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Future Proofing Asset Information in Transportation Infrastructure Projects

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TOWARD FUTURE PROOFING ASSET INFORMATION IN LIQUEFIED NATURAL GAS MEGA-PROJECTS: OBSERVATIONS FROM 'HAND-OVER'

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ABSTRACT

Over the last decade in Western Australia (WA) several mega Liquefied Natural Gas (LNG) mega-projects totaling in excess of $100 billion in value have been constructed and now entering their operational phase. However, low productivity levels contributed to significant increases in their capital expenditure (CAPEX). In particular, the Electrical, Instrumentation and Control Systems (EICS) information 'as-built' documentation provided at 'hand-over' for commencement of the operational phase does not often reflect what has been actually installed. As a result, this can adversely impact productivity and operational expenditure as well jeopardize the asset's integrity. Traditional paper based methods such as Computer-Aided-Design (CAD) have been relied upon to create asset information for 'hand-over'. A reliance on the use of CAD to document for EICS (e.g., specifications, and 'as-built') increases the propensity for errors, omissions and information redundancy. Attending to issues of this nature during the construction of the asset can result in scope changes, losses in productivity, and increases in project costs. This paper presents preliminary observations from a research project that is examining the nature of EICS documentation provided at 'hand-over' for the operation mega LNG projects. Using a case study, the 'as-built' documentation for a domestic gas metering, which formed an integral part of an LNG plant's production process is examined. Issues hindering productivity during the production of the documentation, communication and information exchanges, and change management involved with the deliver of the EICS are presented. In addressing problems identified in the case study, it is suggested that if LNG plants are to make headway to being 'future-proofed', then their EICS should be digitized (i.e. process of converting information into a digital format) using a Systems Information Model (SIM). The use of SIM to ensure effective and efficient production and management of EICS information throughout an LNG asset's lifecycle, and will contribute towards safeguarding its integrity.

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KEYWORDS

Asset information, documentation, digitization, hand-over, Liquefied Natural Gas (LNG), Systems Information Modelling (SIM)

INTRODUCTION

The State of Western Australia (WA) produces approximately 90% of the nation's estimated recoverable conventional gas reserves, which are located in the Carnarvon and Browse basins in the State's North West. These gas fields support the Liquefied Natural Gas (LNG) export industry of WA, as well as its domestic gas market. Domestic gas is provided by Chevron's Gorgon and Wheatstone, and Woodside's Karratha Gas Plant. In fact, the State Government policy aims to ensure that 15% of the gas produced from offshore developments are made available for domestic use (Government of WA, 2015). Having in place reliable and robust infrastructure that is able to supply gas for industrial processing, manufacturing, residential use and electricity generation within the State is critical to supporting its economic and social well-being. It is, therefore, a necessity that the supply of gas is not adversely impacted. However, maintenance and upgrading of the infrastructure has the potential to hinder this supply, especially, if works are not effectively planned and regular inspections and maintenance are inadequately undertaken.

In 2008, for example, WA experienced a significant disruption to its supply of natural gas as a result of a rupture in a pipeline that had been subjected to corrosion, which led to an explosion at the processing plant on Varanus Island. The plant supplied a third of WA's gas and subsequently needed to be shut down for almost two months while detailed engineering investigation and major repairs were undertaken. The WA Chamber of Commerce estimated the overall economic impact of this disruption to be in the magnitude of AU$6.7 billion (Sydney Morning Herald - SMH, 2008). According to the National Offshore Petroleum Safety and Environmental Management Authority- NOPSEMA (2008), the main causal factors that contributed to this event were:

- ineffective anti-corrosion coating at the beach crossing section of the sales gas pipeline;
- ineffective cathodic protection of the wet-dry transition zone of the beach crossing section of the pipeline; and
- inadequate inspection and monitoring by the operator of the beach crossing and shallow water section of the pipeline.

With the benefit of hindsight, it suggested that events of this nature could have been mitigated if real-time condition monitoring and sensing technologies had been employed and integrated with a Systems Information Model (SIM). Yet, there has been a tendency for inspection and monitoring of asset information to be manually recorded using paper based systems. As a result of recording information in this format, it can be misinterpreted due to illegible handwriting and incomplete information that is often difficult to retrieve as it tends to be stored in a variety of disparate locations. An inability to instantly obtain access to the correct information from a reliable consolidated 'point of truth' (POT) can result in ineffectual decision-making, adversely impact productivity levels and jeopardize safety (e.g., Hossain *et al*., 2015; Zhou *et al*., 2015; Choi *et al*., 2016). LNG operators have recognized the significance of this problem and as a result have begun to embrace a wide range of innovative technologies (e.g., Internet of Things, Radio Frequency Identification (RFID), Sensors, Geographical

Information Systems (GIS) and Quick Response (QR) codes) to ameliorate process safety and the management of information during operations and maintenance (Zhao, 2015; Tanabe *et al*., 2016).

Despite the widespread support of operators to adopt technology to maintain their assets' integrity and ensure that their production levels meet their contractual obligations supplying gas for overseas purchasers (e.g., China and Japan), a fundamental problem persists and has been avoided. The design and documentation of Electrical Instrumentation and Control System (EICS), for example that are required to operate an LNG plant and its associated infrastructure, are generated using Computer-Aided-Design (CAD). They are then issued in a paper format for contractors to prepare and submit a tender price for specific EICS work packages.

A reliance on the use of CAD to produce documentation can result in errors, omissions and considerable information redundancy, which can hinder the ability of those who are contracted to deliver specific work packages (Love *et al*., 2016a). As a result of errors, omissions and inconsistencies that may arise in the documentation created for construction, requests for information (RFI) are raised by contractors. A response to a RFI often requires amendments to documents, which are then re-issued to the contractor. In essence, this process continues until construction is completed and 'as-built' documentation is provided to the operator at hand-over. Seldom, however, does 'as-built' documentation reflect what has been actually installed. Moreover, the 'as-built' may be stored at locations that are inaccessible during operations (Gallaher *et al*., 2004; Love *et al*., 2013). This poses significant risks to operations and maintenance activities and may unnecessarily compromise the asset's integrity.

This paper presents preliminary observations from a research project that is examining the nature of EICS documentation provided at 'hand-over' for the operation of a mega-LNG project that was in excess of $13 billion to construct. Using a case study, the 'as-built' documentation for a domestic gas metering, which formed an integral part of an LNG plant's production process is examined. It is particularly important to have access to reliable and accurate information for ECIS as in they can represent 29% of the world's capital expenditure on plant within the hydrocarbon industry (Aveva, 2012). In addition, during operations, EICS typically account for 60% of maintainable items and are critical to safe and efficient operations. Issues hindering productivity during the production of the documentation, communication and information exchanges, and change management involved with the deliver of the EICS are presented. In addressing problems identified in the case study, it is suggested that if LNG plants are to make headway to being 'future-proofed', then their EICS should be digitized (i.e. process of converting information into a digital format) using a Systems Information Model (SIM). The use of SIM to ensure effective and efficient production and management of EICS information throughout an LNG asset's lifecycle, and will contribute towards safeguarding its integrity.

