatic.

Of the four worldview categories, the required research aligns largely with that of a pragmatic approach with its tendency towards a mixture of qualitative and quantitative methods. Pragmatists are not committed to any one particular philosophy whereby "*instead of focussing on methods, researchers emphasize the research problem and question all approaches required to understand the problem* [10]"

Application of the qualitative and quantitative components are discussed in 1.4.2 and 1.4.3.

1.4.3 Qualitative Research

Qualitative research involves "*data typically collected in the participant's setting, data analysis inductively building from particulars to general themes, and the researcher making*

interpretations of the meaning of the data [10]" Application of qualitative research within this thesis is directed towards investigating the vulnerabilities present within project organizations on brownfield automation upgrades thus to establish the relationships between causal factors and negative outcomes.

Review of some case studies in automation upgrades to oil and gas assets will provide an understanding of the planning, design and implementation for automation upgrades. A swimlane diagram developed from the case studies will provide an overview model of the sequenced activities and communication between the participants in a typical upgrade thus offering, a means to identify potential vulnerabilities in the project organization. This will provide focus for qualitative data collection and root cause analyses that will offer the research a set of causal factors related to underperformances.

1.4.4 Quantitative Research

Quantitative Research is "*an approach for testing objective theories* [10]" with a written report that has "*a set structure consisting of introduction, literature and theory, methods, results and discussion* [10]".

Further analysis with quantitative techniques will provide a means to prioritize the causal factors in terms of the actual levels of impact any of these may have on project outcomes. Setting a threshold between tolerable and unacceptable levels will differentiate between those factors that may just require monitoring and those that require mitigation.

The research will finally develop the tools to exert mitigation where this is required. The tools will then be validated by application on two live automation projects thus to conclude the research.

1.4.5 Method

Research methods fall into the categories of questions, data collection, data analysis, interpretation and validation.

A model of the intended approach developed for this thesis is presented in Fig 2 below.

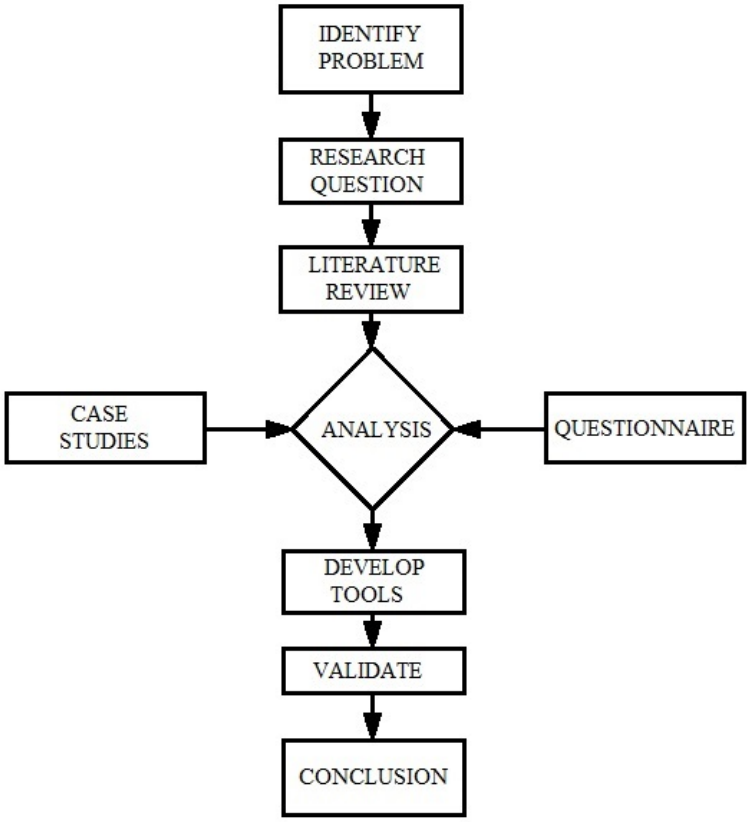


Fig 2: Research Model

The research is directed towards collection of raw data from projects, analysis of identified problems and their causal factors, arrival at theories intended to improved outcomes on future projects then proof testing these on live automation projects.

The Research Plan will be comprised of the following.

a) A literature review to establish a model for design, management and implementation of automation upgrades, and to identify the relevant research tools for data collection and analysis.

b) Case studies of 3 historic projects leading to development of a swimlane diagram for a typical automation upgrade.

c) Use of CATWOE to categorize the data to be collected for RCA Analyses.

d) Collection of data via a questionnaire circulated to participants on automation upgrades.

e) Root Cause Analysis (RCA) to identify Causal Factors linked to underperformances.

f) Grading of the causal factors to determine the extent of mitigation required.

1.4.6 Research Question

Within an automation project group, what are the underlying relationships between vulnerabilities and poor outcomes?

1.4.7 Deliverable

The output deliverable is a set of heuristic tools that will be discussed and presented in Chapter 6 of this thesis. These are intended to guide the decision-making processes of the project teams and stakeholders towards optimal outcomes.

The tools may be mind maps, procedures, workflows, checklists or a combination of these.

1.4.8 Validation

Innovation can sometimes be called for during the course of a project to manage a unique situation for which no method or procedure exists. From the audit trail of the event, a potential Best Practice may become apparent at the debrief. Following initial validation of this by the project manager, it would be forwarded to the Project Management Office (PMO) for further validation and eventual institutionalization as an established Best Practice.

Alternatively, the Project Manager might be excluded from the decision making process where the organization may prefer for the entire matter to be handled by the corporate PMO. "*Companies that have a PMO place a heavy reliance on the PMO for support because the approved best practices are later incorporated into the methodology, and the PMO is usually the custodian of the methodology* [11]" The PMO may then choose to engage a change management team or other entity to convene and participate in the debrief.

The objective within the validation is to determine, from practical implementation, if the mind tools are fit for purpose and for possible consideration as a new Best Practice. The

heuristic tools developed within the research are to be applied and tested on a couple of live automation projects that will test the robustness of the deliverable. The exercises will be discussed and implemented in Chapter 7 of the thesis.

Chapter 2
Literature Review

2.1 Introduction

The Literature Review will be split into three topics focusing on the Research Question in 1.4.6 “Within an automation project group, what are the underlying relationships between vulnerabilities and poor outcomes?”

The three topics are as follows.

(i) Research into best practice in design and engineering of industrial automation systems.

(ii) Research into best practice in project and operations management.

(iii) Data collection and analysis techniques to be employed within the research.

In researching available literature in journals, the author discovered there was little information that specifically discusses the poor outcomes in upgrade projects. In order to address the gap, in the next chapter the author presents three case studies of automation upgrades with information drawn in conversation with industry experts through professional engagement on projects.

2.2 Design and Engineering of Automation Upgrades

As presented in Fig 2 below, a typical automation project is planned into 8 phases starting with planning and finishing with start-up and handover, and the training of operations and maintenance personnel.

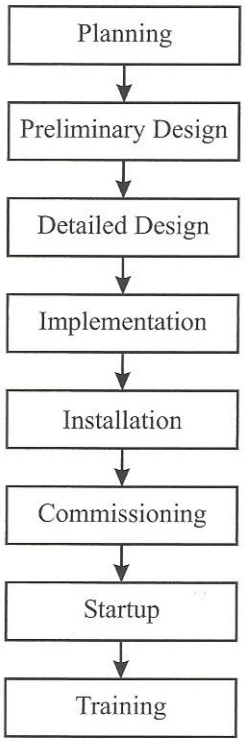


Fig 3 Automation Project Phases

Source: Erickson [1]

In Fig 3 above, the project phases are shown in the order in which dependencies occur. Whilst appearing discrete, actual industry experience indicates that phases may overlap somewhat.

This thesis focusses specifically on 'brownfield' projects, reflecting on automation upgrades as opposed to 'greenfield' projects for entirely new installations.

A good understanding is nevertheless required of the full design process as the analysis of the vulnerabilities may look both into the design of the legacy asset and into that of the upgrade.

The project phases are discussed in 2.2.1 to 2.2.8.

2.2.1 *Planning*

At the planning phase, the project requirements are defined and the resources required are estimated. The estimate at this stage will be rough, sometimes referred to as the Rough Order of Cost (ROC). Stakeholders will be required to give their approval to the ROC and

make provision for the strategic funding required that will enable the subsequent project phases.

Once stakeholder approval is given, the project moves into the preliminary design phase.

2.2.1 Preliminary Design

Within the preliminary design phase, the automation engineer contributes towards the following activities..

- Develop process operating description (POD).
- Develop the control concept.
- Define the preliminary automation and control strategy.
- Define the preliminary system architecture.
- Prepare the preliminary control technology budget

Source: Erickson [1]

The preliminary design is produced by process discipline engineers with support from piping, instrument, vessels, mechanical and electrical disciplines. The Process Engineer defines the process and operating parameters including major underlying control philosophy for the process to function.

The philosophy is to some extent represented on the Piping and Instrument Diagram (P&ID). The Automation Engineer will read this in conjunction with other philosophy documents, e.g. Cause & Effect diagrams, to fully understand the parameters from which to correctly specify the automation system and field devices.

Fig 4 below presents a typical P&ID sheet for part of a multi-stage compressor. *"The three major equipments are V-230A Third Stage Suction Scrubber, C-235 Third Stage Compressor, E-236A Third Stage Discharge Cooler* [11]. Key design attributes for vessels and rotating equipment are tabulated on the P&ID. Piping line numbers are shown coded with service, line size and material specifications. Instrumentation is represented with ISA symbology and tag numbers.

