

# 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.

**Keywords:** Errors, omissions, mining, object oriented, information redundancy, SIM

## 42 **1.0 Introduction**

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

55  
56 In this paper, the quality of information in the tender documentation provided to an electrical  
57 engineering contractor for a port expansion facility (which formed an integral part of an Iron  
58 Ore mega-project) is analyzed. Notably, such information is rarely made available for analyses  
59 due to its commercial sensitivity. Moreover, there has been limited empirical research that has  
60 examined the quality of information contained in the documentation that has been prepared to  
61 solicit tenders. Such research, however, is needed to demonstrate the prevailing issues that  
62 adversely impact the costs of mining projects to clients.

63  
64 The participating contractor is hereafter referred to as ‘Contractor A’ to preserve confidentiality  
65 agreements made between both parties. The aim of this paper is to examine the nature of errors,  
66 omissions and information redundancy that were presented in the tender documents and the  
67 potential risk exposure that the contractor would have faced in the field should they have been  
68 awarded the project. To address the deficiencies contained within the drawings provided in  
69 tender documents for EIC systems, it is suggested that the use of an object oriented approach,  
70 referred to as a System Information Model (SIM), to design and document the project instead  
71 of Computer-Aided Design (CAD) can significantly reduce the occurrence of errors, omissions  
72 and information redundancy [2-6]. Thus, a SIM can be integrated with a Building Information  
73 Model (BIM), yet the use of software applications of this nature to produce EIC object models  
74 are rarely used in the Australian mining sector [6]. Yet in the mining industry, EIC accounts

75 for approximately 29% of the world's capital expenditure on plant. Furthermore, in plant  
76 operations, EIC typically accounts for 60% of maintainable items as well as being critical to  
77 safe and efficient operations [6]. Despite their importance, there has been limited research that  
78 have examined EIC systems within an object oriented environment within the construction,  
79 energy and resources sectors [5,10]. A SIM forms an integral part of the BIM nomenclature  
80 and has been described in detail in Zhou *et al.* [7].

81

## 82 **2.0 Case Study**

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

89

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

97

## 98 **2.1 Background**

99 Growing demand for iron ore from countries such as China and India has stimulated the  
100 development of existing facilities to better accommodate increased iron ore production from  
101 45 Million tons per annum (Mtpa) to 155Mtpa. The expansion project (referred to as T155),  
102 situated in Western Australia (WA), required additional port facilities and rail systems.  
103 Company Iron Ore (IO) procured the project using an Engineering, Procurement, Construction  
104 and Management contract (EPCM). In this instance, the EPCM contractor assumes  
105 responsibility for coordinating all design, procurement and construction work.

106

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

114

115 The port facility's upgrade was planned to be completed within three stages. Stage one, referred  
116 to as T60, constructed a second outloading circuit, which increased the port's export capacity  
117 from 45Mtpa to 60Mtpa. The works that had been completed were dredging, installation of a  
118 new wharf for the third berth, a shiploader, sample station, reclaimer, two transfer stations and  
119 all the conveyors between them. Stage two provided the port with the second and third  
120 inloading circuits. The work involved the installation of two new train unloaders, a stacker,  
121 three transfer stations, the conveyors between them and the associated equipment. Stage three  
122 involved an additional outloading circuit, which increased the port's export capacity further to  
123 155Mtpa. The work involved the construction of a new wharf for the fourth and fifth berths, a  
124 shiploader, reclaimer, sample station and all the interconnecting conveyors and Transfer  
125 Stations.

126

## 127 **2.2 Control System Upgrade for Port Facilities**

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

133

134 The tender documentation that described the control system upgrade requirements of the  
135 existing port facilities were provided to several Electrical Engineering firms for review prior  
136 to bidding for the works. The tender invitation was sent to potential contractors on 12/04/11.  
137 The tender submission deadline was 03/05/11, which meant that interested applicants needed  
138 to complete the activities identified within three weeks. A lump sum bid was required for the  
139 control system by 'Company IO' and all work specified in the contract was required to be

140 completed by the specified date. In addition, it was explicitly stated that any cost overrun  
141 incurred by latent uncertainties and insufficient information contained within the contract  
142 documents were at the contractor's risk.