There has been limited research that has examined the nature of poor quality documentation and its impact on operations and maintenance within the process industries, particularly in the LNG sector (Love *et al*., 2016a). Additionally, there has been a tendency for operators to integrate and synchronize 'as-built' documentation with their asset management systems and inspection technologies. However, those who are charged with inspecting, repairing and maintaining assets are invariably confronted with incomplete and/or inappropriate information. Before decisions and sign-offs can be undertaken, the information must be sought, which, as noted above, can take a significant amount of time and therefore impact productivity and costs. The potential application of a SIM based upon the experiences from previous empirical studies in other sectors such as mining are drawn upon to demonstrate its effectiveness for use within the LNG sector. For a detailed review of the issues surrounding the production of documentation, the management of information and creation of 'as-builts' in process related industries refer to Love *et al*. (2013; 2016a).

RESEARCH APPROACH

To better understand the issues that confront the LNG sector, an exploratory case study approach was undertaken to analyze existing 'practice' and how digitization may lead to process improvement and ensure an asset's performance over its lifecycle (Yin, 1984). Research of this nature is dependent upon a variety of data sources, which is referred to as *triangulation* (Love *et al*., 2002). Documentation provided by an EICS organization who adopted the role of 'off-site project management and technical support' afforded the researchers with documentary data juxtaposed with informal interviews and discussions, which were used to develop a narrative for the case study, as well as clarify issues raised by researchers. Data was collected and analyzed in the offices of the participating organization for reasons of commercial confidentiality. Data was extracted from numerous contractual documents such as the project's scope of work (SoW), Bills of Materials (BoMs), schedules, drawings, and Inspection Test Reports (ITR). A total of 12 unstructured interviews with EICS engineers ranging from 30 to 60 minutes and daily informal discussions over a two-month period were also undertaken to provide a context to the documentation that was made available to the researchers.

GAS METERING UPGRADE

The case study gas plant forms an integral part of Australia's largest oil and gas development. The gas plant produces LNG, domestic gas, condensate and Liquefied Petroleum Gas (LPG). The metering system for one of the pipelines, installed in the 1990s had four metering runs (i.e. utilizing ultrasonic flow meters), but only two were utilized for tariff metering. Of the two remaining metering runs, the piping of one metering run had been demolished between its isolation valves and thus required a new one to be installed, while the other had been permanently removed. Considering the condition of the existing metering station, the new project required all metering facilities to be upgraded, which included replacing the Ultrasonic Flow Meter (UFM) spools as well as the associated instrumentation (e.g. pressure and temperature sensors).

The new metering system also required the supervisory and mass flow computers to be replaced, which were comprised of its own stand-alone metering network with connectivity to the site wide Distributed Control System (DCS) and remote customer Supervisory Control and Data Acquisition (SCADA) systems. In addition, the metering system's moisture (H_2O) and hydrogen sulphide (H_2S) online analyzers for both pipelines were replaced with a single combined moisture/hydrogen sulphide analyzer. Essentially, the project's upgrade required the replacement of the:

- UFM and the associated instrumentation and relocation of two isolation valves;
- moisture and hydrogen sulphide analysers;

- supervisor and mass flow computers and associated metering network and cabinets; and
- associated structure, mechanical and piping works.

A total of six contractors were employed by the client to undertake the following work packages: (1) Off-site project management and technical support; (2) Installation; (3) Metering; (4) Fabrication; (5) Fibre optic cable installer; (6) DCS. These works can be categorized into the following disciplines: (1) electrical instrumentation; (2) process engineering; and (3) structural mechanical and piping (SMP) engineering. The configuration of the previous metering facility that was upgraded is presented in Figure 1.

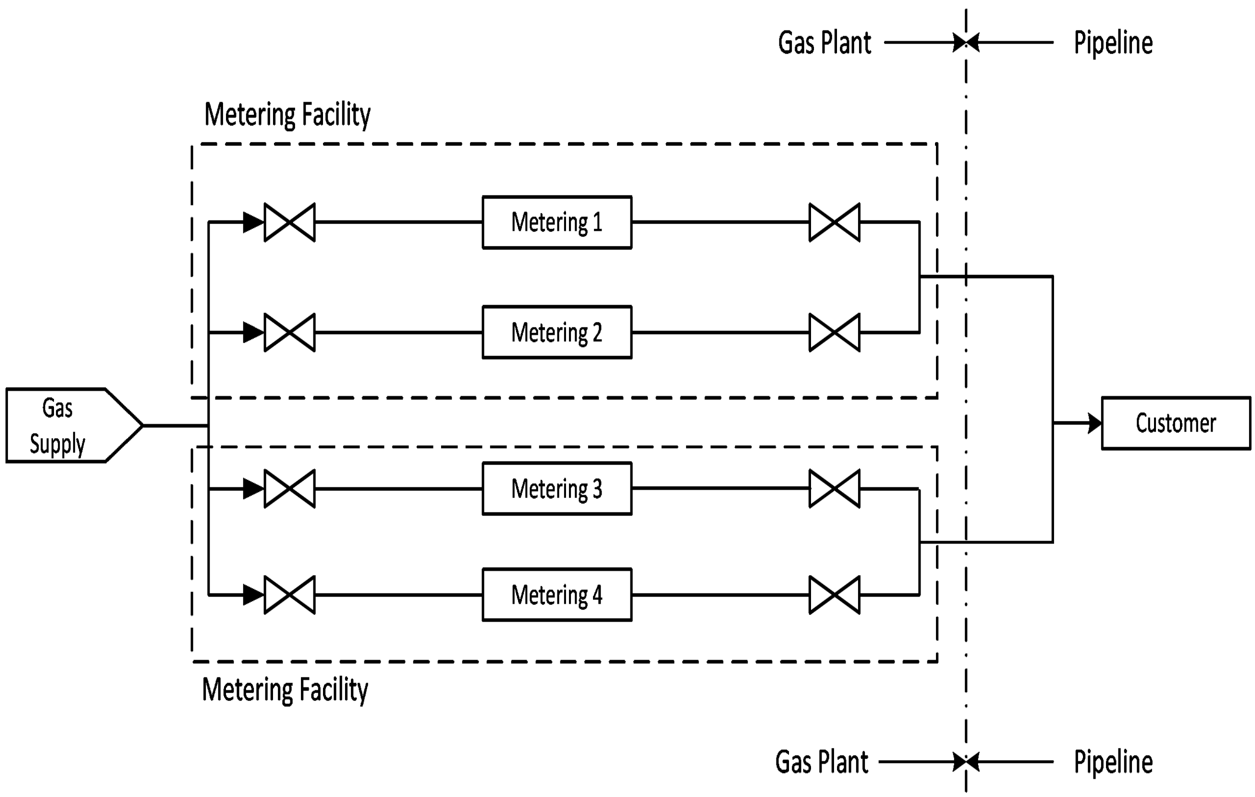

Figure 1. Metering configuration prior to the upgrade

The work was divided into a number of discipline specific work packages and job-cards, that is, Instrument, Electrical, Structural, Piping/Mechanical and Commissioning. Table 1 identifies the off-site management services for design, implementation and commissioning activities for 23 work-packages that were the responsibility of the electrical contractor. The schedules for the work packages are also provided in Table 1, which includes the ‘planned/actual start’ and ‘planned/actual finish’ dates for the work that was undertaken.