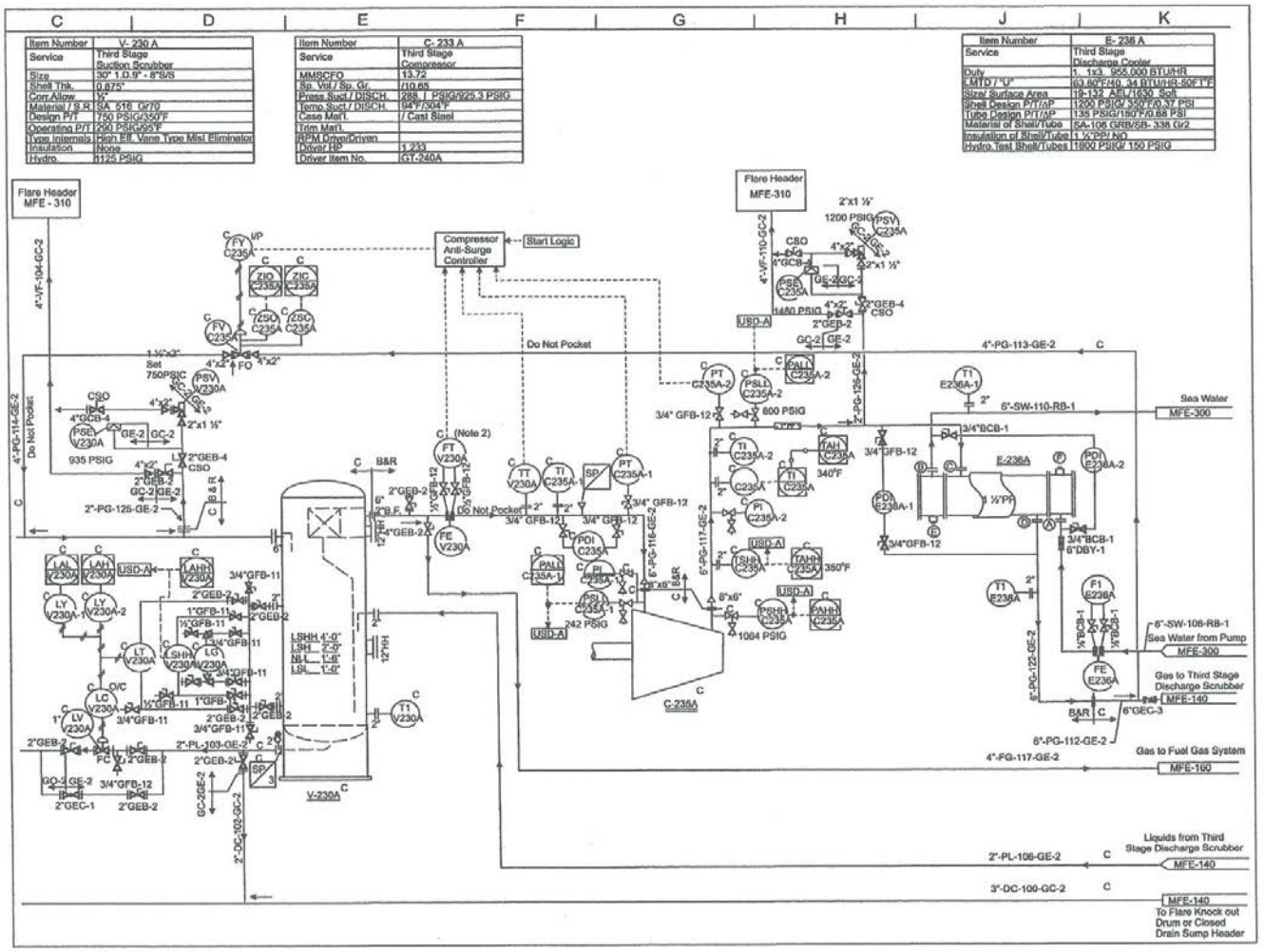


Fig 4: Piping and Instrument Diagram (P&ID)

Source: Nandagopal [13]

At the preliminary design phase, some research needs to be taken up with automation system vendors to refine the user requirements "*To learn more about the available technologies, the best place to start would be to discuss applications with a manufacturer's salesperson* [14]" One significant recent development in the design of automation systems is the emergence of integrated safety and process control systems replacing the more traditional BPCS and SIS systems. "*In integrated safety systems, the controller and safety network architecture operate within a single CPU to manage both control and non-safety functions* [14]" Thus the components are all converged onto a single backplane "*The CPU for safety and the CPU for control are on the same backplane – within the controller* [14]"

There is usually some time lag between the development of innovative designs and the evolution of standards that would permit their application in industry. When making initial enquiries to automation vendors users can nevertheless benefit from an awareness of future trends from discussion with vendors.

2.2.2 Detailed Design

"*The detailed design phase requires many times the effort spent in preliminary design* [1]".

The design team will be expanded at the transition between the two design phases that may of necessity overlap due to the dependency on the additional expertise for conclusion of the preliminary design.

Detail design involves development of functional specifications that will provide inputs to the implementation.

The detail design phase develops the following

- Measurement and final control functional specifications
- Safety instrumented system functional specification
- Discrete and regulatory control functional specification

- Procedural Control functional specification
- Process information data models
- User interface functional specifications

Source: Erickson [1]

In additional to writing functional specifications, detail design also embraces production of design deliverables, typically

Loop Diagrams

Electrical Schematics

Panel Layouts

Sequence Control Description

Graphical User Interface (GUI) Description

Implementation Standards

Source: Erickson [1]

Process information data models provide the information to enable the instrument engineer to produce instrument data sheets with instrument ranges, wetted materials, control valves body size, rating and material, trim type and materials. The data sheets are attached to tendering documentation and are finalized on close out of vendor selection following bid appraisals.

A large proportion of the detail design will be production of multi-sheet drawings and schedules. The repetitive format of these lends itself to the creation of master templates with fields to be auto-populated with attributes extracted from spreadsheets created for such

purpose. The attributes represent information such as the numbering of field junction boxes, equipment room marsalling cabinets, cables, terminals, cores and the rack / bin / slot numbers of I/O interfaces, etc., required for I/O lists, termination diagrams and loop drawings, etc. "*Three worksheets provide an ordered list of all homerun wire pairs, I/O channels, and IT MUX channels. Every possible pair of wires in all of the homerun cables is listed in the Instrument Junction Box (IJB) worksheet. The IOP worksheet lists every input / output channel, while the MUX Worksheet lists every TI multiplexer channel* [12]"

2.2.3 Implementation

The functional specifications and implementation standards produced within the detailed design provide key inputs to the actions performed by system specialists engaged in the implementation of the automation system. Other drawings and schedules, e.g. cable schedules, control room general arrangements, etc. produced by the design team will provide further input to the vendor package design. P&IDs can be used as feed for producing the HMI graphics.

Implementation first requires procurement of the measurement and control hardware, the related software and also procurement of services to configure logic, PID and advanced process control algorithms, graphics, alarms, any other HMI interfaces, data communications, etc.

Firmware will be constructed and the software loaded and programmed. Often at this stage the equipment may be set up at the fabrication facility with temporary power and system cabling interconnecting the components to enable configuration and testing. These actions are concluded with a client witnessed Factory Acceptance Test (FAT) to an approved test procedure before release for shipment to the jobsite.

An automation upgrade may involve interfacing a new automation system with a mixture of new and legacy field instrument devices from different eras and over a variety of communication architectures. *"Whether it is a "smart" temperature transmitter, a panel-mounted process controller with Ethernet communication capability, a variable-speed electric motor drive with Modbus signalling, a large-scale DCS controlling an oil refinery, or a SCADA system monitoring a power distribution system spanning across national borders, digital measurement and communication is an essential part of modern measurement and control systems* [3]"

A typical DCS architecture in Fig 5 below provides some indication of the diversity that can exist between networked components and communications. The architecture diagram contains two local areas each represented by a dashed line boundary. In the upper diagram components are networked with a common local area network (LAN). In the lower diagram there are three LANS.

The common LAN in the upper box communicates with the three discrete LANs in the lower box over the wide area network (WAN) via network hubs.

Field devices communicate with field control units (FCU) and Scada Data Servers via local fieldbus. Some devices may communicate directly with the fieldbus whereas others may only communicate via I/O modules.

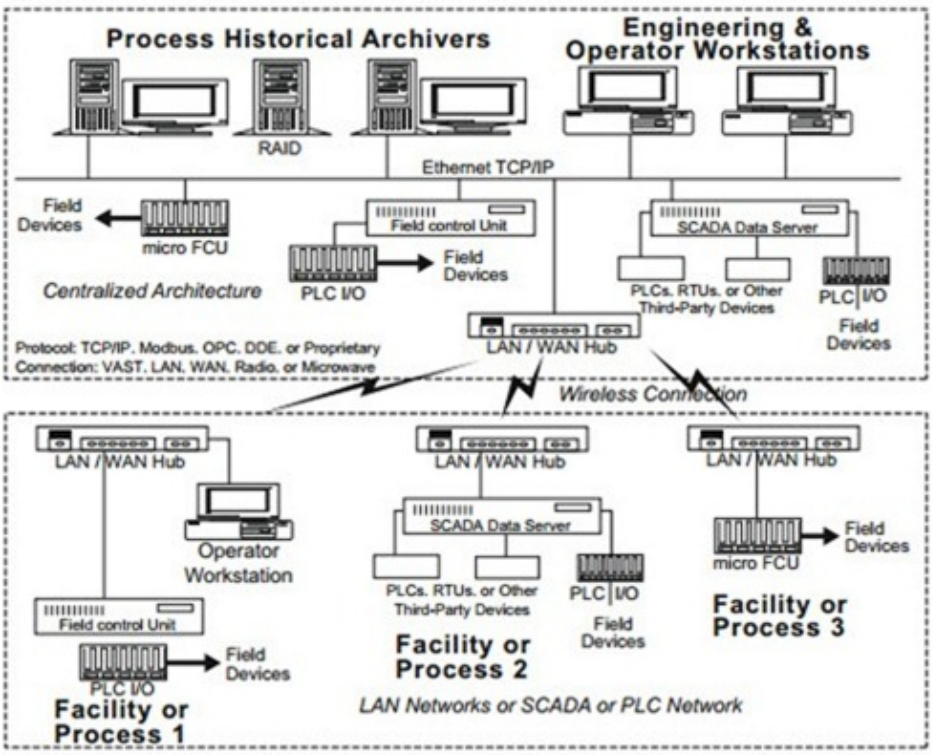


FIGURE 1.13

Distributed control system architecture.

(Courtesy of Control Systems International, Inc.)

Fig 5: Typical DCS architecture

Source: Hudedmani, Kaberalli, Hittalamani (2017) [7]

2.2.4 Installation

Installation requires location of the equipment in the control and equipment rooms and, where appropriate, in field enclosures. A Site Acceptance Test (SAT) with the equipment powered up will confirm that no damage has occurred during transportation and installation.

All field devices, junction boxes, marshalling cabinets and cabling needs to be installed, inspected and tested using an inspection and test and plan within a quality management system approved by the stakeholders. The completed test and inspection forms are included within the handover documentation at the end of the project.

Once the system is powered and operational, each instrument loop will be tested in turn as part of the pre-commissioning tests.

2.2.5 Commissioning

Each plant system will be brought on line often using water as a test fluid before live process fluids are introduced. Water testing enables safe testing of the measurement and control systems.