143

### 144 **2.3 Tender Documentation**

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

155

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

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

176

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

185

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

190

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

206

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

215

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

223

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

233

### 234 **3.0 Research Findings**

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

239

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

253

### 254 **3.1 Errors and Omissions**

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

259

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

267

268 A thorough review of the tender documents was conducted to identify the extent of errors and  
269 omissions found (Table 1). It can be seen that a total of 426 errors and omissions occurred  
270 within the 77 drawings. A total of 84 omissions (65 cables, 19 components) were identified on  
271 the CAD drawings; as information was not dynamically linked, information traceability was



272 significantly reduced. A total of 244 errors and omissions (i.e. 57.28% of all problems  
273 identified) were attributed to cables. 182 (42.72%) errors and omission were associated with  
274 components. Noteworthy, the classification of ‘Missing Label’ was the most prevalent  
275 accounting for 59.86% of all issues identified. A typical example of ‘Missing Label’ is denoted  
276 in Figure 3 (a portion of drawing 515P-10016-DR-EL-3203) where cables and components  
277 were created but corresponding labels not allocated.

278

### 279 **3.2 Reference Drawing Numbers**

280 Considerable amounts of cross coupled reference drawing numbers were identified in the  
281 drawings. Notably, 70 of the drawings referred to were not made available to the applicants at  
282 the tender package and three drawings were mistakenly referenced. For example, Figure 4 (a  
283 portion of drawing 505P-10016-DR-EL-0505) illustrates that a transformer TF586 and motor  
284 control center MC586 are shown in drawing 505P-10016-DR-EL-0507. However, they could  
285 not be located in the designated target drawing.

286

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

292

### 293 **3.3 Unavailable Cable Schedule**

294 In the case of electrical engineering projects, there is a proclivity for cable schedules to be used  
295 to document inter-connections between components and cables, and to estimate the quantity of  
296 materials used to form the control networks. If the information extracted from cable schedules  
297 is different from that expressed on a drawing, then the risk of an error or omission arising is  
298 elevated. No cable schedule however was provided in the tender documents and so  
299 consequently, contractors tendering for the project could not check that the information  
300 conveyed on the drawings with the cable schedule. Furthermore, to take-off the quantities, the  
301 contractors would have had to examine all the drawings, which would have been an  
302 unproductive process.

303

### 304 **3.4 Information Discrepancy**

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

314

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

328

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

335

336

337

338 **3.5 Unavailable I/O and Cause/Effect documents**

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

348

### 349 **3.6 Information Redundancy**

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

359

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

368

369 For the port expansion project a total of 8633 drawings were used to document the electrical  
370 engineering related designs including: 831 layout diagrams; 398 general arrangement  
371 diagrams; 168 single line diagrams; 2767 schematic diagrams; 1644 termination diagrams; and

372 2825 other miscellaneous drawings. Assuming the drawings were of a similar quality to the  
373 tender drawings, then a total of 338,586.26 person-hours would be required to create the 8633  
374 drawings at a cost of AU\$44,016,213. The original budget for the port expansion project was  
375 AU\$2.4 billion with 12% of the budget allocated to the EPCM, which is approximately  
376 AU\$288 million. The electrical engineering related design and documentation required 20%  
377 of the EPCM cost (AU\$57.6 million). Thus, the cost to produce the 8633 electrical drawings  
378 consumed 76.42% of the electrical engineering portion of the budget and 1.83% of the entire  
379 project's budget. Notably, this is only for the draftsman's cost to generate the initial  
380 drawings. The cost of revising these drawings due to errors and omissions has not been  
381 considered.

382

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

393

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

400

#### 401 **4.0 System Information Model**

402 To effectively and efficiently address the problems that were identified in this case study, it is  
403 suggested that an object oriented modelling process enabled using a SIM should be employed  
404 in EIC projects rather than using a documentation process that utilizes CAD. A SIM can be

405 applied to model the connected systems where components are interconnected and possess  
406 various relationships. For example, when a SIM is used to model the electrical, power and  
407 communication systems, the physical objects and cables can be modelled as digital components  
408 and connectors in a database, which can be accessed through specific software such as Dynamic  
409 Asset Data.