Table 1. Work package and schedules

Phases	Work packages		Schedule				
		Planned Start	Actual Start	Days delayed	Planned Finish	Actual Finish	Days delayed
Early-works	WP001	03/Jun/14	06/Jun/14	3	13/Jun/14	02/Jul/14	19
	WP002	10/Jun/14	18/Jul/14	8	20/Jun/14	29/Aug/14	39
	WP003	17/Jun/14	13/Jun/14	-4	27/Jun/14	30/Jun/14	3
	WP004	24/Jun/14	03/Jul/14	9	04/Jul/14	16/Jul/14	12
	WP005	01/Jul/14	15/Jul/14	14	11/Jul/14	10/Sep/14	52
	WP006	08/Jul/14	06/Jul/14	-2	11/Jul/14	10/Sep/14	52
Phase 1	WP007	17/Jun/14	14/Jul/14	27	27/Jun/14	28/Aug/14	72
	WP008	27/Jun/14	16/Jul/14	19	11/Jul/14	09/Sep/14	51
	WP009	24/Jun/14	15/Oct/14	113	04/Jul/14	21/Oct/14	109
	WP010	01/Jul/14	29/Oct/14	121	11/Jul/14	07/Nov/14	118
	WP011	17/Jun/14	04/Jul/14	17	27/Jun/14	13/Nov/14	139
	WP012	08/Jul/14	15/Oct/14	84	18/Jul/14	21/Oct/14	95
	WP013	15/Jul/14	21/Oct/14	98	25/Jul/14	07/Nov/14	74
	WP014	01/Jul/14	15/Oct/14	107	11/Jul/14	13/Nov/14	126
	WP015	08/Jul/14	01/Dec/14	145	18/Jul/14	10/Dec/14	145
Phase 2	WP016	29/Jul/14	14/Nov/14	108	08/Aug/14	12/Dec/14	126
	WP017	29/Jul/14	13/Nov/14	107	08/Aug/14	19/Dec/14	133
	WP018	05/Aug/14	06/Nov/14	93	15/Aug/14	26/Nov/14	103
	WP019	12/Aug/14	14/Nov/14	94	22/Aug/14	19/Dec/14	119
	WP020	05/Aug/14	14/Nov/14	87	15/Aug/14	06/Mar/15	203
	WP021	12/Aug/14	28/Nov/14	108	22/Aug/14	19/Dec/14	119
	WP022	02/Sep/14	06/Nov/14	65	12/Sep/14	26/Nov/14	75
	WP023	19/Aug/14	26/Nov/14	99	29/Aug/14	29/Dec/14	123

The documentation for the upgrade project was based on a workflow that was entirely paper based; the SoW, BoMs, schedules, drawings, and ITR were all recorded on paper documents. Each party was supplied with a set of documents to suit their own specific SoW. Ensuring that each discipline's documentation was up-to-date and reflected changes that had been incurred was a challenging process for the electrical contractor, as there was no consolidated POT. Each discipline had its own view of the information required to undertake their respective works. Access to documentation for 13 out of the 23 work packages was provided (Table 2). The type and number of documents for each of the 13 work packages are presented in Table 2.

COMMUNICATION AND INFORMATION EXCHANGE

In executing this complex project, a considerable amount of communication needed to be maintained between parties and thus required them to work collaboratively to meet the pre-defined deliverables (Figure 2). In addition, contractors needed to ensure stakeholders' needs were also met (e.g., ensuring a continuous gas supply). The project team was required to ensure that there was a smooth transition between each phase, minimal delays to operations and that all were committed to ensuring a win-win outcome. To achieve these requirements, all parties were fully informed of the project's objectives and progress at all times, feedback was encouraged and any concerns that arose were promptly identified and addressed. As the project progressed, the volume of information contained within the work packages increased as drawings, BoMs, schedules, ITRs, change orders, certificates were produced.

A document control systems required all information contained within a work-package to be checked and signed off using the following sequential procedure: engineer → contractor → project management organization (off-site) → client. Following this sequence was a time consuming and costly process to prepare and issue paper based documents. It was estimated that to produce a CAD drawing for the EICS required a draftsperson, on average, 40 man-hours at a cost of AUD $130/hour; a total of $5,200 to produce a single drawing.

Table 2. Work package documentation

Phases	Work Package	Number of Job-cards	Types/Numbers of Documents					
			Scope of work	Drawings	ITRs	Completion Certificates (Required)	Others	Sum
Early-works	WP001	3	13	47	19	1 (4)	19	99
	WP003	2	14	55	60	2 (3)	13	144
	WP004	2	3	88	80	1 (3)	37	209
	WP005	2	14	69	20	1 (3)	18	122
Phase 1	WP007	4	7	59	27	1 (5)	39	133
	WP008	7	72	72	37	3 (8)	129	313
	WP009	2	21	78	34	3 (3)	17	153
	WP010	2	16	70	61	3 (3)	26	176
	WP011	1	33	33	12	2 (2)	51	131
	WP014	2	25	55	14	3 (3)	91	188
Phase 2	WP017	2	55	27	20	3 (3)	71	176
	WP020	5	69	54	26	6 (6)	79	234
	WP023	1	7	9	2	2 (2)	46	66
Σ	13	35	349	716	412	31 (48)	636	2144

INSPECTION TEST REPORTS

In this project ITRs accounted for a significant portion of the documents that were issued (Table 2). A total of 412 (19.22%) out of the 2144 documents were distributed to the project team. Upgrades of this nature are highly dependent on EICS and the issue of high volumes of ITRs was the norm due to the large number of components and cables involved. Each individual component, cable and termination was checked and tested several times by different parties to ensure their integrity. Essentially, the ITRs were used to plan the activities and the objects that needed to be inspected. Outcomes of the checking/testing process were recorded as 'Pass', 'Fail' or some specific readings. Comments were made to indicate the further work that was required to be undertaken. The person who conducted the checking/testing was required to sign against each item that had been inspected. Figures 3 and 4 illustrates two examples of ITRs from the metering upgrade project.

In Figure 3, a portion of an ITR sheet for the telecommunication cables is presented. Here it can be seen that the cables numbered 1 to 6 were required to be inspected against the 12 listed tasks. The inspector manually recorded the results for each individual task and cable that was completed. Figure 4 illustrates an example of the ITR sheet for the instrumentation cables. In this instance, the inspectors had to manually input the cable schedule information, which included their numbers, termination destinations, size, number of cores, and reference drawings. During this manual process the likelihood to incorrectly label cable schedules increased. Consequently, this can reduce the traceability of information and hinder a reviewer's ability to ensure conformance.

