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System information modelling in practice: Analysis of tender documentation quality in a mining mega-project

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ABSTRACT

The quality of information contained in tender documentation produced using Computer-Aided-Design (CAD) and provided in a hard-copy format to an electrical engineering contractor for a port expansion facility, which formed an integral part of an Iron Ore mega-project is analyzed. A System Information Model (SIM), which is an object oriented approach, was retrospectively constructed from the documentation provided to assist the contractor with their tender bid preparation. During the creation of the SIM, a total of 426 errors and omissions were found to be contained within the 77 tender 'drawing' documents supplied to the contractor by an Engineering, Construction, Procurement and Management (EPCM). Surprisingly, 70 drawings referenced in the tender documentation, and the Input/Output lists and Cause/Effect drawings were not provided. Yet, the electrical contractor was required by the EPCM organization to provide a lump sum bid and also guarantee the proposed schedule would be met; the financial risks were too high and as a result the contractor decided not to submit a bid. It is suggested that if the original tender documentation had been prepared using a SIM rather than CAD, the quality of information presented to the contractor would have enabled them to submit a competitive bid for the works. The research concludes that the economic performance and productivity of mining projects can be significantly improved by using a SIM to engineer and document electrical instrumentation and control (EIC) systems.

1. Introduction

Design and engineering is only effective when it serves its intended purpose and is constructible within desired budget, time, quality and safety objectives [1]. An electrical instrumentation and control (EIC) contractor, for example, must be supplied with high quality information so as to enable them to construct their work effectively and efficiently and without hindrance [2–7]. Rarely, however, is the design and engineering of EIC documentation for mining projects produced with all the necessary information being made available when tenders are sought [8]. More often than not contractors are supplied with incomplete, conflicting and erroneous documents [9]. In addition, contractors are often required to submit a tender within a limited time frame. In such a case, a considerable amount of contingency may be incorporated into the bid, especially if requests for information (RFI) fail to provide information needed to ensure works can be carried out efficiently and effectively. Consequently, bids can be inflated and/or render a project unfeasible.

In this paper, the quality of information in the tender documentation provided to an electrical engineering contractor for a port expansion facility (which formed an integral part of an Iron Ore mega-project) is analyzed. Notably, such information is rarely made available for analyses due to its commercial sensitivity. Moreover, there has been limited empirical research that has examined the quality of information contained in the documentation that has been prepared to solicit tenders. Such research, however, is needed to demonstrate the prevailing issues that adversely impact the costs of mining projects to clients.

The participating contractor is hereafter referred to as 'Contractor A' to preserve confidentiality agreements made between both parties. The aim of this paper is to examine the nature of errors, omissions and information redundancy that were presented in the tender documents and the potential risk exposure that the contractor would have faced in the field should they have been awarded the project. To address the deficiencies contained within the drawings provided in tender documents

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for EIC systems, it is suggested that the use of an object oriented approach, referred to as a System Information Model (SIM), to design and document the project instead of Computer-Aided Design (CAD) can significantly reduce the occurrence of errors, omissions and information redundancy [2–6]. Thus, a SIM can be integrated with a Building Information Model (BIM), yet the use of software applications of this nature to produce EIC object models are rarely used in the Australian mining sector [6]. Yet in the mining industry, EIC accounts for approximately 29% of the world's capital expenditure on plant. Furthermore, in plant operations, EIC typically accounts for 60% of maintainable items as well as being critical to safe and efficient operations [6]. Despite their importance, there has been limited research that have examined EIC systems within an object oriented environment within the construction, energy and resources sectors [5,10]. A SIM forms an integral part of the BIM nomenclature and has been described in detail in Zhou et al. [7].

2. Case study

Thus, against this contextual backdrop, the following research question is examined in this paper using a case study: Is a SIM able to provide significant cost and productivity improvements during the production of design and engineering documentation for EIC systems? To address the aforementioned question, triangulation was used as the basis for data collection process, which took place at the offices of an electrical engineering firm who had been invited to tender for a system upgrade for an existing Port Facility.

Triangulation involves the use of multiple research methods and/or measures of a phenomenon, in order to overcome problems of bias and validity [11,12]. Data collection methods employed were unstructured interviews, observations and documentary sources (e.g., tender documents). In addition to the active day-to-day interactions between the participating organization and lead researcher, unstructured interviews with key personnel were also undertaken by a secondary researcher. This approach was undertaken to provide additional context to the problem and provide validity to the research process.

2.1. Background

Growing demand for iron ore from countries such as China and India has stimulated the development of existing facilities to better accommodate increased iron ore production from 45 Million tons per annum (Mtpa) to 155 Mtpa. The expansion project (referred to as T155), situated in Western Australia (WA), required additional port facilities and rail systems. Company Iron Ore (IO) procured the project using an Engineering, Procurement, Construction and Management contract (EPCM). In this instance, the EPCM contractor assumes responsibility for coordinating all design, procurement and construction work.