On completion of all activities the design package is revised to reflect all changes and is issued ‘as built’ within the handover documentation.

2.2.6 Start Up

Once the commissioning team has demonstrated the control requirements are met the system is purged of test fluids and is ready for live operation. During this phase, the operations team can take ownership while the commissioning team partially demobilizes

leaving a core team to monitor performance and operation and to deal with any lingering issues.

The project team will deliver to the operations group manuals fully updated with vendor product information and certificates, as built drawings and schedules, test and inspection records, etc.

2.2.7 Training

"*During the latter stages of the implementation activity, training of the plant personnel that must use the system should start* [1]". Training may actually extend beyond the end of the project as further operations and maintenance personnel are recruited into the organization.

2.3 Project Management

2.3.1 Project Management

"*Most experienced project management practitioners know there is no single way to manage a project* [2]"

The Project Integration Management model presented in Fig 6 below provides an overview of project management processes. The project management team needs to select the processes relevant to the automation upgrade project.

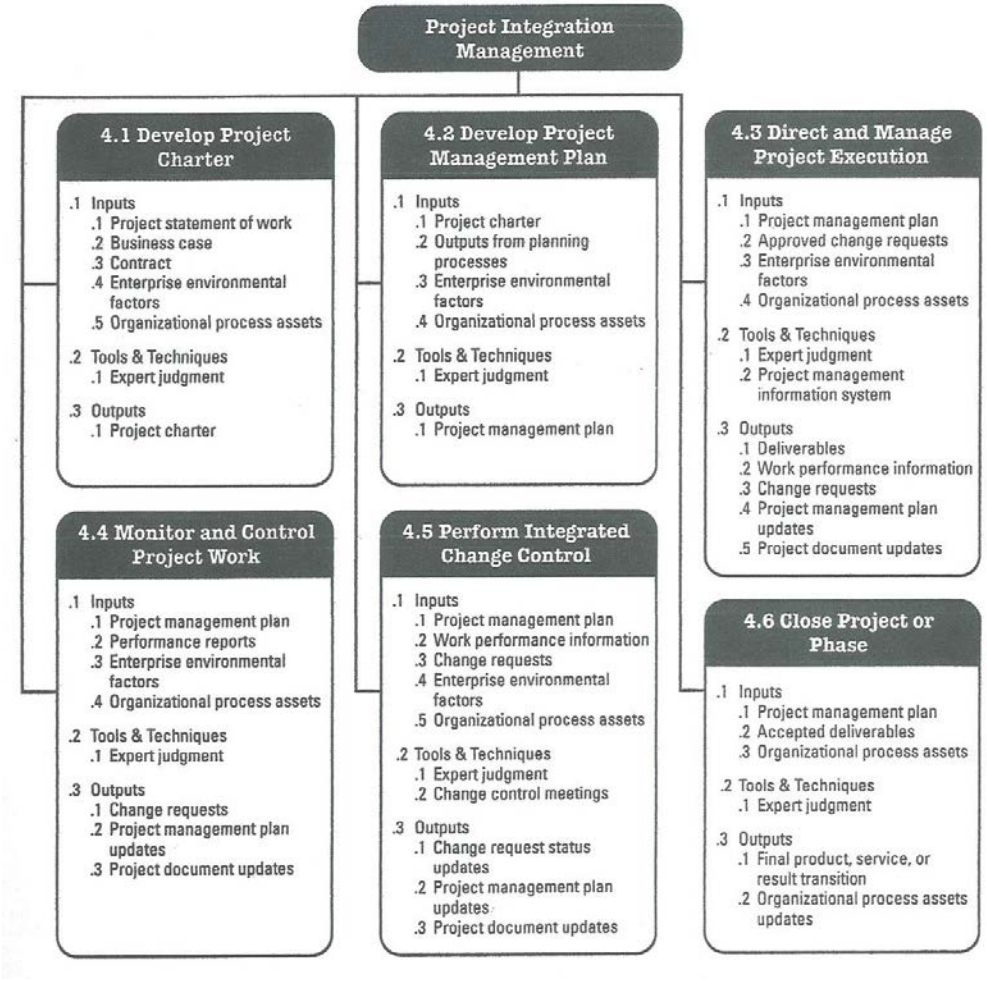


Fig 6: Project Integration Management Overview

Source: PMBOK [2]

Effective communication between the project management team and the discipline specialists representing design, procurement, installation and commissioning ensures overall synthesis for productive outcomes.

2.3.2 Management of Change

An automation upgrade is likely to encounter challenges arising from lack of information, lack of clear definition of stakeholder requirements and the need to research solutions. The outcome of these and other challenges can lead to changes in scope, schedule or cost that need to be managed within a robust change procedure.

A management of change (MOC) procedure will perform the following:

- Manage each change request from initiation through to closure.
- Process change requests based upon direction from the appropriate authority.
- Communicate the impact of changes to appropriate personnel.
- Allow small changes to be managed with a minimum of overhead.

Source: www.projectmanagement.com [8]

The MOC process thus ensures full accountability within a clear audit trail.

2.3.3 Document Control

Successful outcomes on automation projects rely heavily on good management of documents both in the operator's technical library and in the project team's document control. Drawings and schedules on legacy assets can often be incorrect even without the owner's knowledge so it is important to identify any such deficiencies and manage the associated risks on the upgrade project.

An extensive upgrade can often result in a complete change out of design documentation so, with the application of best practice in the quality management of project documentation, a solution to the previous poor records will be embedded within the handover manuals.

2.4 Data Collection and Analysis

2.4.1 Causal Factors Overview

The methods involve collection of data categorized within CATWOE to provide inputs to Root Cause Analysis.

2.4.2 Root Cause Analysis - RCA

The stakeholder's requirement for a fit for purpose automation system can be hindered by problems. A Root Cause Analysis (RCA) provides a clear statement of a problem to be solved together with its causal factors.

2.4.3 CATWOE

"CATWOE is an acronym that stands for the categories of Client, Actors, Transformation Processes, Owner, Environment. CATWOE Analysis is a method of problem solving that asks you to look at an issue from six unique perspectives. This in-depth approach requires that you think about any given problem in a variety of ways, and you will find that you have a better understanding and appreciation for the issue after you do so [6]"

Categorization in CATWOE thus provides a logical framework for the collection and manipulation of the data within the RCA.

The categories relating to an automation upgrade are discussed in 2.4.4 to 2.4.9.

2.4.4 Client

A typical client may be a petroleum and natural gas producer with global interests. Core activities would be exploration, production, refining, chemicals, distribution and marketing. Typical products would include fuels, lubrication oils, bitumen, tar and fuel gas.

2.4.5 Actors

On an automation upgrade, the actors will be employees and / or contractors performing the activities in Table 2 below.

Project management team	A small team of key personnel supplied by EPC contractor
Design Engineers	Specialist personnel employed to generate drawings, schedules and data sheets
DCS and PLC specialists	Specialists provided to the project by system vendors to perform implementation and give field support.
Field Engineering Team	Field engineering is a subset of the design engineering.
Construction Team	Specialist resources supplied by EPC contractor
Commissioning Team	Specialist resources supplied by EPC contractor
Client Project Team	A team engaged to monitor progress, resolve interface and communicate.

Table 2: Actors

2.4.6 Transformation Processes

Transformation Processes are broken into Inputs, Transformation and Outputs.

Planning	Inputs:	Knowledge from plant operations and multidiscipline project engineers
	Process:	Collect Requirements and estimate resources
	Outputs:	First draft of project requirements and rough estimate or resources
Preliminary Design	Inputs:	Initial research, specialist knowledge, assumptions
	Process:	Evaluate feasibility of upgrade options then finalize the preliminary design
	Outputs:	Process Operation Description, Control Concept, Automation & Control Strategy and Preliminary System Architecture
Detail Design	Inputs:	Preliminary Design, surveys, records searches
	Process:	Perform calculations, design drafting and record key data in required format.
	Outputs:	Functional specifications for the automation system. Data sheets for field devices (instruments and control valves, etc.). Drawings and schedules for construction and commissioning.

Implementation	Inputs:	Detail design and automation specialists
	Process:	Set up system, power up, test software and data communications, build graphics, configure logic and PID algorithms, perform Factory Acceptance Test (FAT). Share knowledge with detail design team.
	Outputs:	Firmware and software with documentation
Installation	Inputs:	Firmware and software with documentation, installation drawings, installation team.
	Process:	Equipment installation with power and system cables, powering up, Site Acceptance Test (SAT), installation of field cables and loop testing
	Outputs:	Fully tested automation system
Commissioning	Inputs:	Fully tested automation system
	Process:	Test operation with inert process fluid
	Outputs:	System ready for operation
Start Up	Inputs:	System ready for operation, operations team, residual commissioning team members
	Process:	Operate and monitor system
	Outputs:	Full handover to operations

Training	Inputs:	Learning and development plans
	Process:	Demonstrations and practical training
	Outputs:	Knowledge

Table 3: Transformation Processes

2.4.7 World View

The world view is reflected in an organization's strategic plan normally with a 5-year horizon and to some extent on the operation plan over the next 12 months. The investment decision will be heavily dependent upon these plans.

2.4.8 Owner

The owner is the manager or the investor in the project. On an oil and gas project the owner might typically be an individual operator or a consortium.

2.4.9 Environment

A policy giving due consideration to health, safety and the environment must exert control over the works at the operator's facility. Operators will normally have own libraries of corporate HSE policies, procedures and workflows.

2.4.10 Design Attributes

The research provides a focus on development of key attributes to address the Research Question in 1.4.6 "Within an automation project group, what are the underlying relationships between vulnerabilities and poor outcomes?". The research will lead to the development of the heuristic tools in Chapter 5 of this thesis.

2.4.11 The 5 Whys

The "5 Whys" is a technique that was developed for use in the analysis phase of the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) methodology.

"5 Whys typically refers to the practice of asking, five times, why the failure has occurred in order to get to the root cause(s) of the problem [4]"

The layers of symptoms are thus peeled away at the lead until the root cause of the problem is identified.

Fishbone Diagram

Fig 7 below presents a typical diagram.