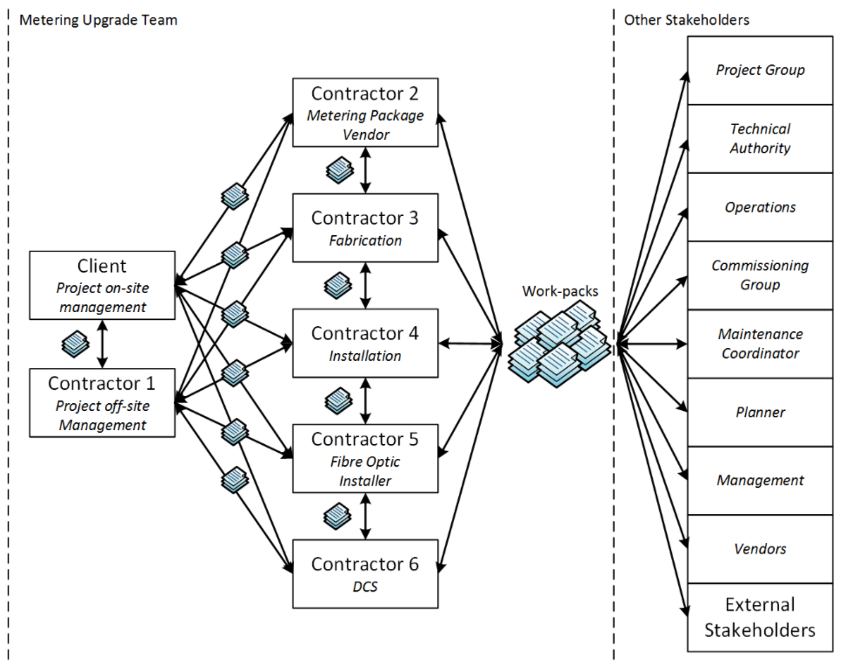

Figure 2. Inter-organizational communication

CHECK No.	ACTION – CHECK/VERIFY/RECORD (AS APPROPRIATE) (PLEASE REFER TO PROCEDURE)	Cable No.'s (refer list) 1	2	3	4	5	6	INITIAL
	INSPECT							
1	Cable voltage rating, size, cores, screen and colour correct as per cable schedule	ok	ok	ok	ok	ok	ok	
2	Cable for damage	ok	ok	ok	ok	ok	ok	
3	Route and route segregation correct	ok	ok	ok	ok	ok	ok	
4	Cable ID's and ferrules correct	ok	ok	ok	ok	ok	ok	
5	Cable markers at each end and at both sides of transits	ok	ok	ok	ok	ok	ok	
6	Gland assembly - correct type and installation	ok	ok	ok	ok	ok	ok	
7	Gland plate correct	ok	ok	ok	ok	ok	ok	
8	Earthing correct	NA	NA	NA	NA	NA	NA	
9	Termination correct	ok	ok	ok	ok	ok	ok	
10	Cable fixing and bend radius as per manufacturers spec.	ok	ok	ok	ok	ok	ok	
11	Cable mechanical protection (kick guards etc.)	ok	ok	ok	ok	ok	ok	
12	Specialist Vendor termination & test reports attached	NA	NA	NA	NA	NA	NA	

Figure 3. Telecommunication cable ITR example

TEST RESULTS

INSULATION RESISTANCE TESTS

Test Points	*Test Voltage*	*Acceptance Criteria*	*Result (Lowest Value - MΩ)* 1	2	3	4	5	6
CORE-TO-CORE	500 V DC	> 10 MΩ	>500MΩ	>500MΩ	>500MΩ	>500MΩ	>500MΩ	>500
CORES-TO-SCREEN	500 V DC	> 10 MΩ	>500MΩ	>500MΩ	>500MΩ	>500MΩ	>500MΩ	>500MΩ
CORES AND SCREEN-TO-EARTH	500 V DC	> 10 MΩ	>500MΩ	>500MΩ	>500MΩ	>500MΩ	>500MΩ	>500
		INITIAL						

TEST EQUIPMENT RECORD

Type	Manufacturer	Model	Serial No	Calibration Details
Insulation Resistance	Kyoritsu	3125	W0356165	Due 08-09-2015
Process Meter	Fluke	789	94890028	Due 09-10-2015

Item No.	CABLE No.	From	To	Size (Sq mm)	No. Cores/Pairs	Cable Code	Connection Drawing	Punchlist Y/N
1	327-GBS-94	327GBS94	27JI24	1·5	2PR		L2700DJ070.0139W1	N
2	227-GBS-94	227GBS94	27JI24	1·5	2PR		L2700DJ070.0132W1	N
3	327-GBS-93	327GBS93	27JI24	1·5	2PR		L2700DJ070.0138W1	N
4	227-GBS-93	227GBS93	27JI24	1·5	2PR		L2700DJ070.0131W1	N
5	327-GBS-92	327GBS92	27JI24	1·5	2PR		L2700DJ070.0137W1	N
6	227-GBS-92	227GBS92	27JI24	1·5	2PR		L2702DJ070.0014W1	Y N

Figure 4. Instrumentation cable ITR example

CHANGE MANAGEMENT

During the upgrade, requested change-orders required the approval of the client or project management contractor. Examples of changes that were incurred included: deviations to the basis of design, and agreed standards and specifications. The change-order management procedure implemented in the project is presented in Figure 5. When a change-order was initiated, its details (e.g., cost, and impact on program) were assessed to determine its need and whether it was within the scope of the project.

If the change-order exceeded the project's scope, it was then evaluated against the 'Project Execution Plan' and had to be approved by the project management contractor before it could be formally raised as a change application. When a change-order was approved, the existing plan was modified. All documents that related to the change-order such as drawings, BoMs, schedules and budgets were updated and its cost and influence on the schedule monitored. To maintain a traceable record of the project's execution process and the change-orders that were approved, all documents and their revisions were required to be chronologically retained and archived by the document management team. Thus, the latest version of the documents should, in theory, reflect the current status of the project. For example, the 'as-built' documentation should mirror what has been actually constructed, but evidence indicates this is seldom the case in reality (Love *et al*., 2015).

In this project, a cost reimbursement contract was awarded for the project management contractor (off-site). Table 3 provides the original budgets and the actual costs paid to the project management organization. The original contract value for the off-site project management contract was AUD$2,410,078 with change orders accounting for an additional AUD$1,734,708, an increase of 72% from the original budget. The cost for the management component of the contract increased by an additional AUD$382,868 (i.e. 66% increase), which was attributable to the preparation and processing of change-orders, revising the cost/schedule, and reporting on and amending documentation. The design component of the project manager's contract incurred an additional cost of AUD$1,105,476; an 82% increase to the original budget for design. A copy of the 'as-built' documentation was made available to the client, and is also being retained by the project management contractor for a seven-year period after the project's closeout date.

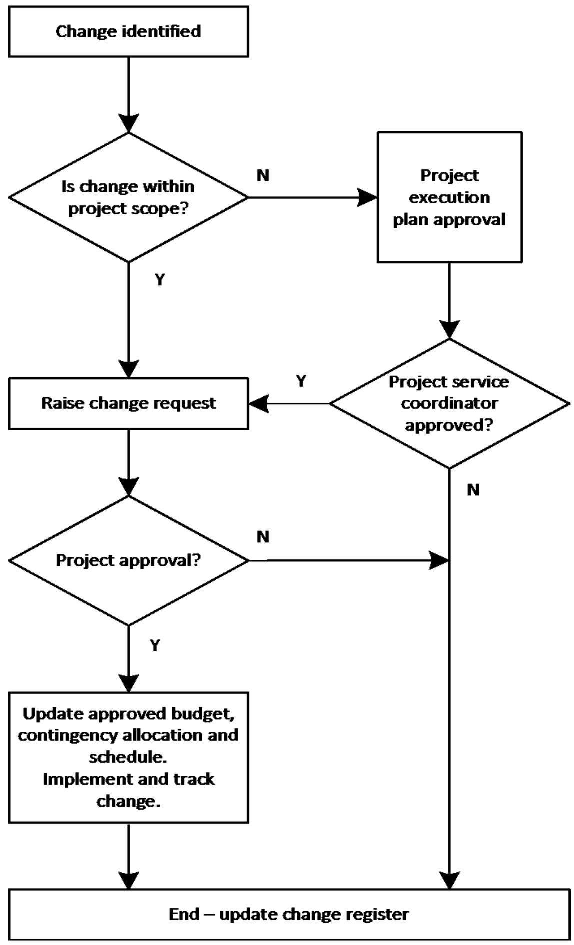

Figure 5. Management of change-order procedure

The documentation for each of the work packages handed-over at completion was found to be incomplete; for example, completion certificates for several job cards were missing. Such certificates ensure that the inspected works accords with the project plan, the manufacturers' instructions and current legislation, industry guidelines and best practice. Table 2 shows the number of completion certificates that did not marry for six work packages. The use of paper-based systems to document the upgrading of the metering facility contributed to information provided at handover being inaccurate and unreliable. As a result, this had the potential to jeopardize the asset's integrity.