The expansion project consisted of two parts: (1) the facility upgrade at the existing port; and (2) the construction of a rail spur to the two new mine sites. The railway spur was approximately 135 km long connecting the mainline railway to the newly developed mine sites which include an airstrip, operations and construction accommodation, plant, roads, power, water, fuel, utilities and stockyards. An upgrade to the existing mainline railway was also undertaken to enhance the rail system's capacity. A 155 km duplication of the selected section of the mainline rail was also constructed to connect the port and an existing mine site.

The port facility's upgrade was planned to be completed within three stages. Stage one, referred to as T60, constructed a second outloading circuit, which increased the port's export capacity from 45 Mtpa to 60 Mtpa. The works that had been completed were dredging, installation of a new wharf for the third berth, a shiploader, sample station, reclaimer, two transfer stations and all the conveyors between them. Stage two provided the port with the second and third inloading circuits. The work involved the installation of two new train unloaders, a stacker, three transfer stations, the conveyors between them and the associated equipment. Stage three involved an additional outloading circuit, which increased the port's export capacity further to 155Mtpa. The work involved the construction of a new wharf for the fourth and fifth berths, a shiploader, reclaimer, sample station and all the interconnecting conveyors and Transfer Stations.

2.2. Control system upgrade for port facilities

The control system expansion of the port facilities were also implemented in three stages in accordance with the project schedule. In Stage one (Upgrade to 60 Mtpa) ten new High Voltage (HV) and Variable Speed Drive (VSD) switch rooms were constructed and linked into the existing T45 network. Stages two and three consisted of constructing 21 HV and VSD switch rooms which were tied back into stage one's T60 network.

The tender documentation that described the control system upgrade requirements of the existing port facilities were provided to several Electrical Engineering firms for review prior to bidding for the works. The tender invitation was sent to potential contractors on 12/04/11. The tender submission deadline was 03/05/11, which meant that interested applicants needed to complete the activities identified within three weeks. A lump sum bid was required for the control system by ‘Company IO’ and all work specified in the contract was required to be completed by the specified date. In addition, it was explicitly stated that any cost overrun incurred by latent uncertainties and insufficient information contained within the contract documents were at the contractor's risk.

2.3. Tender documentation

The tender documents comprised of 126 files, containing a total of 1687 pages. The tender documents studied in this research described the requirements of the control system installation, Programmable Logic Controller (PLC) and Supervisory, Control and Data Acquisition (SCADA) software development of the port facilities. Fig. 1 illustrates the structure of the proposed control system after the expansion project. In addition to the existing system, the port facility expansion project requires new field devices, marshalling panels, switch rooms and the cables to be installed on site. The newly introduced devices were required to seamlessly interact with the existing system forming an integrated monitoring and control system, which would provide information for the plant operation managers' supervision. In preparing the tender, an electrical contractor would typically undertake the following steps:

- allocate a dedicated engineering team to undertake the tender;
- read through the 126 files (1687 pages) provided as part of the tender package;
- determine the system functions and requirements to be achieved;
- examine the 77 contract drawings and estimate the quality of the required equipment to construct the control system;
- identify errors and omissions contained in the contract drawings;
- raise an RFI to the principal's engineering team seeking clarifications of the problems identified;
- investigate the principal and technical specifications and determine the proper classes of the equipment and cables required by their corresponding safety classifications;
- estimate the Input/Output(I/O) points of the expansion system;
- investigate the existing T45 system to determine the interface and control schemes between the proposed and existing systems;
- clarify the functions to be coded so as to realize the required control system functionalities;
- define the Human Machine Interface (HMI) graphics;
- estimate and calculate the cost of equipment, cables and software;