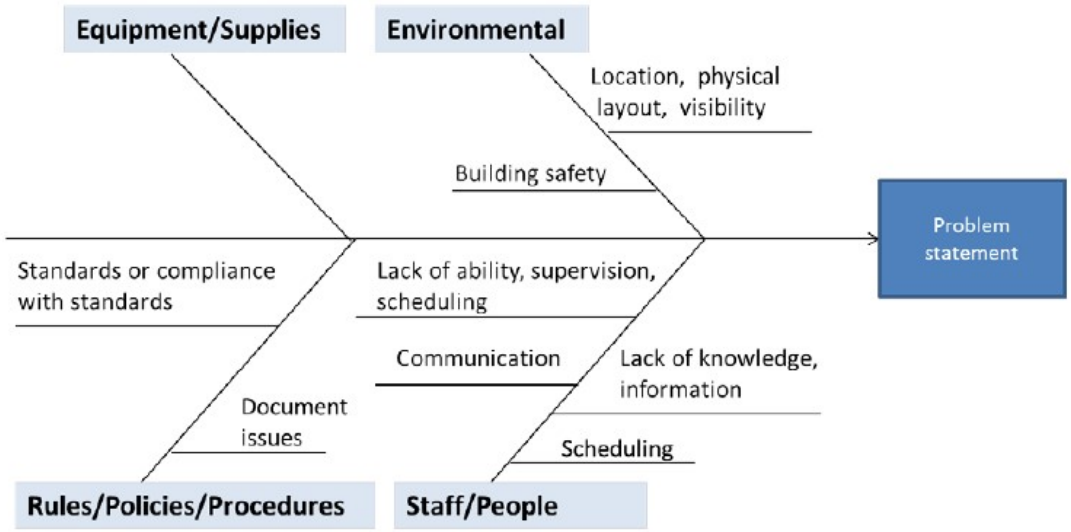


Fig 7: Fishbone Diagram

Source: www.cms.gov/medicare [9]

The problem statement is written at the head of the 'fish' with the main categories of causes as branches from the main arrow. In the example shown the four main categories giving rise to the problem statement are Equipment / Supplies, Environmental, Rules / Policies / Procedures and Staff / People with sub-categories within them.

a) Equipment / Supplies
b) Environmental
c) Rules / Policies / Procedures
d) Staff / People

Causal factors are identified by repeatedly asking the question "why does this happen" (i.e. The 5 Whys). The ideas thus generated are each given as a branch from the main category.

In the diagram it can be seen that within the category of Staff & People there are sub-categories of

a) Scheduling

b) Communication

within which the causal factors towards the problem statement are

a) Lack of ability, supervision, scheduling
b) Lack of knowledge, information

By continuing to ask the question ‘why’ deeper levels of causes can be identified and mapped into fishbone diagrams thus to provide a clear understanding of the root causes of problems.

2.4.12 Preventative Techniques

RCA can be used proactively to develop preventative techniques simply by tabulating the causal factors identified, estimating their severity and look for appropriate ways to mitigate them.

2.4.13 The Development Plan

The need for preventative techniques will develop the design of the heuristic tools that will provide the thinking framework for design and management of automation projects.

2.5 Summary

In Chapter Two literature was researched in order to establish conceptual models in engineering and project management relevant to the Research Question in 1.4.6 “Within an automation project group, what are the underlying relationships between vulnerabilities and poor outcomes?”. Data collection and analysis techniques were then discussed to identify those that are relevant to development of the heuristic tools that will be the deliverable from the research.

In the next chapter three case studies will be discussed to provide an illustration of typical good and bad scenarios that may occur on automation upgrades.

Chapter 3
Case Studies

3.1 Introduction

In the previous chapter, the literature review researched design, engineering and project management of instrument upgrades to legacy oil and gas assets.

In this chapter discussion of three historic upgrade projects performed in various environments that will provide some understanding of the opportunities available to the operators and of the challenges to project teams.

In order to protect the identity of the stakeholders and actors the names of the projects are masked, however the author authorizes EIT to provide contact details should the examiner require further information.

The three case studies are as follows

1) CASE STUDY ONE: A site wide automation and safety system upgrade to an oil refinery in Central Asia.

2) CASE STUDY TWO: A site wide automation and safety system upgrade to a cryogenic LNG liquefaction unit in Africa.

3) CASE STUDY THREE: An automation and safety system upgrade to a cracking complex on an oil refinery in Europe.

3.2 Case Study One

3.2.1 Background

The key stakeholder is a large producer of petroleum, natural gas and other chemicals based in Central Asia.

3.2.2 The Facility

A refinery in Central Asia producing 100,000 to 150,000 bbl. of product.

3.2.3 Initial Scope

The objective of the upgrade project was to migrate the operator interfaces from control panels to visual display screens and keyboards.

This involved introduction of a new DCS system replacing the panel front indicators, controllers, recorders, annunciators, graphics, etc. and a triple redundant ESD systems replacing relay logic with a reliable, robust shutdown system

Legacy pneumatic instruments were replaced with electronic instruments mostly compatible with the 4-20 analogue signal range into I/O modules installed locally in the field that communicated with the DCS via the fieldbus.

3.2.4 The Positive Outcomes

On handover of the project to operations, the DCS system immediately enabled centralization of operations into a single control building. The project also enables opportunities for improvements in process control, one such being the introduction of Multivariable Control (MVC).

Multivariable Control (MVC) is a subset of Advanced Process Control (APC) that can be used to improve control processes whereby instability occurs between processes currently

controlled with single PID controls each with a single input and single output (SISO) configuration. MVC replaces multiple PID control loops with a multiple input multiple output (MIMO) controller within which a more complex control algorithm writes outputs each based on more than just one input variable. Savings of up to $5 million per year may be achieved with closer control of the process.

3.2.5 Project Risk

In order to design an upgrade to an existing facility, an accurate picture of the existing situation must be made known. A heavy dependency on a small field engineering team to perform records searches and surveys was required. The constraint in doing this was in mobilizing a team with the required competencies into a hardship location and in managing the communications.

3.3 Case Study Two

3.3.1 Background

The key stakeholder is a major LNG producer based in Africa that exploits reserves of natural gas that are compressed, chilled and liquefied for transportation by sea to overseas clients

3.3.2 The Facility

The automation upgrade was part of a total renovation and upgrade of the gas compression and liquefaction facility involving all disciplines. The automation scope was to introduce a DCS system to replace pneumatic control room installation with a DCS system and to establish interfaces with new and existing field instrumentation.

3.3.3 Initial Scope

The automation scope included introduction of a DCS system to replace legacy pneumatic instrumentation and a safety PLC to replace hardwired relay logic.

When introducing a new concept, one of the key challenges is to overcome resistance to change. In order to transition the change of operator interface in acceptable stages from legacy control panel instrumentation to the real time displays and keyboard controls in the DCS, the DCS conversion was initially only partial, with the DCS system used only for indication while the legacy pneumatic panel controllers were retained in service then gradually cutting over to DCS control.

During the design phase, the design team was split into two groups which were a site-based field engineering team and an office-based engineering team of design engineers in Europe. The field team performed record searches and field surveys at the facility thus to provide designers and engineers in Europe with information to perform the detail design.

Most of the existing legacy field devices were in poor condition. Decisions based on the reporting were made by the engineering team in Europe to purchase either spare parts kits or replacement instruments.

3.3.4 The Positive Outcomes

User resistance to change was quickly overcome and a full change out to DCS from the pneumatic panel instrumentation was implemented.

3.3.5 Project Risk

Design scope required records searches in the client technical library with surveys to validate the extracted information. Whilst this was a fairly successful measure, the condition and reparability of control valves and other in-line devices could not be assessed from visual surveys leading to assumptions and thus risks in the design process.

3.4 Case Study Three

3.4.1 Background

The key stakeholder was a large oil and gas producer with worldwide interests.

3.4.2 The Facility

The cracking complex forming part of a large oil refinery in Western Europe

3.4.3 Initial Scope

The scope was conversion of Cracking Complex area control rooms containing legacy electronic panel instrumentation and obsolete logic panels to DCS control and PLC shutdown systems.

3.4.4 The Positive Outcomes

The project was largely successful, resulting in a full upgrade of control room instrumentation with improved reliability, diagnostics and operator interfaces together with a robust PLC system for safety trips and interlocks.

The cost of the project was minimized by assembling a project team from in house resources adequately knowledgeable to perform most of the design and installation work. Initial assembly of the DCS system and powering up with sustained performance testing was performed by the DCS vendor. The majority of the remaining implementation, typically configuration of field bus inputs, PID algorithms, design of graphics, etc. was performed in house by systems specialists with vendor product specific training.

As a result of lack of control and methodology over modifications, existing records at the refinery were poor so before any project design work could be undertaken the existing record drawings had first to be updated to as built. All classes of drawings including P&IDs, Cause

& Effects together with wiring and loop diagrams had to be as built to the best extent possible from surveys and any information gaps requiring further actions identified.

The upgrade was a key enabling feature for a subsequent refinery wide project to relocate all operations into a Central Control Building thus bringing all operations personnel into a single central control building in a safe location.

3.4.5 Project Risk

Whilst the base scope was very well planned and successfully implemented, risk emanated from scope creep that allowed insufficient time for extra work to be completed within the constraints of two planned turnarounds. Lingering issues post-handover to operations became an undesirable outcome.

Chapter 4
Data Collection and Analysis

4.1 Introduction

In this section, a root cause analysis will be performed on the case study projects. The outcomes are derived largely from experience.

The intention within the research is to discuss and analyze the outcomes, establish the likely root causes of failures. From the analysis a set of theoretical heuristics will be developed then tested on

Step One is to produce a swimlane diagram for a typical automation upgrade to an oil and gas asset with guidance extracted from the literature review and case studies in Sections 2 & 3.

Step Two is to examine the swimlane diagram looking for potential vulnerabilities within the communications and interactions between the various actors involved in the management, design and implementation of the typical upgrade.

Step Three is to identify causal factors for which the data must be collected and analyzed thus to have a better understanding of the root causes of project failures. These actions are data collection in CATWOE followed by GAP analyses in 4.1 to 4.2.

Step Four is to perform the Root Cause Analyses (RCA) to clearly link the negative outcomes to the causes.

Step Five is an exercise to assess the relative importance of causal factors by determining the severity of the consequences. Application of a threshold between broadly acceptable and intolerable outcomes will differentiate between causes that require monitoring and those that require mitigation.

4.2 Swimlane Diagram

The Swimlane Diagram presented in Fig 8 below is developed within the research from the discussion in the Literature Review and the Case Studies.

This displays the cross functional interactions and communications between the six significant parties involved in the automation upgrade, i.e.

Client

Project management team (to include planning and procurement)

Design Engineers

Automation System Vendor

Field Engineering

Construction (to include commissioning).