To address this issue, and improve the management of information during the operations and maintenance, the design, construction and commissioning for the EICS should have been digitized using a SIM. In the next section of this paper, an explanation of how a SIM can be used to improve the management of information throughout an EICS assets lifecycle for an LNG plant is provided.

Table 3. Budget and actual cost for the off-site project management contractor

Type of costs	Responsibilities	Original budget AU$	Approved change-orders AU$	Ratio of change to original %	Total cost AU$	% of Total cost
Management	Cost/schedule management and reporting; rework management; endorse change applications.	574,414	382,868	66.65	957,282	23.0961
Expenses	Related expenses	5,550	2,233	40.23	7,783	0.1878
Design	RFI processing; engineering design of rework, drawing revision and reissue.	1,338,250	1,105,476	82.60	2,443,726	58.9590
Construction	Technical support of installation and demolition.	190,080	96,457	50.74	286,537	6.9132
Commissioning	Technical support of commissioning; coordination of contractors.	115,164	80,629	70.01	195,793	4.7238
Closeout	Training of the DCS; preparing upgrade requirements, maintenance plans and procedures; spare requirement; project files submission.	186,620	67,045	35.92	253,665	6.1201
Σ		**2,410,078**	**1,734,708**	**71.97**	**4,144,786**	**100**

A SHIFT TO THE DIGITIZATION OF EICS: SYSTEM INFORMATION MODELLING (SIM)

System information modelling is a generic term used to describe the process of modelling complex connected systems. A SIM is a shared information resource of a system forming a reliable basis of knowledge during its lifecycle (Love *et al*., 2016a;b). A SIM can be applied to model complex connected systems such as electrical control, power and information and communication technology systems.

When a SIM is used to model a connected system, all the physical objects in the real world are modelled in a relational database. Each object is only modelled once and thus a 1:1 relationship is achieved between the digital SIM model and the real world (Love *et al*., 2016a;b). This is in stark contrast to the traditional CAD approach to producing EICS documentation, such as that presented in this case study, which focused on the production of drawings where an object can be represented on many drawings. Data can be attached to objects that are created in the SIM as the project progresses, and therefore enable the formation of a consolidated POT (Zhou *et al*., 2015). Hence, a SIM can be used to manage project information throughout each phase of a project's lifecycle and provide a mechanism to ensure effective and efficient asset management (Love *et al*., 2015; Zhou *et al*., 2015).

DESIGN AND PROCUREMENT

A SIM can be used to design and document an EICS project. A digital model can be gradually created by the engineering team as the design progresses. To create a SIM, two basic attributes are allocated to each individual component; that is its 'Type' and 'Location' as noted in Figure 6. The 'Type' defines the functionality of the equipment and the 'Location' describes the physical position of the component within the plant. These two basic attributes provide a classification for the objects, which aligns with the common practices that have been adopted by many object oriented software applications. These attributes can therefore enable a SIM to act as a shared knowledge resource for information about a facility and provides a reliable basis for decisions during its lifecycle.

Within a SIM environment, connections between components are modelled as connectors, which are classified according to their types. The classifications of components and connectors enable communication and interoperability between the SIM and other object oriented software applications through data exchanges. Noteworthy, as the design is created using the digital SIM, drawings are no longer needed and thus the role of draftsperson is no longer required.

As an object-oriented approach is used to create a SIM, information such as the component model, specification, serial number, can be assigned to each individual object through attributes, which are defined and made available to all objects. For example, an attribute 'Rating' can be defined in the SIM and assigned to different types of component such as an electrical motor, sensor or transmitter. Objects are structured hierarchically, which enables child objects to inherit attributes from their parent (Figure 7). Moreover, documents, such as vendor manuals, or spreadsheets, can be linked to objects and made available down to the related 'children'.

The components and connections can be modelled to ensure the data associated with them forms a digital connected system, which enables users to dynamically review design information. Within the SIM, the object with data attached forms a consolidated POT for the corresponding physical object. As a result, errors, omissions and redundancies that often reside on paper drawings can be reduced significantly (Love *et al*., 2013). Figure 8 illustrates an example of a connected system with attached data to each individual object forming a consolidated POT of the physical connected system. When the design is complete, a digital SIM is created and information can be provided to different users, third parties and stakeholders to conduct reviews.