410

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

419

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

426

427 On completion of the design, the model is protected from any unauthorized changes to the data  
428 stored. As a result, the design can then be exported and issued to other users as a read-only  
429 copy that is made available via a ‘Kernel’ (Figure 5). Users can access the design information  
430 based on their authorization level. Private user data can be created and attached to the model  
431 such as attributes, photos and documents. To protect the design from unauthorized changes,  
432 the contents of the Kernel can only be modified by the design engineers. If users identify  
433 conflicts or design errors in the Kernel, an RFI can be generated from a dedicated folder within  
434 the user portal. A spreadsheet can be automatically generated that contains all the object  
435 information either in Microsoft Excel or portable document format (pdf.) file format [7]. On  
436 receipt of the spreadsheet, the project team can review the design and rectify the problems  
437 before generating and exporting a new ‘revised’ Kernel to users for further application [7].

438

439 With the adoption of a SIM, drawings can be eliminated and the error rectification process  
440 becomes straightforward, as all required changes can be carried out within the digital model.  
441 This approach eliminates the need for an engineer to identify all other relevant drawings and  
442 thus revise them manually. Time and cost can be therefore reduced and productivity increased  
443 [2]. When CAD drawings are used, relationships between components contained within  
444 various drawings are denoted by reference numbers that increase the propensity for errors to  
445 be made. The linkages between components can become very complex if a project's size  
446 increases. Incorrect or incomplete labeling reduces information traceability. As noted above,  
447 the allocated time to recover this missing data can significantly be increased. The use of SIM  
448 overcomes this issue. For example, in Figure 6 an engineer can inspect the connection of a  
449 junction box (JB-101) directly within a SIM model. The components connected to the selected  
450 junction box can be displayed automatically and dynamically, and as a result the tracing of  
451 connections via drawing reference numbers is no longer required.

452

453 Quantity take-offs can be accurate when using a SIM. Interpreting and recovering information  
454 presented on several drawings is clearly an unproductive process; errors and omissions  
455 contained within drawings can adversely impact a contractor's procurement process (e.g.  
456 material waste, and rework). As all the components are categorized according to their 'Type'  
457 and 'Location' classes (Figure 7), users are able to identify and locate the required equipment.  
458 Using the 'Quick Spreadsheet' function provided equipment numbers can be identified directly  
459 by users. Cost information for these items can also be acquired automatically through the 'cost  
460 attribute', which is assigned to each individual component. This can enable users to produce  
461 an estimate and determine the man-hours required to complete the job at hand [7].

462

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

470 **5.0 Conclusion**

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

479

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

488

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

498

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

- 503 • an increase in operational demands as projects will be expected to be completed and  
504 commissioned earlier;

- 505 • an increased need for interoperability, coordination and integration with other  
506 disciplines that are using object-oriented software and the establishment of a  
507 consolidated point of truth; and
- 508 • a requirement for people to obtain more knowledge and skills.

509

510 Future research is required to address and alleviate the complexities that may materialize within  
511 the introduction of a SIM. New technologies are often used by organizations to re-assert their  
512 professional status, which can be seen as threatening and even result in power shifts happening.  
513 A key challenge, therefore will be to educate EIC practitioners about the benefits of using a  
514 SIM rather than CAD and develop new processes and procedures that can accommodate its  
515 implementation throughout the mining sector.

516

517 **Acknowledgements:** The authors would like to thank the four anonymous reviewers and  
518 the Editor-in-Chief Professor Skibniewski and Associate Editor Professor Castro-Lacouture  
519 for their constructive and insightful comments, which have helped us improve the quality of  
520 this manuscript.

521

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Table 1. Classification of errors and omissions

	Error Types						Sum	Percentage
	Incorrect Labeling	Inconsistent Labeling	Incorrect Connection	Drawing Omission	Missing Label	Incomplete Labeling		
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%	

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Table 2. Comparison between estimation and calculation of instrument numbers

<b>Instrument Type</b>	<b>Estimated by Client</b>	<b>Counted on Drawings</b>
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

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Table 3. Instruments missing from client estimations

<b>Instrument Type</b>	<b>Counted on Drawings</b>
Blocked Chute Switch	28
Emergency Stop	38
Flow Transmitter	10
Hand Switch	22
Isolator	70
Local Control Station	19
Motor	50
Speed Switch	23