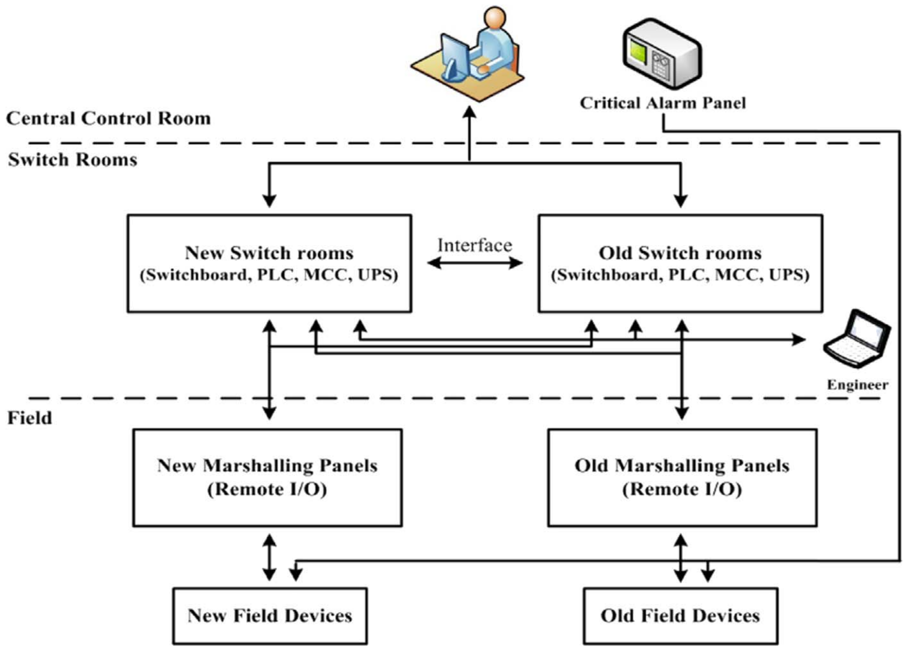

Fig. 1. Control system illustration.

- determine the manpower requirements;
- complete all the tables and schedules listed in the tender package (over 30); and
- submit the tender application.

A detailed examination of the tender documents by the contractor and researchers revealed numerous errors, omissions, and misleading and conflicting information. Consequently, the date required to produce a tender was considered unachievable by the electrical contractor. In particular, designing and constructing the project's first switch room within seven weeks would have been a herculean task considering the paucity and inaccuracy of information provided. 'Contractor A' decided not to risk submitting a tender due to the gravity of commercial risks posed. In trying to decipher and comprehend the scope and nature of work contained within the tender package, a principle engineer stated:

> "The documents contained many internal conflicts and omissions so we failed to understand the required scope. The work required was not sufficiently defined for a lump sum contract. Offering a bid, in its present form, would be an unacceptable commercial risk to us.'

The overall structure of the control system, as defined in the tender documentation, was not clearly specified. The typical process within ports for exporting iron ore consists of unloading (from trains or trucks), transporting and sampling and loading (to ships). Often (depending on the size and capacity of port), a number of devices and facilities are involved such as train unloaders, conveyors, shuttles, stackers, reclaimers, sample stations, ship loaders and other miscellaneous equipment. To achieve a safe and environmental friendly production process, all the devices were required to conform to a robust safety control system where a number of risk controls must be implemented (i.e. dust suppression, structural anti-collision, materials route sequencing and stockpile management). Several environmental auxiliary systems, such as oil water separation, sewerage treatment and potable water generation, also needed to be integrated into the plant to facilitate production. All the systems are controlled by the PLCs and supervised via the Central Control Room (CCR) through Supervisory Control and Data Acquisition (SCADA) networks. It was implied that the process and safety control system would be designed together to maximize productivity by being capable of immediate fault detection and diagnosis so as to minimize system down time.

A brief overview of the existing control system for the transportation of iron ore was presented in the tender documents and included information such as the number of control rooms installed, the configuration of the SCADA system and its functionalities. It also numerated the new devices to be installed so as to form the 2nd/3rd inloading and outloading circuits. However, tender documents failed to provide a clear hierarchy of how the control devices (new and old) should be integrated together to form a Distributed Control System (DCS). The contractor's principle engineer, suggested that a preferred DCS structure would have assisted them to understand the design and should have contain the following key features:

- hierarchies of the control network such as divisions within the central control unit, local control unit, communications, power supplies and field devices;
- divisions of the process control system and the safety control system;
- types of field buses jointing the control network and the connection techniques interfacing different types of buses; and
- configuration of Supervisory Control and Data Acquisition (SCADA) networking; and
- devices involved in each hierarchy.

Moreover, the tender documents did not specify how the expansion project could be integrated into the existing system. For example, a portion of iron ore from the new train unloaders (TU602, TU603) were to be shunted to an existing stacker (SK701) through a new transfer station (TS906) and an existing stacker conveyor (CV911) for stockpile distribution. This raised the question as to how TS906 and CV911 would react at the failure of stacker SK701 (Fig. 2). As the new inloading and outloading circuits would work in conjunction with the existing circuits, PLC coding needed to effectively integrate both new and old systems. In the absence of a clear description of the system integration, applicants were unable to accurately estimate the coding workload involved.

3. Research findings

A total of 77 EIC drawings were provided in the tender package. These drawings included 60 single line diagrams (SLD) to illustrate how various configurations of the HV, VSD and motor control panels were to be constructed, and eight Piping and Instrumentation Diagrams (P & IDs) describing the process flows and installed instruments.

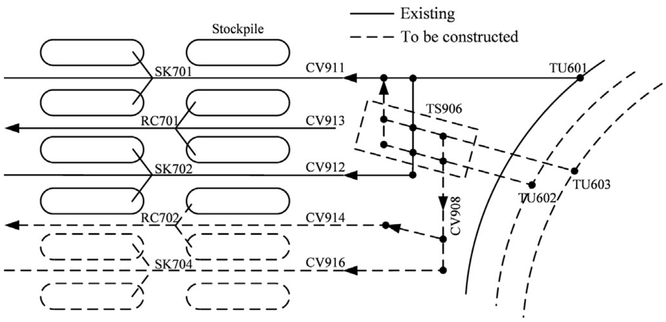

Fig. 2. Connection example between circuits.