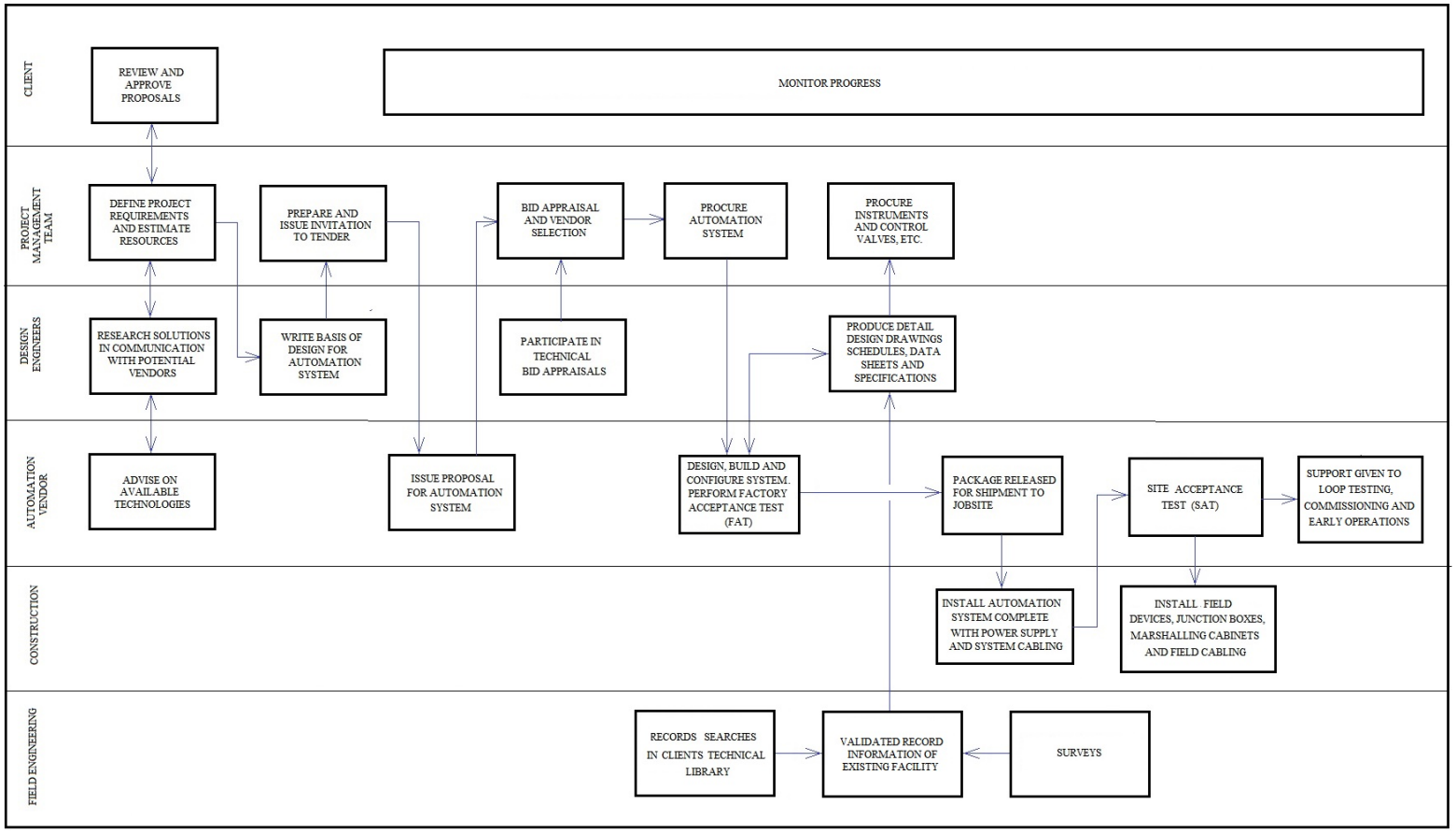


Fig 8: Swimlane Diagram

4.3 GAP Analyses

Significant deviations between Conceptual Theory derived within the Literature Review and the actual outcomes are tabulated below in 4.4.1 to 4.4.7. These correlate with the transformation processes tabulated under CATWOE in the Literature Review in 2.4.6.

4.3.1 Planning Stage

Stage	Actions	Conceptual Theory	Identified Gaps
Planning	Define project requirements and estimate resources	Requires multidisciplinary team approach including both plant operation and project engineering expertise.	CASE ONE The extensive punch-list suggests that the resources required for design and engineering had not been adequately assessed.
			CASE TWO The planning appears to have been assessed adequately with inevitable risks for a hardship location.
			CASE THREE The work was planned around two complex turnarounds. Risks were managed and milestones achieved thus no major gaps were identified

4.3.2 Preliminary Design Stage

Stage	Actions	Conceptual Theory	Identified Gaps
Preliminary Design	Prepare the preliminary Control Requirements Definition (CRD) containing the Process Operating Description (POD) and Control Concept. Define Automation and Control Strategy and System Architecture and prepare Preliminary Control Technology Budget	Operating personnel are key participants in the development of the CRD The POD should describe all operational activities, the extent of automation, human interfaces and any variables in the process to consider such as different feedstocks The high-level conceptual feature of the preliminary design is helpful in reviewing proposals from various control concept candidates and allows some flexibility in the budgeting	CASE ONE The extensive punch-list generated during the construction and commissioning phases emanated from design flaws relating to external equipment interfaces and field devices. This reflects on a need to adequately assess the competency requirements for designers and engineers
			CASE TWO The initial assessment scope was poor. Essential scope was missed and the reparability of existing instruments and control valves was too optimistic. The partial conversion to DCS conceived at this stage reflected on a disproportionately high weighting given to stakeholder resistance to change.
			CASE THREE The project was to be performed to the best extent possible by in-house resources who had already been well drilled in similar upgrades on other refinery areas. At this stage the opportunity to include the safety PLC in the planning was overlooked.

4.3.3 Detail Design Stage

Stage	Actions	Conceptual Theory	Identified Gaps
Detail Design	Development of functional specifications for the following Basic Process Control System (BPCS) Safety Instrumented System (SIS) Discrete and regulatory control Procedural Control Process Information data models User Interfaces	Typical design deliverables P&IDs Loop Diagrams Electrical Schematics Panel Layouts Logics Graphic User Interface (GUI) Description Implementation Standards	CASE ONE A full set of design deliverables had been prepared but on issue for construction the drawings had gaps of information, some covered with 'holds' and others not even identified leaving hidden risks carried into the construction phase. CASE TWO The detail design was based on inadequate surveys and records searches in the client's technical library, and on overly optimistic assumptions as to the reparability of existing field devices. CASE THREE Existing record drawings, on which the base scope detail design was based, were not fully up to date requiring risk management to be exerted over the unknown information. Some of the 'unknowns' required testing as opposed to visual inspection only possible during planned complex turnarounds.

4.3.4 Implementation Stage

Stage	Actions	Conceptual Theory	Identified Gaps
Implementation	Procurement of the following Measurement and control hardware with embedded software A service to configure logic, PID algorithms and graphic user interfaces according to the detail design. Verification in system testing normally concluded with a witnessed Factory Acceptance Test (FAT) before shipment	In selecting a suitable vendor's proposal, a thorough bid evaluation procedure must be implemented. Appropriate weightings must be allocated to the various technical and commercial attributes considered within the analysis. Following award, ongoing interaction between the project team and the system vendor are required to ensure exchanges of information are managed and all design interfaces are resolved.	CASE ONE The scope was limited to simply replacing the existing control panel functionality with real time graphics and user interfaces, thus not taking advantage of further features a DCS system can offer. CASE TWO As with CASE ONE, the existing functionality was represented in real time but with an additional constraint in that the initial concept was to retain the existing obsolete pneumatic control panel and field instrumentation and simply read the measured variables on the DCS via P/I converters. A timid and ultimately wasteful approach. CASE THREE The DCS vendor provided training in configuration and graphic building to the CASE THREE in-house project team. This proved highly beneficial in cost saving and for knowledge for use in operations and maintenance. The safety PLC was not fully function tested before delivery to the work site.

4.3.5 Installation Stage

Stage	Actions	Conceptual Theory	Identified Gaps
Installation	Location of the system at the plant site, connection of cabling for system interfaces and field devices. Powering of the system and performance check	A full set of detail design information is required supported by project specifications for supply and installation. Installation, inspection and testing should be performed within an approved Quality Management System.	CASE ONE Quality was managed to the best extent possible considering the incomplete nature of the construction issue drawings. An extraordinarily large punch-list of incomplete items due to holds, missing and incorrect design information required input from an expanded field engineering team.
			CASE TWO Quality was well managed by QA/QC but the construction was delayed by the need to order replacement instruments and control valves for existing devices that had previously been assessed as repairable. The construction schedule was recovered although the scope creep gave rise to considerable cost variances.
			CASE THREE Installation was performed by a term contractor employed continuously on maintenance and small projects. Neither CASE THREE nor the contractor operated QA/QC. Whilst this carried only a low 'human factors' risk because of the familiarity with the work, the risk escalated when external tradesmen were drafted in to meet with milestones on shutdowns.

4.3.6 Commissioning Stage

Stage	Actions	Conceptual Theory	Identified Gaps
Commissioning	After calibration and loop testing, the system is function tested to prove that it works as per design.	Water testing is often used as an inert process fluid for commissioning purposes. On completion lines are purged in preparation for start up	CASE ONE It was not necessary to replace inline devices such as orifice plates and control valves for the project so there was little or no breaking containment of process lines and vessels. The transition from pneumatic control panel to DCS could largely be performed on a live process thus minimizing the turnaround scope.
			CASE TWO All equipment and field devices were inspected and tested prior to handover to commissioning regardless of each being new or existing or of any existing certification. Some devices required repairs and / or recalibration. The majority of root causes are mishandling during lifting operations and scaffold strikes.
			CASE THREE Lingering problems with the safety PLC were carried over into this phase. The PLC failed to communicate with the HMI so a temporary workaround was developed. The disinvested legacy annunciators were wired to the PLC to enable operations while the PLC vendor investigated the root cause of failure.

4.3.7 Start Up

Stage	Actions	Conceptual Theory	Identified Gaps
Start Up	After commissioning, the process is handed over to the operations team	The operations team runs the process with a small residual core team of project engineers in attendance to monitor performance and operation. Once the handover is complete the project is closed and the documentation is revised with all changes to 'As Built' status.	CASE ONE The close out was completed as planned having resolved the punch-list items. Extensive as building was required to update the drawings and schedules to go into the handover documentation.
			CASE TWO Because of the close interaction between the projects and operations teams during previous phases, the handover and operation of the systems were successful. Extensive as building was required due to scope creep.
			CASE THREE Handover and start up was successful. Extensive as building of record drawings and documents was required mostly due to the extent of unknown information that had been identified in scope and reflected in construction notes on the drawings.