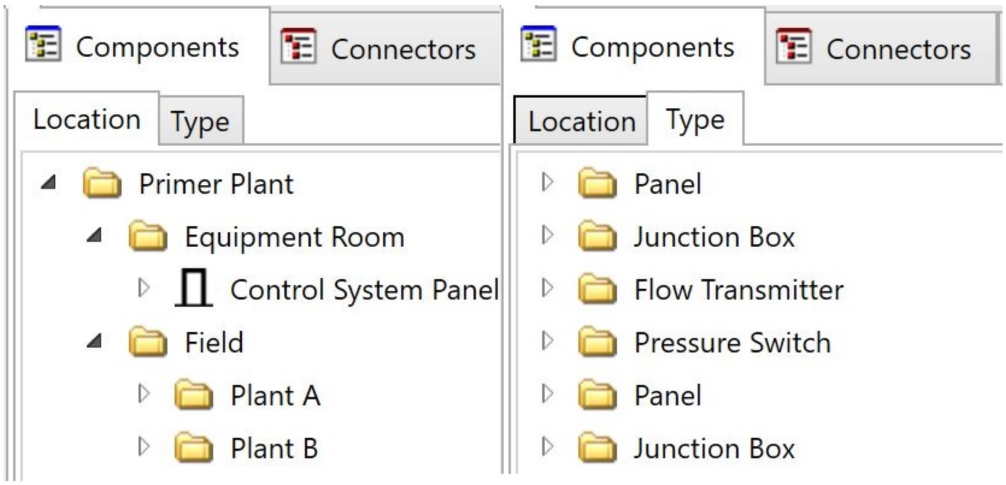

Figure 6. ‘Type’ and ‘Location’ classifications

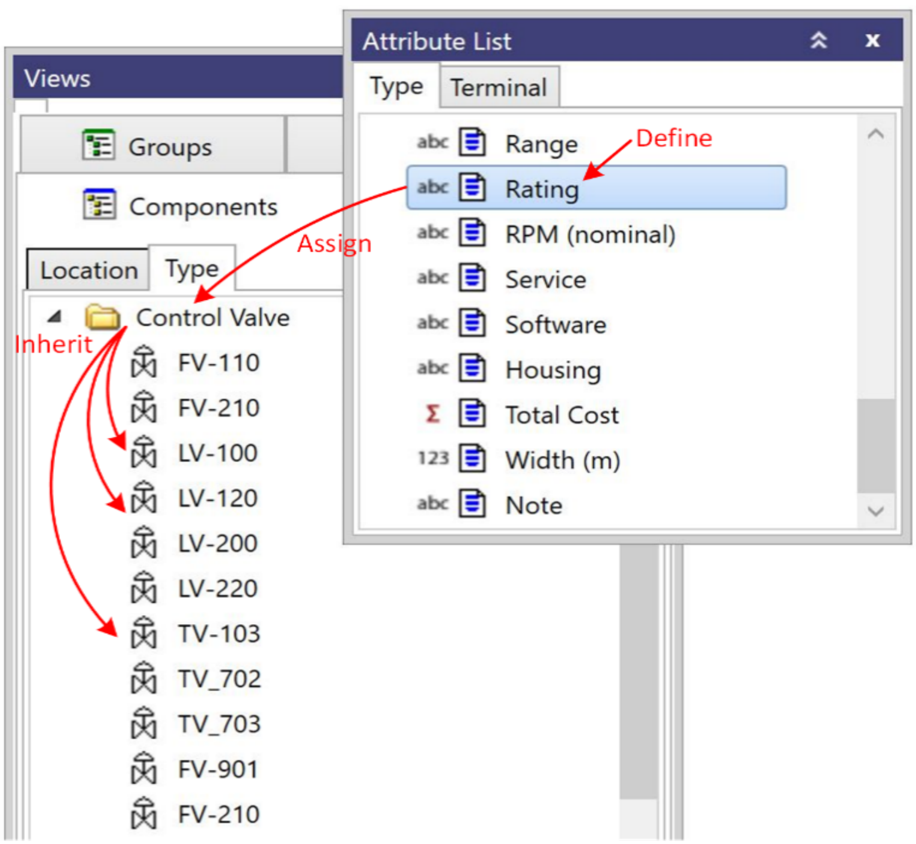

Figure 7. Object-oriented modelling for attribute assignment

CONSTRUCTION AND COMMISSIONING

The use of a digital SIM provides the means for construction and commissioning activities to be undertaken seamlessly as information can be retrieved from a consolidated POT for the EICS. For example, tasks for the installation, termination, separation and test can be created and assigned to each individual object within a SIM. This could not have occurred in the metering up-grade project studied as CAD is not object oriented. Schedules to complete tasks can also be detailed at the object level. Moreover, different kinds of tasks can be bundled as a work package and assigned to various contractors and subcontractors (Figure 9).

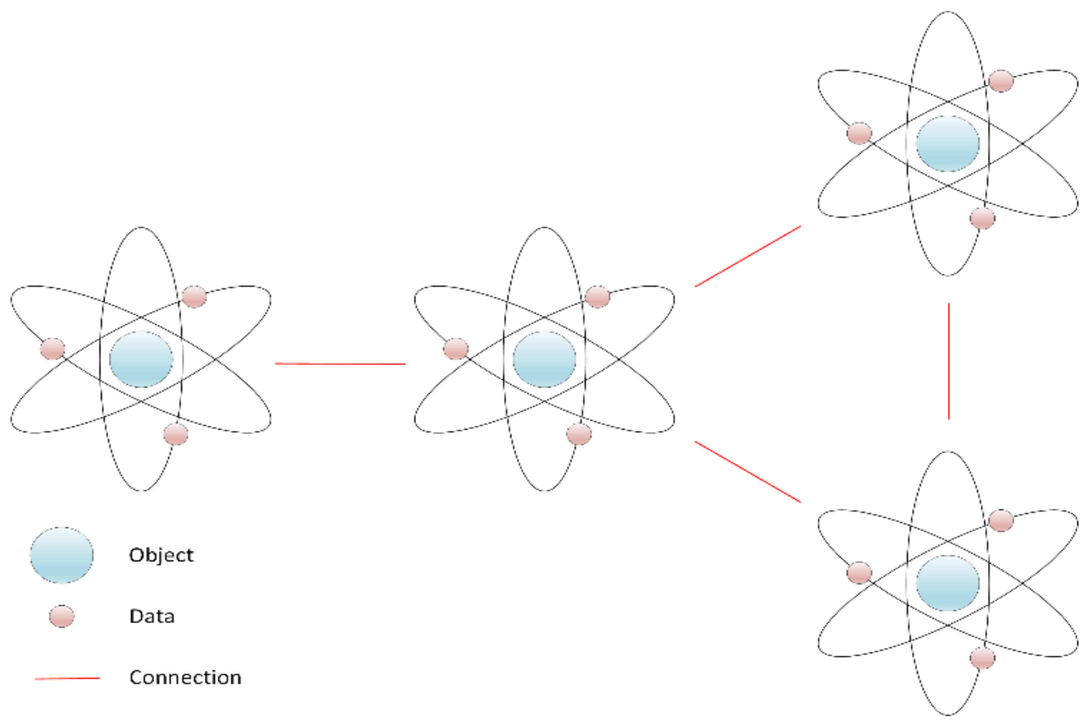

Figure 8. Connected system with data attached to objects

As traditional paper documents were used in the domestic gas up-grade project, site engineers were required to seek information from a multitude of engineering drawings, specifications and vendor manuals to plan their work. When an anomaly or error was identified in the design documents, site engineers raised a RFI for clarification from the design team. The time to respond to a RFI varied depending on the nature of the query. This resulted in documentation having to be modified, signed-off and re-issued to the contractor. Such additional costs and time for reissuing documentation had to be borne by the design team and was not recoverable.