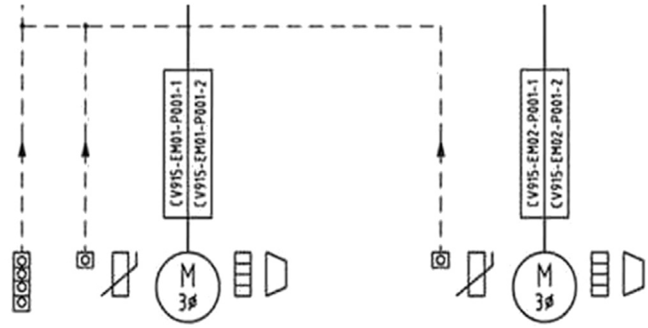

Fig. 3. Example of missing label.

The relationships between the cables and components were extracted from the tender documentation and inputted into a SIM. This enabled a description of the connected systems such as control, power, information technology (IT) and communications using a single digital representation [2]. The tender documents, however, did not include a cable schedule and as a result, designs had to be manually transferred from CAD drawings into a SIM; this established a 1:1 relationship between designs to be constructed in the real world and their digital realizations. Each piece of equipment was created with 'Type' (i.e. defined equipment functionalities) and 'Location' (i.e. described the physical position of equipment) attributes. Such classifications, enabled engineers to browse the SIM model and locate the required information. For example, a conveyor drive motor (CV915-EM01) can be found under the folder 'Type\Motor' as well as the folder 'Location\CV915'. As each cable or component is only modeled once, errors and omissions contained within the CAD drawings were identified and rectified during the SIM conversion process.

3.1. Errors and omissions

The completed modelling process identified a total of 1545 cables and 1518 components within the 77 drawings. Numerous errors and omissions found would have hindered the engineers' ability to interpret the information contained within these tender documents. These errors and omissions were classified as follows:

1. *Incorrect labeling*: Cables or components are labeled with incorrect names;
2. *Inconsistent labeling*: Cables or components are named differently within various contractual drawings;
3. *Incorrect connection*: Cables or components were connected to wrong connections;
4. *Drawing omission*: Cables and components were missing from some drawings;
5. *Missing label:* Cables or components are drawn on drawings but are not labeled;
6. *Incomplete labeling*: Labels of cables or components are not completely shown.

A thorough review of the tender documents was conducted to identify the extent of errors and omissions found (Table 1). It can be seen that a total of 426 errors and omissions occurred within the 77 drawings. A total of 84 omissions (65 cables, 19 components) were identified on the CAD drawings; as information was not dynamically linked, information traceability was significantly reduced. A total of 244 errors and omissions (i.e. 57.28% of all problems identified) were attributed to cables. 182 (42.72%) errors and omission were associated with components. Noteworthy, the classification of 'Missing Label' was the most prevalent accounting for 59.86% of all issues identified. A typical example of 'Missing Label' is denoted in Fig. 3 (a portion of drawing 515P-10,016-DR-EL-3203) where cables and components were created but corresponding labels not allocated.

3.2. Reference drawing numbers

Considerable amounts of cross coupled reference drawing numbers were identified in the drawings. Notably, 70 of the drawings referred to were not made available to the applicants at the tender package and three drawings were mistakenly referenced. For example, Fig. 4 (a portion of drawing 505P-10,016-DR-EL-0505) illustrates that a transformer TF586 and motor control center MC586 are shown in drawing 505P-10,016-DR-EL-0507. However, they could not be located in the designated target drawing.

A total of 203 reference drawing labels that appeared on 77 contract drawings were not annotated completely. For example, a reference drawing was labeled as 505P-10016-DR-EL-× × × × where the last four digits were replaced by '× × × ×' instead of a specified drawing number. Given such an obscure expression, it proved impossible to locate the drawing where the reference information resides.

3.3. Unavailable cable schedule

In the case of electrical engineering projects, there is a proclivity for cable schedules to be used to document inter-connections between components and cables, and to estimate the quantity of materials used to form the control networks. If the information extracted from cable schedules is different from that expressed on a drawing, then the risk of an error or omission arising is elevated. No cable schedule however was provided in the tender documents and so consequently, contractors tendering for the project could not check that the information conveyed on the drawings with the cable schedule. Furthermore, to take-off the

Table 1
Classification of errors and omissions.