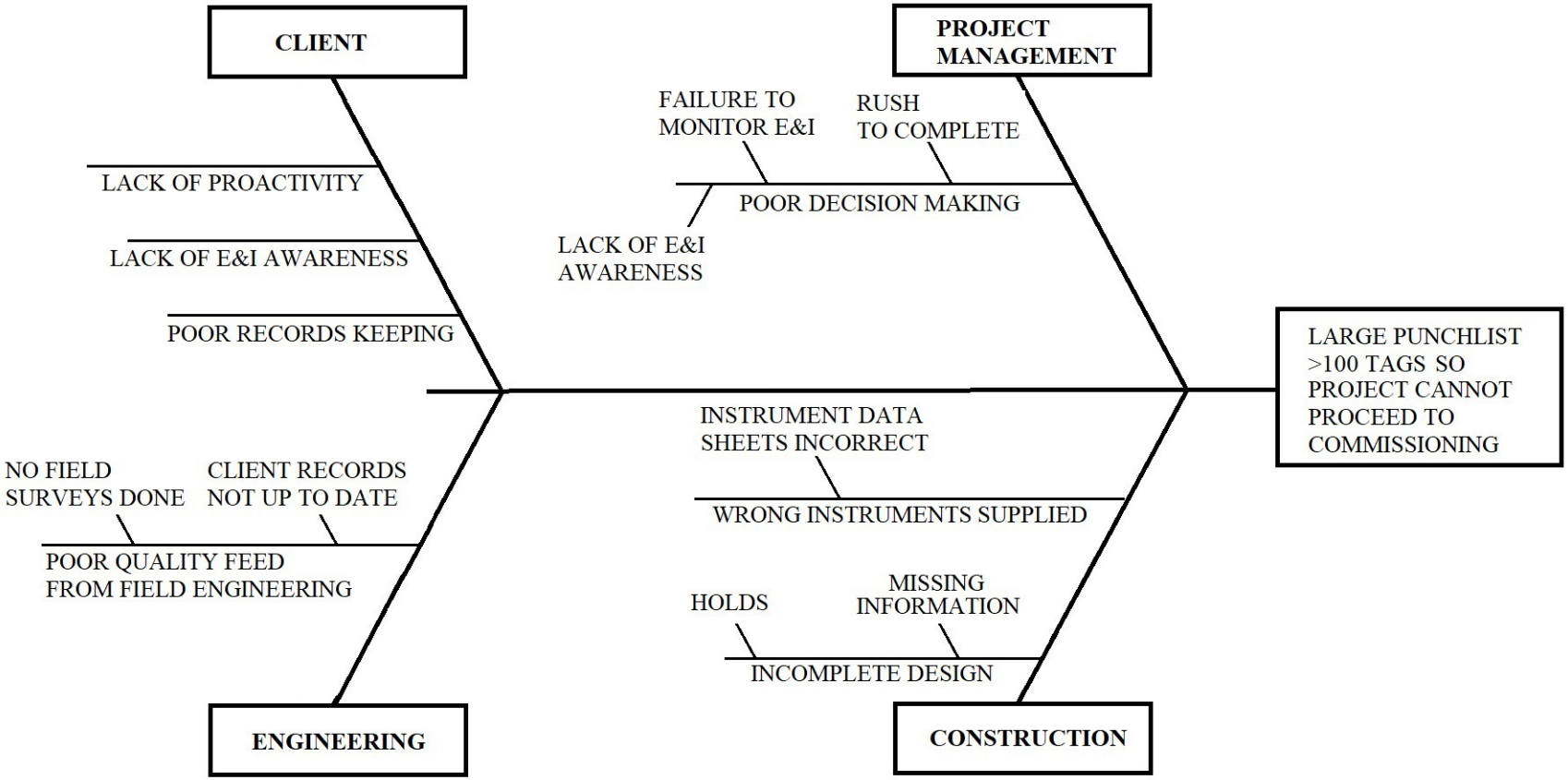
4.3.8 Training

Stage	Actions	Conceptual Theory	Identified Gaps
Training	Training of operations and maintenance personnel is required	Training should commence in the latter part of the implementation phase and be ongoing throughout the remainder of the project	CASE ONE There has been considerable resistance to change. The project was completed in the year 2000 and it has since taken many years for MPC to be considered reflecting on an apparent reluctance to embrace any new technologies.
			CASE TWO Training occurred for very few client personnel during the project who were then reluctant to share the knowledge with peers. This constraint limits the extent to which training can be effective.
			CASE THREE Training in configuration and trouble shooting was included in the DCS product offerings. The in-house project team was thus able to perform the implementation and carry knowledge over into operations and maintenance.

4.4 Root Cause Analyses

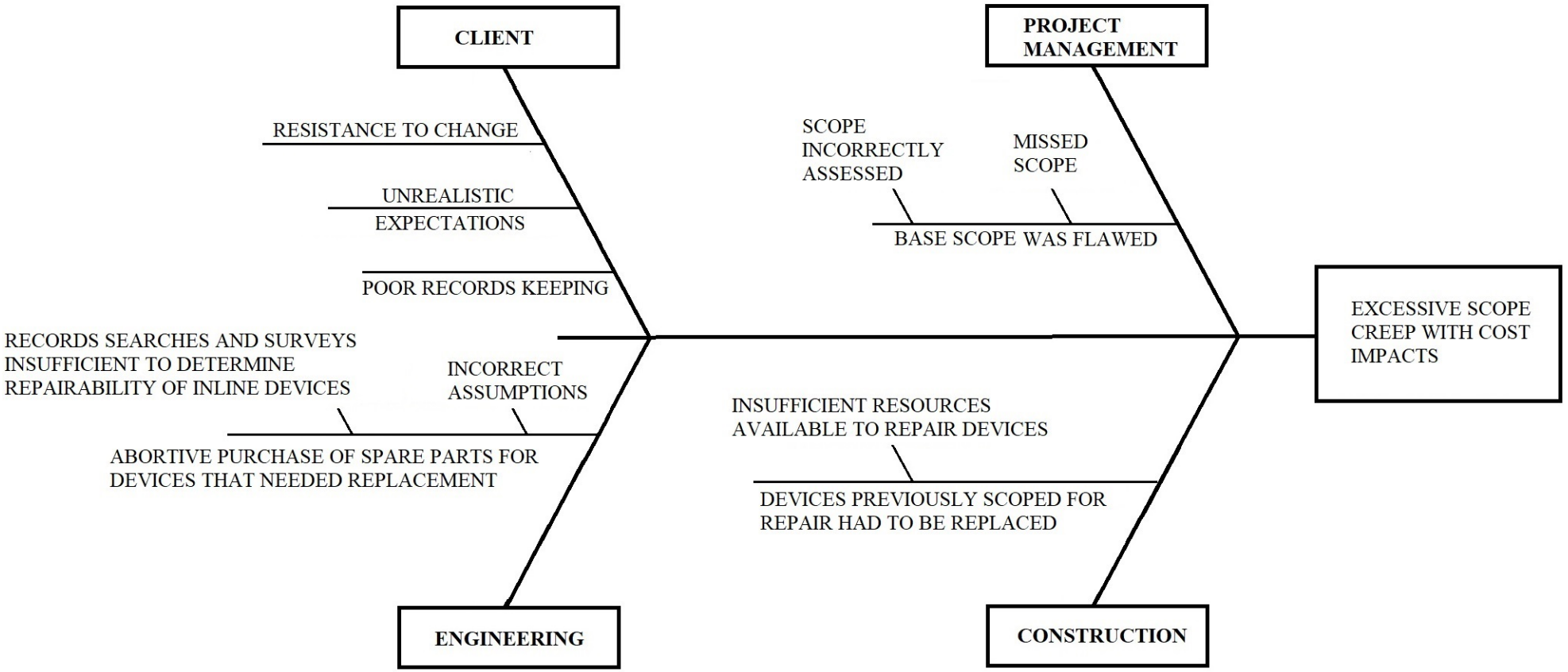
4.4.1 Causal Factors

The situation analysis is the outcome of the collection and analysis of data in 4.1 to 4.3 and presented in fishbone diagram format for the three projects in Figs 9 to 11.



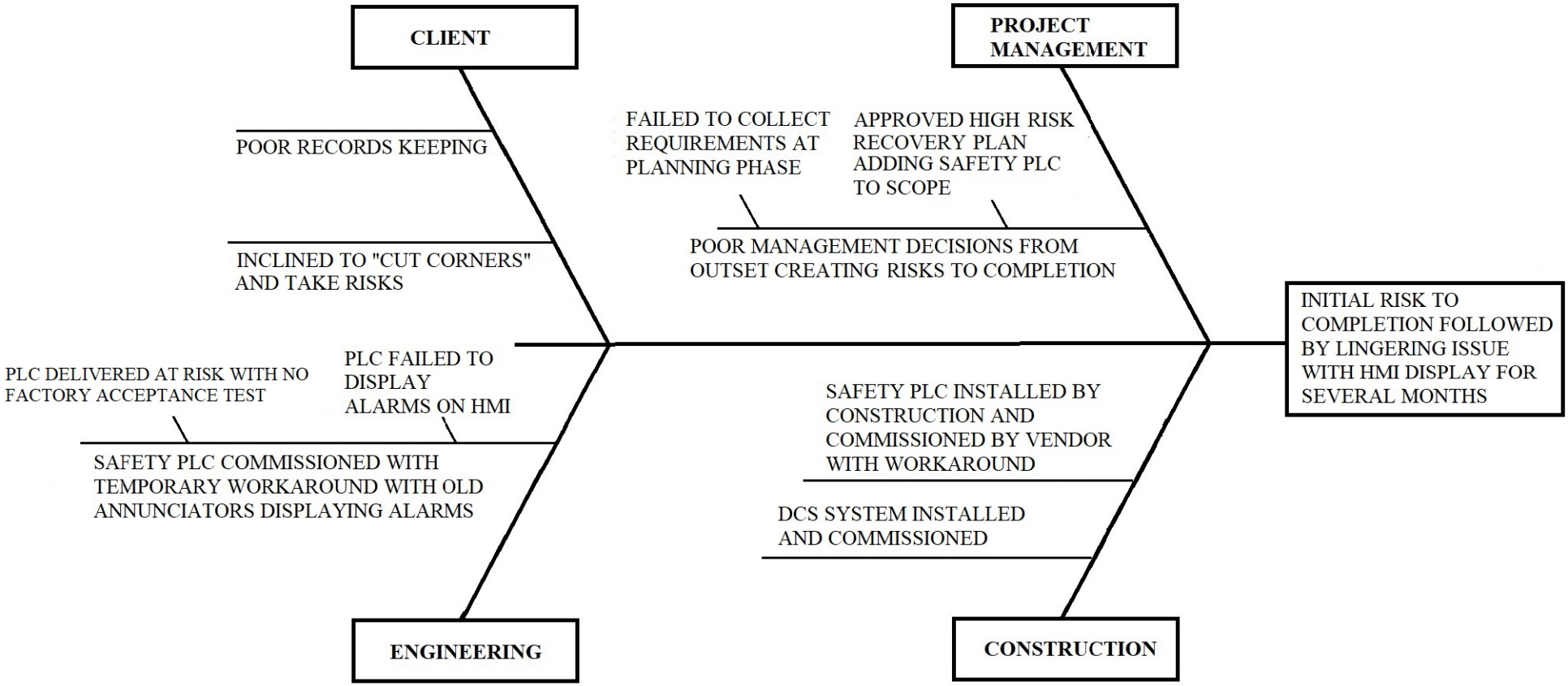
RCA CASE ONE

Fig 9



RCA CASE TWO

Fig 10



RCA CASE THREE

Fig 11

4.4.2 The Findings

The causal factors from the RCA of the three case studies are tabulated below with some suggested mitigation measures.