623

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

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

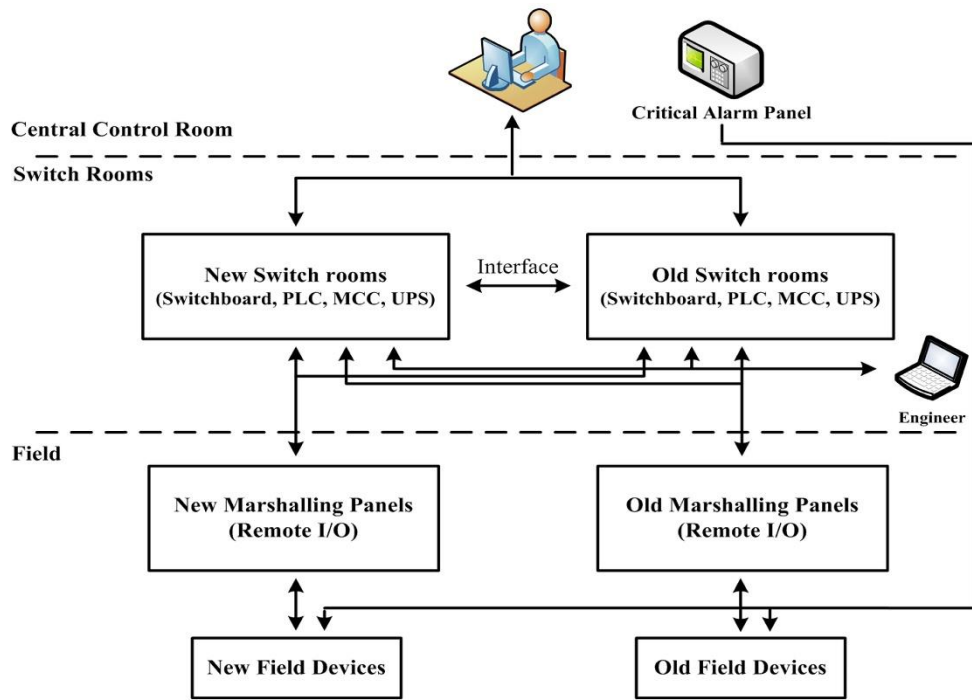


Figure 1. Control system illustration

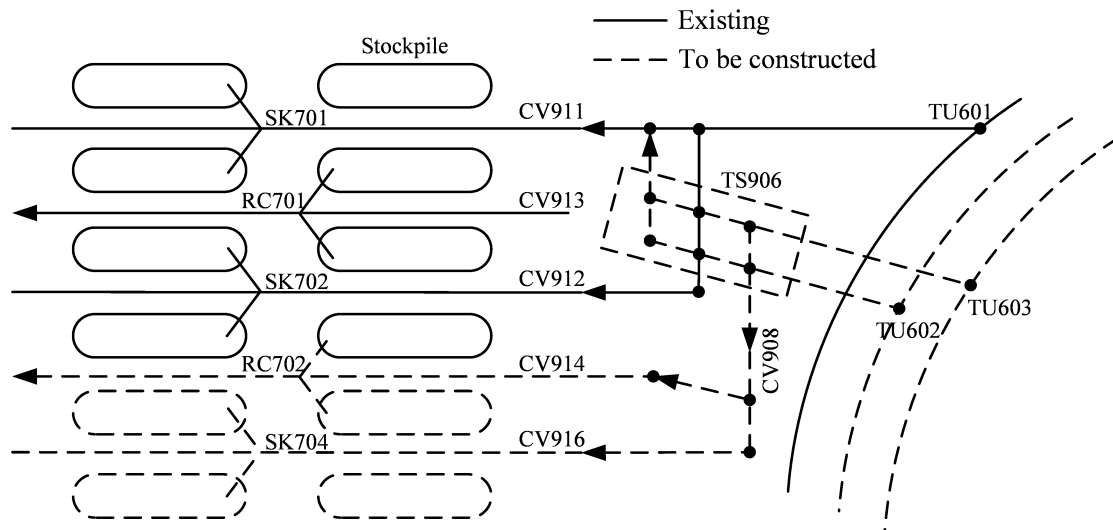


Figure 2. Connection example between circuits



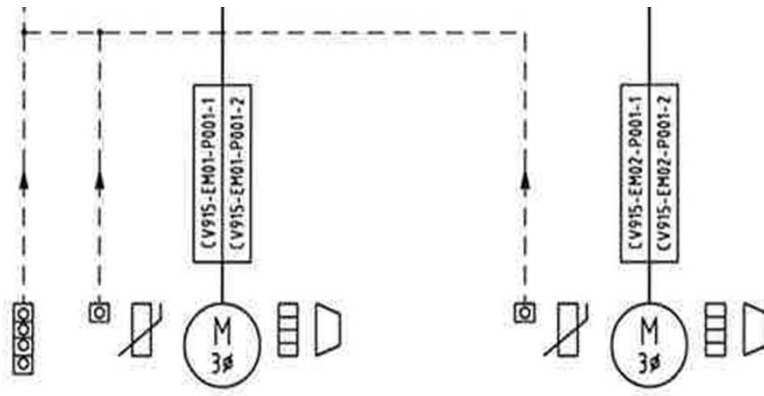
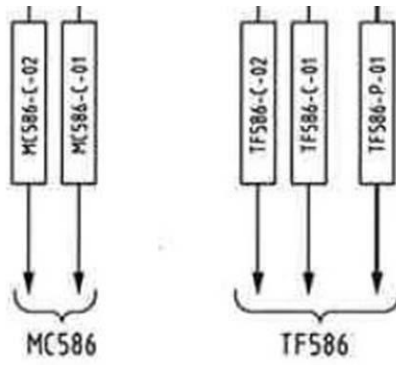


Figure 3. Example of missing label



TF586 22kV/400V  
MCC MCS86  
REF DRGs  
505P-10016-DR-EL-0507

Figure 4. Example of incorrect reference