	Error Types							
	Incorrect labeling	Inconsistent labeling	Incorrect connection	Drawing omission	Missing label	Incomplete labeling	Sum	Percentage
Cable	22	13	4	65	139	1	244	57.28%
Component	16	25	4	19	116	2	182	42.72%
Sum	38	38	8	84	255	3	426	100.00%
Percentage	8.92%	8.92%	1.88%	19.72%	59.86%	0.70%	100.00%	

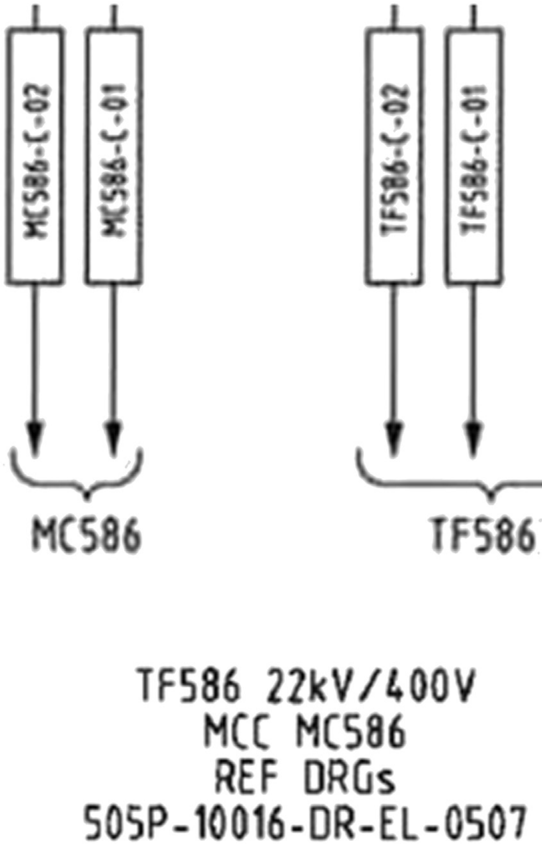

Fig. 4. Example of incorrect reference.

quantities, the contractors would have had to examine all the drawings, which would have been an unproductive process.

3.4. Information discrepancy

A list containing the instrumentations required was provided to the tenderer for reference (Table 2). Major discrepancies were found between the EPCM organization's estimations and what were actually required. Table 2 reveals that the numbers of instruments calculated from the available 77 drawings are far less than those estimated by the EPCM. It was also observed that many instruments found on the drawings are not mentioned by the EPCM. Table 3 identifies several examples of instrumentations that were missing from the EPCM's estimations but were identified on drawings. Such information discrepancies would have prevented engineers from accurately determining the required equipment and man-hours to complete the project.

Table 2
Comparison between estimation and calculation of instrument numbers.

Instrument type	Estimated by client	Counted on drawings
Belt Drift Switch	135	77
Absolute Encoder	6	3
Flow Switch	16	13
Level Switch	13	12
Magnet	6	1
Metal Detector	6	2
Moisture Analyser	6	1
Pressure Switch	184	8
Pressure Transmitter	4	1
Proximity	209	55
Pullwire switch	200	127
Rip Detector	46	25
Solenoid Valve	209	39
Hydraulic Controller	2	2
Temperature Switch	3	0
Temperature Transmitter	60	40
Tilt Switch	28	0
Vibration Switch	17	0
Warning Siren	100	50
Weightometer	20	8

Table 3
Instruments missing from client estimations.

Instrument type	Counted on drawings
Blocked Chute Switch	28
Emergency Stop	38
Flow Transmitter	10
Hand Switch	22
Isolator	70
Local Control Station	19
Motor	50
Speed Switch	23

To demonstrate the information discrepancies inherent within the tender documents, the control systems of three equivalent conveyors (CV908, CV914 and CV916) were chosen and compared. By examining the Control and Operating Technical Specification (COTS) documents provided in the tender package, the basic functionalities and the associated equipment that consisted of the control system of a typical iron ore conveyor were determined (Table 4). The first column in Table 4 specifies the basic functionalities for each conveyor and the second column lists the devices required to perform key functionalities. The numbers of equipment involved may vary due to different lengths and locations of the conveyor systems. Designs of the three conveyors were analyzed and the devices associated to each conveyor system were extracted from the 77 tender drawings (Table 4). It was apparent that a large number of devices were missing from the designs of conveyors CV908 and CV916. Only a few devices could be identified, for example, motors and the associated equipment, which are used to drive the

Table 4
Comparisons between conveyors.