CLIENT	
CAUSAL FACTOR	**MITIGATION MEASURES**
Client Lack of Proactivity	The client must interact with the project team and respond to the external communications. The project management plan developed by the project team and approved by the client will define the required interactions and communications.
Client Limited E&I Awareness	Client to consider recruitment of a qualified E&I consultant to represent the client. Normally the client HR would write the job spec although this may best be performed with the assistance of a recruiter.
Poor records keeping in clients technical library	Historic poor records keeping must be recognized at the earliest stage of the project allowing time to address the gaps before these become an issue. Records searches, surveys, technical queries, etc. can all be effective measures if employed without delay.
Client resistance to change	A natural tendency but changes must occur because all instrumentation is constantly evolving. No instrumentation system is completely future proof.. Presentations together with learning and development plans may address some concerns.

CLIENT	
CAUSAL FACTOR	**MITIGATION MEASURES**
Client unrealistic expectations	Managing client expectations is a process within Project Management. Documented change requests together with updates to the organizational process assets, project management plan and project documents are good measures.
Inclination to ‘cut corners’	Where such culture exists it must not be imported into the project.

PROJECT MANAGEMENT	
CAUSAL FACTOR	**MITIGATION MEASURES**
Failure to monitor E&I progress	Maintain control with regular reporting.
Rush to complete	Plan recovery from slippages
Limited E&I Awareness	HR to map required competencies, identify gaps and issue job profiles to recruiter.
Poor Decision Making	Project manager to manage communications within team and externally with stakeholders.
Failure to collect requirements leading to flawed or missed scope	Early part of a project is vital to give adequate opportunity to plan all activities. The approach requires brainstorming and other research to ensure all requirements are captured.
Approval given to high risk recovery plan	Assess each situation, identify and manage all risks.

ENGINEERING	
CAUSAL FACTOR	**MITIGATION MEASURES**
No QA / QC operated	Contentious situations and even litigation can emanate from lack of quality control. Develop and implement a quality plan.
Workaround was required for Safety PLC	Any packaged equipment to be temporarily hooked up, configured and tested at vendor facility. Any simulations unless using a tried and proved method are not a suitable substitute for testing the software loaded into the firmware. Following a full Factory Acceptance Test (FAT) Procedure, approved by the project management team, the FAT test is witnessed by the client who then authorizes release for shipment. It is important to ensure there is adequate knowledge of all package interfaces and to check the design for data communications thus to ensure compatibility.
Records Searches incomplete	Fully identify scope to perform records searches in terms of drawings and surveys. Identify any information gaps and manage risks and resolve actions to complete the design. Close out holds on project data sheets prior to procuring devices, and on drawings before issuing these for construction.

ENGINEERING	
CAUSAL FACTOR	**MITIGATION MEASURES**
Abortive spare parts purchased	The decision for replacement or repair, must take into consideration the assumed reparability, projected future lifecycle and level of acceptance to the sacrifice of any advantages available in current vendor / product lines. An inline device needs removal from piping linework to adequately assess its reparability.

Table 5: Causal Factors

Chapter 5
Development of Heuristic Tools

5.1 Introduction

In this chapter, heuristic tools designed to address the more severe vulnerabilities tabulated in 4.4.2 are set out with the guidelines designed to mitigate these.

"When selecting reengineering tools, it is best to give consideration to those tools that are easy to learn and easy to use. If a tool requires a long learning period, its value may be diminished. When comparing tools, proportionally discount the value of a given tool relative to the time required to learn to use it. [5]"

The heuristic tools to be developed in the quest of identifying those vulnerabilites with the potential to cause unsuccessful outcomes must in the first instance be easy to use.

The heuristics are those developed from the research performed within the constraints of this thesis and are thus limited just to a literature review and three historic case studies.

The heuristics will need to be proof tested to the best extent possible in the next chapter to provide a basic set of validated rules. These can then be applied in future upgrades and further developed from the feedback on a continuous improvement basis.

5.2 The Heuristics

In Chapter 1, the objective given in 1.1 defines three important characteristics relating to the deliverable.

(i) A fit for purpose automation system

(ii) Delivered on time

(iii) Delivered to or under budget

Table 6 sets out the heuristics and ranks these against each of the three characteristics where

- 1 represents a slight relationship,
- 2 represents a moderate relationship
- 3 represents a strong relationship

HEURISTIC	GUIDELINES FOR RESPONSE	FIT FOR PURPOSE	WITHIN BUDGET	ON SCHEDULE
Does the client seek to act in a 'hands off' role or actively participate within an integrated project team?	The project management plan developed by the project team and approved by the client will define the required interactions and communications.	**2**	**2**	**2**
What is the level of E&I awareness within the client management team?	If any gap exists, consider recruitment of a qualified E&I consultant to represent the client. Normally the client HR would write the job spec although this may best be performed with the assistance of a recruiter.	**3**	**2**	**2**
Are the client records well maintained?	Historic poor records must be recognized at the earliest possible project stage and factored into the risk management.	**3**	**3**	**3**

HEURISTIC	GUIDELINES FOR RESPONSE	FIT FOR PURPOSE	WITHIN BUDGET	ON SCHEDULE
Do the client operations and maintenance personnel show interest in the new technology?	Changes must occur because all instrumentation is constantly evolving. Adherence to legacy systems will ultimately become unsustainable. Learning and development plans formulated and implemented during the course of the project can address some concerns.	**3**	**1**	**1**
Does the client harbour unrealistic expectations?	Managing client expectations is a process within Project Management. Good management requires documented change requests with updates to the organizational process assets, project management plan and project documents.	**3**	**3**	**3**
Are there adequate E&I competencies available to the project team at the preliminary design phase?	HR must map required competencies, identify gaps and issue job profiles to recruiter.	**3**	**1**	**1**

HEURISTIC	GUIDELINES FOR RESPONSE	FIT FOR PURPOSE	WITHIN BUDGET	ON SCHEDULE
Collection of requirements at the preliminary project phase.	Ensure that a fit for purpose design is the key objective Involve engineering in researching available technologies with potential automation system vendors and suppliers of field devices. Establish a rough order of cost for supply, installation and commissioning for stakeholder approval.	**3**	**2**	**2**
Plan and monitor E&I progress avoiding any rush to complete	Assess each situation, identify and manage all risks. Plan recovery from slippages using appropriate techniques.	**1**	**2**	**3**
Is there a Quality Management System available to the project?	A larger project requires implementation of a Quality Management System to ensure an even and consistent approach. This should still be the case even in a small project team unless it can be demonstrated that individuals can and will perform all the required testing and inspection without supervision.	**3**	**1**	**2**

HEURISTIC	GUIDELINES FOR RESPONSE	FIT FOR PURPOSE	WITHIN BUDGET	ON SCHEDULE
How to achieve a fit for purpose automation system	Consider interfaces with all new and existing IEDs, some that may communicate directly with the fieldbus and some via I/O modules or even pneumatics interfaces for earlier generations of instruments. Consider the network, the architecture, geographical layout, operator interfaces, GUI, operating systems. Whilst the automation system may be packaged along with the required expertise for the purposes of design, installation and commissioning, the user must plan to be made adequately aware so as not to avoid a lingering dependency after handover.	**3**	**2**	**2**
Is there any realistic cost saving in repairing existing field instrumentation as opposed to replacement?	The decision for replacement or repair must take into consideration the assumed reparability, projected future lifecycle and level of acceptance to the sacrifice of any advantages available in current vendor / product lines. For example, an inline device cannot be assessed just with a visual survey. It needs removal from piping linework for inspection of wetted parts.	**3**	**3**	**3**

Table 6: Heuristic Model

Chapter 6
Validation

6.1 Introduction

In this chapter, the heuristics will be applied to two projects to upgrade automatic tank gauging facilities on a bulk chemicals terminal in Western Europe. The heuristics will be scored against the characteristics discussed in 5.2 in the format B / A where

A = Strength of the relationship between the heuristic and successful project outcome

B = Score achieved

6.2 Project A

The project is to install automatic tank gauging to 11 tanks storing high flash distillates. The level measurement devices will communicate via Modbus loops with an existing PLC that calculates levels and mass flows for tank filling from the jetty and product transfer between tanks.

Each tank has a radar level transmitter and temperature transmitter mounted in flanges on the tank tops. These communicate via HART over a single cable pair to a tankside monitor located at ground level. The tankside monitor calculates the mass in the tank from the level signal with temperature correction and transmits this serially via Modbus over a single pair of wires to an RTU located in the control room. The RTU communicates with a PLC that monitors and controls operations with an operator interface.

The RTU monitors 53 existing tanks over 3 Modbus loops in the manner described above.

The level monitoring for 11 additional tanks will communicate via a fourth Modbus loop over a single pair of wires terminated at a spare input channel on the RTU.

The heuristics are presented and assessed in the following tables.