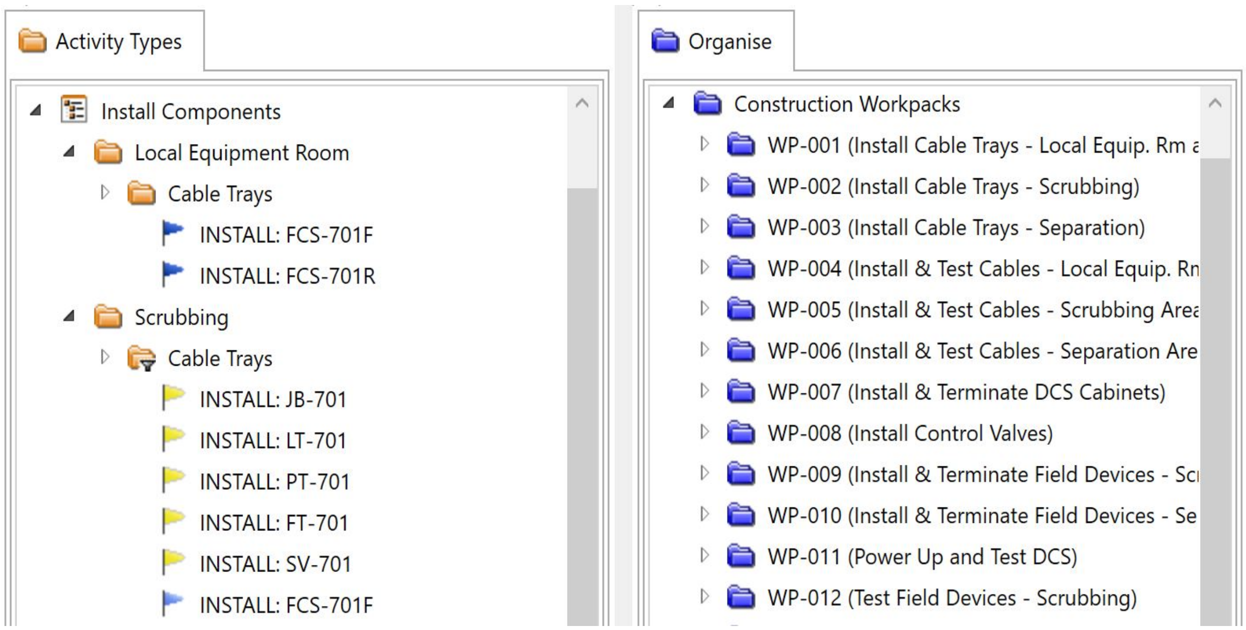

Figure 9. Tasks definition and assignment

Delays in responding to a RFI can impact the work of the contractor and may lead to a claim being made. Love *et al*. (2013) revealed that when a SIM is used in instead of CAD, the time and costs to respond to a RFI can be significantly reduced. In the case of the upgrade project, questions could have been attached to the target object and sent directly to design team. The design engineers would have been able to review the RFI and provide a formal response to the site engineers. Having data stored in a digital format within the SIM, would have enabled site engineers to access information using compatible Personal Computer (PC), tablets or smart phones, either locally or remotely *via* the Cloud (Figure 10). This eliminates the need to sieve through numerous paper based reference documents in the field to locate information. Design modifications can be readily accommodated within a SIM as it is created in an object oriented environment where modifications can instantly occur.

In the case study, CAD objects appeared on a number of different drawings, which needed to be identified, revised, reviewed, reproduced and reissued. Retrospectively, if a SIM had been used the review team could have immediate access information thus been able to review/approve the change online. Once the change had been approved, users and other third parties could have then synchronized their SIM with the latest model released. Noteworthy, a complete history log could have been created to chronically record all activities (including the user) that had been undertaken within the SIM.

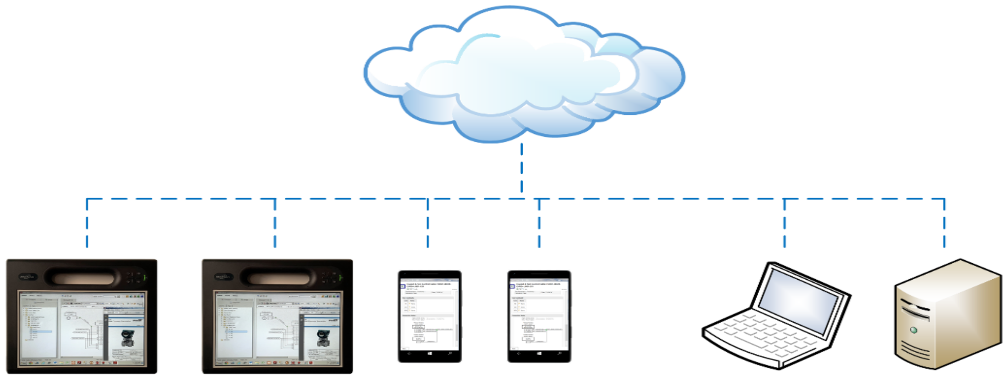

Figure 10. Accessing SIM data

System Checking and Inspection

Multiple levels of inspection can be established within a SIM environment to suit the requirements of a particular project. For example, ITRs could have been created and linked to the 'type' folders for the objects to be inspected in the upgrade project (Figure 11). In this instance, 'children' objects would inherit the ITRs from their parent folders. Inspection activities could also have been defined and allocated to suit the requirements for numerous equipment types. Comments could have been attached to each individual inspection activity and the person performing this task would be automatically recorded using their unique user's login. This process renders the manual signatures for ITRs obsolete. As all project data can be digitally stored in the SIM, a project's progress and status can be monitored in real-time, which enables project managers to review progress and improve their decision-making. Figure 12 illustrates a hypothetical project's progress and identifies activities that are: planned, to do, checked and acted on (i.e. completed).

Asset Management

The information that is required for asset management can be defined by the operator's 'Asset Information Requirements' at the onset of the project. In particular, PAS 1192-3 'Specification for Information Management' for operational management of an asset can be used with a SIM to develop a digital plan of deliverables, which can be specified in a contract. Information capture can be enabled by the use Construction Operations Building Information Exchange (COBie), which is a non-proprietary data format focused on delivering asset data rather that geometric information. Notably, in the up-grade project, information was not captured in this format and limited consideration had been given to the information needed to operate and maintain the metering system.