Functionalities	Equipment required	Equipment identified		
		CV908	CV914	CV916
Conveyor operation	Motors	0	4	0
	Gearboxes	0	0	0
	Hydraulic braking system	1	2	4
	Take-up winch	0	1	1
	Scraper belt washing	0	1	0
Route sequencing	Speed switches	0	2	0
	Belt weigher	0	0	0
	Ore detector	0	0	0
Belt washing	Solenoid valve	0	1	0
Motor operation	Motor RTDs	0	12	0
	Motor heater	0	4	0
	Motor brake	0	4	0
	Gearbox RTDs	0	0	0
	Master VSD	0	1	0
	Slave VSD	0	3	0
Brake operation	DOL motor	1	2	4
	Solenoid valve	0	2	0
	Pressure transducer	0	2	0
Winch operation	DOL motor	1	1	1
	Hand switch	0	0	0
	Position switch	0	4	0
Safety control	Pull wire switch	0	34	0
	Belt drift switch	0	10	0
	Belt rip detector	0	8	0
	Blocked chute switch	0	6	0
	Emergency stop	0	4	0
	Warning siren	0	10	0

conveyor belts.

Safety control devices, which are used to stop a conveyor system in case of any hazardous events, were also not provided. Though more information was provided for conveyor CV914, omissions could still be identified and included gearboxes and associated devices between motors and belt pulleys that had been omitted from the drawings. Moreover, belt weighers (which calculate the weight of ore on conveyor belts), and hand switches (used to manually operate the belt winch) could not be found in the designs of CV914, CV908 or CV916.

3.5. Unavailable I/O and cause/effect documents

It was also found that an I/O list, which is used to define the inputs and outputs of the system, was not issued with the tender documentation. An I/O list provides a tool to measure the project complexity and estimate the man-hours to complete the work. As the I/O list was not made available, the contractor could not calculate the numbers of ports for the field instruments and control devices. Cause/Effect (C/E) drawings, which are used to document the functions of a control system (i.e. descriptions of what actions will be taken in the presence of a cause event), were also not provided to the tenderers. Consequently, the contractor was unable to estimate the number of PLCs and remote I/O modules to be used and the labor required to code the control system.

3.6. Information redundancy

Information redundancy embedded within CAD drawings has been identified as another critical element that contributed to delays experienced during the engineering phase [2]. Each equipment item in the real world may appear several times on different drawings forming a 1:n mapping. The redundant information for cables and components identified from the tender drawings are presented in Table 5. In total, 1348 cables and 1334 components appeared once on those 77 drawings; 196 cables and 144 components appeared twice; 22 components appeared three times; and 12 components appeared four times. Surprisingly, one component appeared nine times! In this instance, a change to any object acts as a catalyst for manually changing drawings, which is a costly and time-consuming process.

Prior to the production of engineering documentation, a draftsperson is required to determine the exact information that should be presented and the correct relationships between components for each particular drawing. A draftsperson also ensures that labels for cables and components remain consistent with one another to avoid confusion or any misunderstanding. It is estimated that 3020 person-hours were required to produce the 77 tender drawings, and an average of 39.22 person-hours per drawing. The market pay rate for a draftsperson in WA at the time of the tender was being prepared was AU$130 per hour; this work approximately amounted to AU$392,600 in direct pay and possibly more if indirect costs were included.

For the port expansion project a total of 8633 drawings were used to document the electrical engineering related designs including: 831 layout diagrams; 398 general arrangement diagrams; 168 single line diagrams: 2767 schematic diagrams: 1644 termination diagrams; and 2825 other miscellaneous drawings. Assuming the drawings were of a similar quality to the tender drawings, then a total of 338,586.26 person-hours would be required to create the 8633 drawings at a cost of AU$44,016,213. The original budget for the port expansion project was AU$2.4 billion with 12% of the budget allocated to the EPCM, which is approximately AU$288 million. The electrical engineering related design and documentation required 20% of the EPCM cost (AU$57.6 million). Thus, the cost to produce the 8633 electrical drawings consumed 76.42% of the electrical engineering portion of the budget and 1.83% of the entire project's budget. Notably, this is only for the draftsperson's cost to generate the initial drawings. The cost of revising these drawings due to errors and omissions has not been considered.

Table 5
Information redundancy.

Number of occurrences	1	2	3	4	5	6	7	8	9
Number of cable	1348	196	1	0	0	0	0	0	0
Number of component	1334	144	22	12	4	0	1	0	1

Analysis of the 77 drawings revealed that 56 (72.73%) contained errors or omissions and a total of 115 RFIs would have been raised to address these problems. In addition, it is estimated that on average, each one of the 56 drawings would have been revised twice after the RFI process; though discussions with the contractor suggested that this was a conservative estimate. As a result, it is estimated that a total of 6446 out of the 8633 drawings would be revised twice. All the revised drawings and their previous versions would need to be archived for version control purposes. The total number of drawings to be controlled would be 21,555. To deal with these drawings more efficiently, a sophisticated numbering system is required; where drawings are categorized and numbered according to their various types and functions. Multiple copies of these drawings can then be printed and issued to different contractors.

Three weeks were insufficient for the contractor to prepare a lump sum bid due to the onerous nature of the documentation provided. The errors, omissions and conflicts contained within the tender documents would have hindered the contractor's ability to interpret the design correctly and present a competitive bid. Decisions taken (based on the erroneous information) could have potentially lead to rework being undertaken downstream and potentially jeopardize the entire project's success.