HEURISTIC	RESPONSE	FIT FOR PURPOSE	WITHIN BUDGET	ON SCHEDULE
Does the client seek to act in a 'hands off' role or actively participate within an integrated project team?	The client manages all communications with vendors and contractors and uses own technicians. **SATISFACTORY**	**2/2**	**2/2**	**2/2**
What is the level of E&I awareness within the client management team?	The client is actively involved in the project and participates in the installation. Vendor expertise is required for configuration of the PLC, tankside monitors and data communications **SATISFACTORY**	**3/3**	**2/2**	**2/2**
Are the client records well maintained?	Existing records are below par. Adequate information is available to implement the project although a full set of as built drawings will need to be produced. **THIS IS AN AREA FOR CONCERN**	**0/3**	**0/3**	**0/3**

HEURISTIC	RESPONSE	FIT FOR PURPOSE	WITHIN BUDGET	ON SCHEDULE
Do the client operations and maintenance personnel show interest in the new technology?	The operations personnel are interested in expanding the tank gauging to the additional tanks. The PLC will need to be upgraded as there is an end of life problem with the firmware. **SATISFACTORY**	**3/3**	**1/1**	**1/1**
Does the client harbour unrealistic expectations?	The end of life problem with the existing PLC must be addressed and interest must be drawn towards solutions with current technologies. **SATISFACTORY**	**3/3**	**3/3**	**3/3**
Are there adequate E&I competencies available to the project team at the preliminary design phase?	The client has personnel with competencies in E&I design, engineering and project management. **SATISFACTORY**	**3/3**	**1/1**	**1/1**
Collection of requirements at the preliminary project phase.	The requirement is to install 11 tank gauges on a new Modbus loop interfacing with an existing PLC to be configured with graphics and interfaces. **SATISFACTORY**	**3/3**	**2/2**	**2/2**

HEURISTIC	RESPONSE	FIT FOR PURPOSE	WITHIN BUDGET	ON SCHEDULE
Plan and monitor E&I progress avoiding any rush to complete	The critical path is availability of the vendor specialists to configure the PLC and the tankside monitors. The planned dates for the vendor visit cannot slip. Civil works on another project in the same area slipped and impacted on ability to complete base scope. A workaround solution to mount the tankside monitors on temporary supports enables completion with follow up work. An early warning notice of a cost variance of 12% over base scope was obtained from the installation contractor for stakeholder approval. **SATISFACTORY**	**1/1**	**2/2**	**3/3**
Is there a Quality Management System available to the project?	Inspection and testing is recorded on check sheets that are witnessed and signed. These are filed along with certification for devices. **SATISFACTORY**	**3/3**	**1/1**	**2/2**

HEURISTIC	RESPONSE	FIT FOR PURPOSE	WITHIN BUDGET	ON SCHEDULE
How to achieve a fit for purpose automation system	Tank top instruments communicate with tankside monitors over a 2 wire HART serial link. The tankside monitors communicate with the PLC over a wired Modbus loop. This is a well-known technology that is widely used at the facility. **SATISFACTORY**	**3/3**	**2/2**	**2/2**
What is the key scope and activities of the automation system vendor?	Installation of the devices and cabling is by others. The automation vendor must configure the PLC with the additional tanks, calibrate the instruments and commission the system. **SATISFACTORY**	**3/3**	**2/2**	**2/2**
Design based on existing records	Existing P&IDs and wiring diagrams are not as built. Due to the simplicity of the system and the expertise of engineers and technicians on the project this has not had any adverse impacts although there is some follow up as building to be performed. **THIS IS AN AREA FOR CONCERN**	**0/3**	**0/3**	**0/3**

HEURISTIC	RESPONSE	FIT FOR PURPOSE	WITHIN BUDGET	ON SCHEDULE
Is there any realistic cost saving in repairing existing field instrumentation as opposed to replacement?	The field devices are all from current vendor product lines. One constraint is that the devices communicate with an existing legacy PLC with an obsolete operating system. A further project needs to be raised for the end of life problem. **SATISFACTORY**	**3/3**	**3/3**	**3/3**
TOTAL SCORES		**30/36**	**21/27**	**23/29**

Table 7: Project A Results

6.3 Project B

Project B is planned to follow on from Project A at the bulk chemicals terminal.

A fibre optic LAN interfaces tank gauging equipment on recently introduced facilities with a current generation PLC system to provide tabulated displays of tank levels, temperatures and key criteria. The PLC interfaces with a SCADA system to provide graphic displays on the HMI.

The PLC software is disliked by the operators due to its slow response time and that the schedule readouts cannot be customised to their preferences. Following feedback from many users, the system vendor has brought out a new version of the software that addresses those complaints.

The objective of Project B is to

- Upgrade the tank gauging software to satisfy the operators preferences.
- Migrate all of the four wired Modbus serial tank gauging loops onto the upgraded PLC and SCADA.
- Disinvest the legacy PLC.

The migration of the wired loops onto the fibre optic LAN is achieved with a simple wiring modification to the data communications equipment.

- Remove the legacy Modbus RTU and wire the four Modbus loops into hubs.
- Connect the hubs into the fibre optic network.

The project is at the preliminary phase where a Rough Order of Cost is under development. Whilst the project is only at a preliminary stage, heuristics will provide some forward thinking to the project team.

HEURISTIC	RESPONSE	FIT FOR PURPOSE	WITHIN BUDGET	ON SCHEDULE
Does the client seek to act in a 'hands off' role or actively participate within an integrated project team?	As with Project A, the client manages all communications with vendors and contractors and uses own technicians. **SATISFACTORY**	**2/2**	**2/2**	**2/2**
What is the level of E&I awareness within the client management team?	The client is aware of both legacy and new tank gauging systems but will be dependent on the knowledge of two external parties a) ATG system vendor b) Data communications specialist **SATISFACTORY**	**3/3**	**2/2**	**2/2**
Are the client records well maintained?	Records are poor. There is sufficient information on which to produce project drawings and these must be revised into as builts on completion **THIS IS AN AREA FOR CONCERN**	**0/3**	**0/3**	**0/3**

HEURISTIC	RESPONSE	FIT FOR PURPOSE	WITHIN BUDGET	ON SCHEDULE
Do the client operations and maintenance personnel show interest in the new technology?	Operations and Maintenance must embrace new technologies, thus some training must be procured from the automation system vendor. **SATISFACTORY**	**3/3**	**1/1**	**1/1**
Does the client harbour unrealistic expectations ?	As revealed within the heuristics for Project A, there is an end of life problem with the firmware. The project must therefore be progressed before this becomes critical. **SATISFACTORY**	**3/3**	**3/3**	**3/3**

HEURISTIC	RESPONSE	FIT FOR PURPOSE	WITHIN BUDGET	ON SCHEDULE
Are there adequate E&I competencies available to the project team at the preliminary design phase?	The client has adequate competencies to interface at a technical level with the automation system vendor data communication specialist and E&I contractor. **SATISFACTORY**	**3/3**	**1/1**	**1/1**
Collection of requirements at the preliminary project phase.	The requirements are to upgrade the PLC and SCADA software and to migrate 53 ATG loops from legacy tanks onto the upgraded system. **SATISFACTORY**	**3/3**	**2/2**	**2/2**
Plan and monitor E&I progress avoiding any rush to complete	The critical path is expected to again be determined by the availability of automation system specialists that must be booked well in advance. **SATISFACTORY**	**1/1**	**2/2**	**3/3**

HEURISTIC	RESPONSE	FIT FOR PURPOSE	WITHIN BUDGET	ON SCHEDULE
Is there a Quality Management System available to the project?	Any installation work will require quality inspection and testing although this work will be minimal. There will need to be debrief meetings with both the automation system engineers and data communications specialist before they leave the site. **SATISFACTORY**	**3/3**	**1/1**	**2/2**
How to achieve a fit for purpose automation system	Tank top instruments communicate with tankside monitors over a 2 wire HART serial link. The tankside monitors communicate over a wired Modbus loop that interfaces with a site wide fibre optic LAN. **SATISFACTORY**	**3/3**	**2/2**	**2/2**
What is the key scope and activities of the automation system vendor?	The automation vendor must upgrade the software and configure the PLC with the additional tanks. Further activities will be within the scope of the E&I installation contractor and the data communications specialist. **SATISFACTORY**	**3/3**	**2/2**	**2/2**
Design based on existing records	Existing P&IDs are not as built although this has been discussed within the heuristics for Project A. **THIS IS AN AREA FOR CONCERN**	**0/3**	**0/3**	**093**

HEURISTIC	RESPONSE	FIT FOR PURPOSE	WITHIN BUDGET	ON SCHEDULE
Is there any realistic cost saving in repairing existing field instrumentation as opposed to replacement?	The field instruments and devices are of current technologies. **SATISFACTORY**	**3/3**	**3/3**	**3/3**
PROJECT B TOTALS		**32/36**	**24/27**	**25/29**

Table 8: Project B **Results**

Chapter 7
Results and Conclusion

In this chapter the results of the validation exercises will be presented and discussed followed by a conclusion.

7.1 Results

In the heuristic tables in Chapter 6, responses are assessed and scored against the three criteria of Fit for Purpose, Within Budget and On Schedule.

The totalised scores for project A are as follows

Attribute	Score	Likelihood of Success
Fit for Purpose	32/36	89%
Within Budget	24/27	89%
On Schedule	25/29	86%

Table 7: Project A Results

The totalised scores for project B are as follows

Attribute	Score	Likelihood of Success
Fit for Purpose	30/36	83%
Within Budget	21/27	78%
On Schedule	23/29	79%

Table 6: Project B Results

It can be seen in the heuristic tables in Chapter 6 that all the concerns exist around vulnerabilities that have a relationship with documentation. Whilst vulnerabilities do indeed exist elsewhere, these are considered manageable. Had that not been the case, the scoring against specific heuristics would have been lower, triggering concerns to be addressed.

This is largely consistent with the causal factors identified from the RCA on the case study projects within which poor documentation has certainly contributed to underperformances.

7.2 Conclusion

The heuristics have been developed to the best extent possible from research into literature, the author's own experience on projects and from discussion with industry experts.

The validation exercise on live automation upgrade projects has demonstrated the functionality of the heuristics in that they have the ability to identify vulnerabilities to be addressed at an early stage before these become critical to the successful outcome of a project.

The validation exercises were limited by the availability of suitable automation projects occurring within the timescale of the thesis. In spite of this constraint, it was possible to apply the heuristics to two automation upgrade projects and check the strengths and weaknesses within the project structure.

The outcome at present is a set of basic heuristics proven in use that author now intends to apply on a wider range of ongoing and future projects. From the feedback the author will continually look for any opportunity to update the heuristics so that they may always be a useful practitioner's tool to have available on automation upgrades.

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