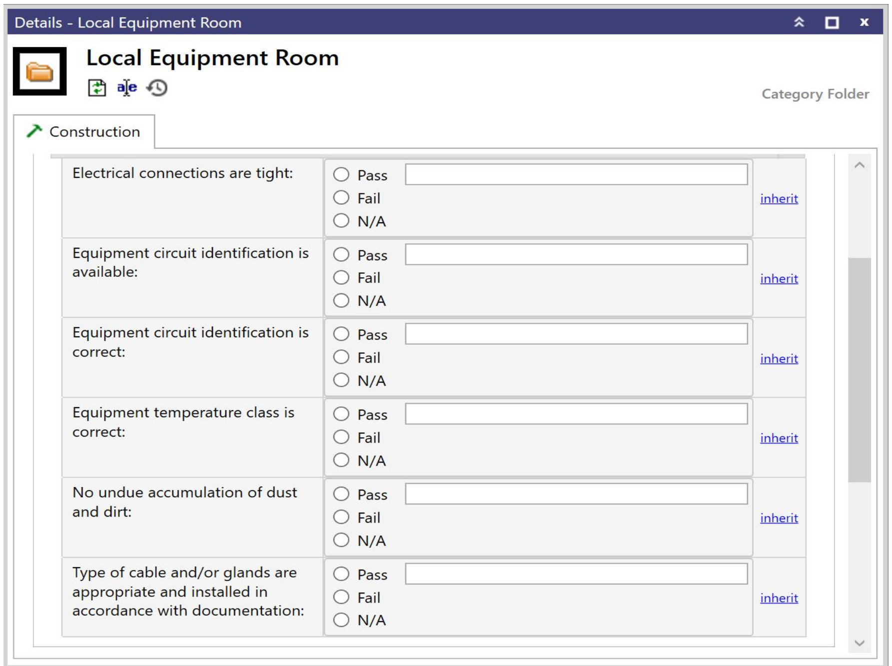

Figure 11. Inspection test report

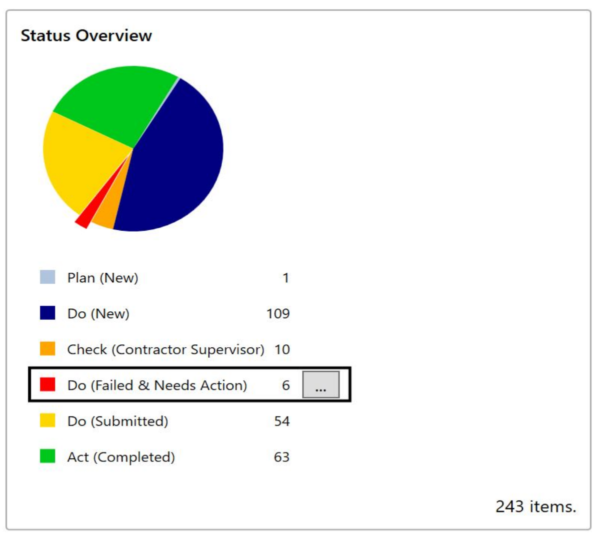

Figure 12. Project progress overview

Essentially, COBie captures and records data at its point of origin and will typically include equipment lists, product data sheets, and warranties. The data can be recorded on a spreadsheet (e.g., csv.file) in a structured format so as to facilitate its ease of access and to overcome interoperability and proprietary software problems, which may have materialized with the legacy systems that an operator had in place. Moreover, data presented in a COBie format would have eliminated the need for re-keying information, thus improving the reliability and integrity of the asset. Operations such as test, calibration, inspection, repair, minor change and isolation could have been defined and scheduled within the SIM. The SIM data would also have been able to be exported and inputted into other third party asset management applications so as to comply with an operator's asset management strategy (Figure 13). In order to validate and regulate the information produced in a SIM, the data developed and provided to the operator would have been extracted at specified milestones. This is referred to as a 'data drop' and reflects the level of development that has been reached within the project. The data drops, would have provided a mechanism to obtain the operator's information requirements at each phase of the project's lifecycle.

ESTIMATED QUANTIFIABLE COST BENEFITS OF SIM

While the use of a SIM has demonstrated the ability to provide significant cost and productivity improvements in such sectors such as mining, petrochemical and rail, there remains limited evidence of it in the LNG sector (Love *et al*., 2016a,b,c). Yet, the LNG sector has been using object-oriented software for a considerable period of time, but this has been limited to elements that possess geometry. This research has identified a myriad of issues that LNG operators face when confronted with considering EICS up-grades to existing systems. Previous empirical research indicates that the time used to produce the equivalent engineering drawings for EICS in a SIM takes approximately 2hrs (Love *et al*., 2013). Thus, taking into account the 716 drawings that were produced for the up-grade project, the cost to produce SIM enabled drawings would have been AU$214,600 compared to production in CAD, which is estimated to be AU$3,723,200.

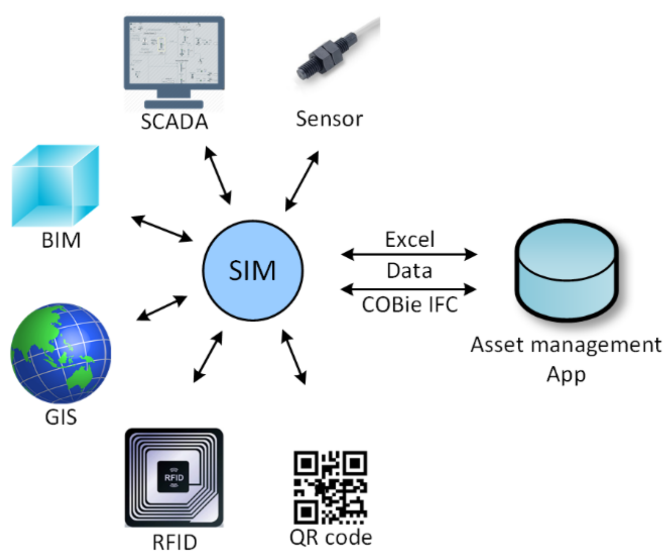

Figure 13. SIM asset management

In this instance, there would be no requirement for draftsperson and thus an engineer can directly create the SIM equivalent drawing. Thus, there is no longer a need for the engineer to spend time checking and approving drawings; while it was not possible to measure the cost saving in this case, taking a mean time based from previous studies, the cost of the time for an engineer to check (2hrs per drawing @AU$150 per hour), and then for a document controller to issue in a paper format (2hrs per drawing @$130), for each drawing, would have been approximately AU$560, and for the entire drawing set AU$400,960. So, just to produce and check the CAD drawings would have cost a total of AU$4,124,160. In this case, a staggering 95% cost reduction would have occurred to simply document the design using a SIM for the metering up-grade. This is similar to previously reported empirical based research presented in Love *et al*. (2013) in a mining project. This case study, however, did not quantify the errors and the non-productive time that would have occurred due to RFIs being raised, but such indirect costs can be significant. For example, as denoted in Table 3, the electrical contractor, who acted as the project manager, incurred an AU$1.105 million (82.60%) increase in design costs to process RFIs, issue revisions and reissue drawings that likely contained errors. The indirect costs, as a result of the idle and waiting time that may materialize during operations and maintenance, due to not having immediate access to information, have not been considered.

CONCLUSION

With an aim to improve the productivity and an asset's integrity during operations and maintenance, a case study of a domestic gas upgrade project, which formed a critical component of the LNG plant's infrastructure, was undertaken to examine the nuances of creating and managing information during its construction for EICS. The research specifically examined EICS as they account for significant capital expenditure of an LNG plant and are the primary maintainable items during operations.

The LNG sector has been proactive in adopting systems and technologies to create and manage information. However, in the case of EICS, CAD and the generation of paper documentation has tended to be the predominant medium to create information, which is subsequently stored in disparate locations that are difficult to find. When there is a reliance on using CAD, there is an increasing propensity for errors, omissions and information redundancy to materialize in the documentation.

An EICS organization provided the role of an off-site project manager for the upgrade project, and part of this role included managing inter-organizational communication, document control process, and the change-order process. While the project team worked collaboratively and had a mutual goal to ensure the project was delivered on-time and to budget, errors, omissions and information redundancy in the documentation generated hindered the project's productivity. The cost of managing the design process for the project management organization increased by 82% due to attending to RFI (i.e., due to errors, omissions, and conflicts in the documentation) and then reissuing drawing revisions in a paper format to respective parties.

To address the problems identified in the case study, it is suggested that if LNG plants are to make headway to being 'future-proofed', then their EICS should be digitized. With this in mind, the object oriented modelling approach, enabled by a SIM, would have been a better solution for creating and managing information for the domestic gas metering up-grade. The cost to produce the 716 drawings alone would have been approximately 95% less to create using a SIM. A consolidated 'point of truth' with information stored in a centralized location and readily retrieved throughout each phase of the assets lifecycle, would have also been established.

The domestic gas metering upgrade case study has illustrated the problems associated with using CAD to design and document EICS and the issues that can materialise during construction and thus influence the quality of 'as-builts' at handover. The metering upgrade project experienced a significant cost increase due to issues that were embedded in the documentation, causing a significant number of RFIs to be issued. In recognizing the inherent problems with using CAD to create and manage the documentation process for EICS projects, the use of a SIM is proposed and explained with emphasis being placed on its use for managing information during the operations and maintenance of LNG assets. Further empirical research is required to ensure the reliability and validity of the approach proposed to improve productivity and safeguard assets and process safety. In particular, the next stage of the research will be to consider the range of alternatives to SIM and to test which approach gives the best results under all conditions and taking account of a range of quantitative and qualitative factors. Whilst this paper summarises the work done by one researcher user SIM, it is recognised that future work will include analyses of SIM and other approaches to determine their effectiveness in a range of situations and environments. It is an evolving area of research which will need further rigorous testing.

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