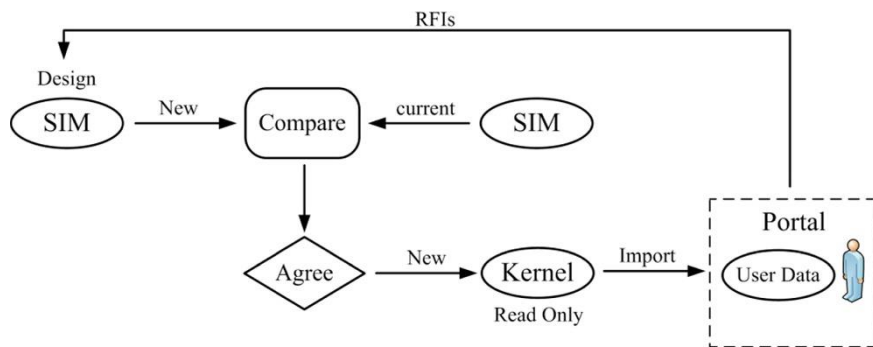


Figure 5. Kernel revision process (Adapted from Love *et al.* 2013)

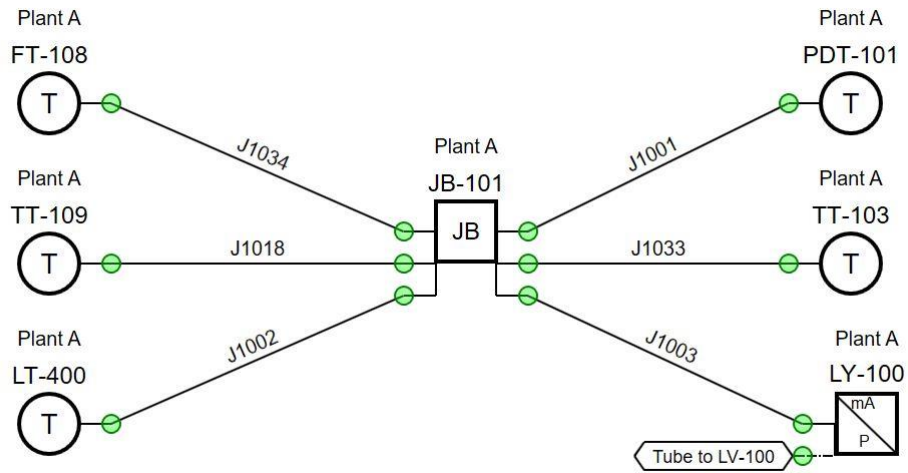


Figure 6. Example of interconnected components

Type	Location	Type	Location
▶	Air Conditioner	◀	Conveyor
▶	Belt Drift Switch	▶	CV905
▶	Belt Rip Detector Switch	▶	CV906
▶	Belt Weigher	▶	CV908
▶	Blocked Chute Switch	▶	CV914
▶	Decontactor Plug	▶	CV915
▶	Distribution Board	▶	CV916
▶	Dust Slurry Mixer	▶	CV917
▶	E/STOP	▶	CV921
▶	Encoder	▶	CV922

Figure 7. Component classifications