4. System information model

To effectively and efficiently address the problems that were identified in this case study, it is suggested that an object oriented modelling process enabled using a SIM should be employed in EIC projects rather than using a documentation process that utilizes CAD. A SIM can be applied to model the connected systems where components are interconnected and possess various relationships. For example, when a SIM is used to model the electrical, power and communication systems, the physical objects and cables can be modeled as digital components and connectors in a database, which can be accessed through specific software such as Dynamic Asset Data.

The SIM forms a digital representation of a 'real system' and each physical object only needs to be modeled once. Therefore, a 1:1 relationship is established between the real world and the model [2,7]. The data stored in a SIM is dynamically linked and therefore enable efficient management of the information [5]. Engineers can work collaboratively and concurrently on the same project model by creating the components and relationships among them [2]. Thus, duplicated modelling of an identical device can be detected and avoided automatically [5]. As each object modeled is allocated with a unique tag number, the problem of 'missing labels' is eliminated [6,7].

Object attributes, (such as type and specification) can be created and assigned to each individual component and connector [5]. These attributes and the associated functions enable the model to be used during the entire lifecycle of a project [3]. A SIM model can be accessed either through a database hosted on a local computer or though remote cloud based services. The devices used to access the database can be a desktop computer, laptop, industrial tablet or smart phone.

On completion of the design, the model is protected from any unauthorized changes to the data stored. As a result, the design can then be exported and issued to other users as a read-only copy that is made available via a 'Kernel' (Fig. 5). Users can access the design information based on their authorization level. Private user data can be created and attached to the model such as attributes, photos and documents. To

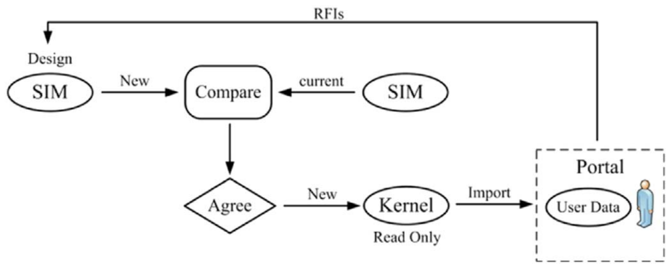

Fig. 5. Kernel revision process.
(Adapted from Love et al. 2013).

protect the design from unauthorized changes, the contents of the Kernel can only be modified by the design engineers. If users identify conflicts or design errors in the Kernel, an RFI can be generated from a dedicated folder within the user portal. A spreadsheet can be automatically generated that contains all the object information either in Microsoft Excel or portable document format (pdf.) file format [7]. On receipt of the spreadsheet, the project team can review the design and rectify the problems before generating and exporting a new 'revised' Kernel to users for further application [7].

With the adoption of a SIM, drawings can be eliminated and the error rectification process becomes straightforward, as all required changes can be carried out within the digital model. This approach eliminates the need for an engineer to identify all other relevant drawings and thus revise them manually. Time and cost can be therefore reduced and productivity increased [2]. When CAD drawings are used, relationships between components contained within various drawings are denoted by reference numbers that increase the propensity for errors to be made. The linkages between components can become very complex if a project's size increases. Incorrect or incomplete labeling reduces information traceability. As noted above, the allocated time to recover this missing data can significantly be increased. The use of SIM overcomes this issue. For example, in Fig. 6 an engineer can inspect the connection of a junction box (JB-101) directly within a SIM model. The components connected to the selected junction box can be displayed automatically and dynamically, and as a result the tracing of connections via drawing reference numbers is no longer required.

Quantity take-offs can be accurate when using a SIM. Interpreting and recovering information presented on several drawings is clearly an unproductive process; errors and omissions contained within drawings can adversely impact a contractor's procurement process (e.g. material waste, and rework). As all the components are categorized according to their 'Type' and 'Location' classes (Fig. 7), users are able to identify and locate the required equipment.

Using the 'Quick Spreadsheet' function provided equipment numbers can be identified directly by users. Cost information for these items can also be acquired automatically through the 'cost attribute', which is assigned to each individual component. This can enable users to produce an estimate and determine the man-hours required to complete the job at hand [7].

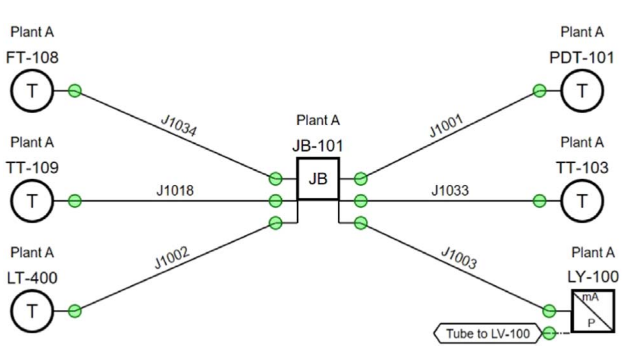

Fig. 6. Example of interconnected components.

The culmination of research presented here suggests that if a SIM model had been adopted, the T155 port expansion project could have been designed and progressed more efficiently as less errors and omissions would have occurred. Essentially, a SIM based design can assist tenderers to evaluate and prepare a competitive bid for scheduled works. A reliable and reasonable bid can reduce 'risk' to the contractor but also facilitate the progress of downstream activities through informed decision-making and therefore mitigate against project delays and cost overruns.

5. Conclusion

A detailed analysis of omissions, errors and information redundancy was undertaken for the EIC tender for upgrading a control system. An analysis of 77 drawings provided in tender documentation revealed 426 errors, and 70 drawings that were referenced had been omitted. Yet, the 'Contractor A' was bound by a fixed lump sum price and a rigid project schedule. Several contractors had been approached to provide a tender price by an EPCM organization. However, 'Contractor A' decided not to submit a bid as the risks of financial loss outweighed the opportunity to generate a profit. However, several firms did provide a tender price and the contract was subsequently awarded.

Considering the quality of documentation provided, the potential for opportunistic behavior by contractors significantly increases as they accommodate for errors and omissions by submitting an increased tender price. This natural reaction is understandable considering the risk and uncertainty they are confronted with, but the creation of such opportunism provides the foundation for an adversarial environment. The rationale for EPCM organization providing contractors with such poor-quality documentation was unclear as the researchers could not gain access to those who had prepared the documentation, but it was suggested that there was a requirement by the client to be producing Iron Ore by a fixed date.

In addressing the issue of information errors, omissions and redundancy contained within the EIC documentation, the use of a SIM has been propagated and described. A SIM is a generic term used to describe the process of modelling complex systems using appropriate software such as Dynamic Asset Data. When a SIM is applied to design a connected system, all physical equipment and the associated connections to be constructed can be modeled into a database. Each object is modeled once. Thus, a 1:1 relationship is achieved between the SIM and the real world. As a result, information redundancy contained within traditional CAD documents is eliminated. Productivity is subsequently improved and the economic performance of mining projects significantly augmented when a SIM is used to engineer and document EIC systems.

It should be acknowledged, however, that the use of a SIM will not reduce errors per se; they may merely be relocated, changed or can even be hidden. The use of a SIM provides practitioners within the EIC domain with new capabilities and abilities to acquire significant increases in productivity, but it also brings new complexities too, which include:

- an increase in operational demands as projects will be expected to be completed and commissioned earlier;
- an increased need for interoperability, coordination and integration with other disciplines that are using object-oriented software and the establishment of a consolidated point of truth; and
- a requirement for people to obtain more knowledge and skills.

Future research is required to address and alleviate the complexities that may materialize within the introduction of a SIM. New technologies are often used by organizations to re-assert their professional status, which can be seen as threatening and even result in power shifts

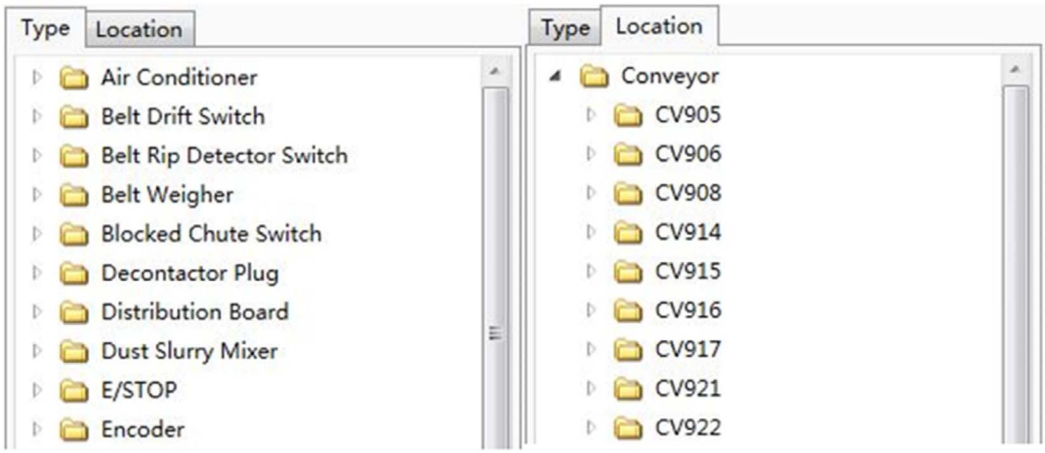

Fig. 7. Component classifications.

happening. A key challenge, therefore will be to educate EIC practitioners about the benefits of using a SIM rather than CAD and develop new processes and procedures that can accommodate its implementation throughout the mining sector.

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