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Systems information modeling: From file exchanges to model sharing for electrical instrumentation and control systems

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ABSTRACT

The mining industry in Australia is in a period of intense introspection as it seeks to improve its productivity and competitiveness in global markets. With mining projects experiencing increasing overruns on capital expenditure, there is a need to re-examine existing business practices to address the prevailing productivity crisis that the industry is experiencing. In addressing this issue, within the context of electrical instrumentation and control systems (EICS), a case study that examines the development of a systems information model (SIM) to improve productivity during the engineering, construction, maintenance, and operations processes of a magnetite iron ore processing plant is presented and discussed. By transforming the established document oriented information exchanges that are typically used in EICS projects to a more collaborative data-sharing environment, processes were streamlined and errors, as a result of duplication and inconsistency, were significantly prevented from occurring. While still working within the restriction of discipline-specific models, the creation of a SIM is the first step towards an integrated and interoperable data without a reliance on drawings.

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1. Introduction

> "The mining industry is decades behind other parts of the economy on productivity, and the industry, not government, must raise its game. In the mining industry, we're some 20 to 30 years behind other more progressive sectors in terms of productivity and business practices." Mark Cutifani, CEO, Anglo American (Ernst & Young, 2013–2014:p.20)

The demand for minerals such as bauxite, coal, iron ore, and nickel from emerging economies has resulted in an unprecedented number of mega-projects being constructed in Western Australia (WA). Such projects, however, have been typically subjected to cost and schedule overruns with poor levels of productivity being experienced. Several factors have contributed to the mining sector's inability to estimate and deliver new projects within their capital expenditure (CAPEX) budgets (e.g., skills shortage, a lack of standardized design and construction processes, and an overemphasis being placed on the early production of the resource). A lack of focus on CAPEX predictability and assurance reviews, for example, contributed to Barrick Gold's Pascua–Lama Gold project's cost estimate increasing from US$0.5 billion in less than 5 months to US$8.5 billion during 2012. Yet, as a consequence of increasing CAPEX overruns, the volatility of currency fluctuations, limited access to infrastructure, and increasingly restricted access to capital, have resulted in executives demanding increasing emphasis being placed on understanding the benefits and risks of the capital execution processes before a project is approved. While there is an increased focus on judicious project selection and planning being undertaken by asset owners, technological innovations such as Building Information Modeling (BIM) can also play a pivotal role in mitigating risks associated with capital execution and operations and maintenance [13,14]. The mining sector has been typically utilizing aspects associated with BIM during the Front End Engineering Design (FEED) process such as three-dimensional (3D) visualization, which is often linked with a schedule to provide a four-dimensional (4D) environment for the purposes of optimizing construction, operations, and maintenance sequences.

Definitions of BIM are abounding in the normative literature with the most comprehensive and meaningful being propagated by the US National Building Information Model Standard Project Committee who defines it as "a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle; defined as existing from earliest conception to demolition" [12]. An inherent feature of BIM is collaboration between project participants and the sharing of information throughout an asset's life cycle. As a result, BIM is often used in combination with relational-based project delivery strategies such as Integrated Project Delivery (IPD). Within the mining sector, however, there has been a proclivity for Engineering Procurement and Construction (EPC) and Engineering Procurement

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Construction and Management (EPCM) contracts to be used by resource-based companies to deliver their projects. Such arrangements are not relationship-based, and as a result, they have contributed to hindering the sector's ability to develop cost-effective engineering solutions that could potentially improve the performance and productivity in an asset's life cycle [13]. Furthermore, they are short-term and tend to focus on the tactical management of contractors rather than establishing long-term strategic relationships where the owner and contractors mutually learn and share knowledge in order to acquire improved efficiencies.

An underlying issue impacting the productivity and performance of mining projects are errors and information redundancy contained within contract documentation, particularly that of electrical instrumentation and control systems (EICS). Traditionally, computer-aided design (CAD) has been used to detail the connections and relationships between ECIS components. However, ECIS have no scale and geometry and therefore are unable to be visualized in a three-dimensional (3D) view, though cable trays and components can be modeled. Recognizing the inherent problem with using CAD to design and document EICS, this paper presents a case study of an iron ore mine owner working collaboratively with the engineering consultants and contractors who implemented a systems information model (SIM) rather than exchanging drawings between each other during the design process; the parties shared digital models; the research presented describes how this process was achieved. Noteworthy, a SIM forms the basis for software that can be integrated to form a single point of truth (SPOT) within a BIM environment. As there has been limited research that has examined the nature of BIM for EICS particularly within the mining sector, a case study approach was undertaken (e.g., [8,9,13]).

2. Research approach

A case study is an empirical inquiry that investigates a phenomenon within its real-life context [4,6,18]. A case study can be either exploratory or explanatory [22]. An exploratory case study investigates distinct phenomena characterized by a lack of detailed research [15]. Contrastingly, an explanatory approach not only explores and describes phenomena but can also be used to explain causal relationships and to develop theory using both qualitative and quantitative research methods. For the purposes of this research, an exploratory approach is adopted to obtain an understanding about how EICS are BIM enabled using a SIM.

Active engagement with industry professionals was required to acquire information about how EICS were designed, engineered, documented, and managed using a SIM. Therefore, a participatory action research (PAR) approach was adopted under the auspices of the exploratory case study [1,10,17,20]. According to Susman and Evered [21]) PAR is

- participatory;
- cooperative, engaging organizational members, and researchers in a joint venture in which both equally contribute; and
- a way to balance research and action.

In this context, the research aimed to understand both the practical concerns of the organizations, and the research goals (i.e. investigating how a SIM can improve productivity and reduce costs), by working collaboratively for a selected case study project. As practitioner involvement was required, they were treated as both subjects and co-researchers. As documentary sources such as drawings, cable schedules, requests for information (RFI) were not issued and used in a paper-based format; the researchers were given access to the SIM and digital models. For the purposes of confidentiality, the names of the companies involved with the research presented in this paper are suppressed.

2.1. Case study background

The case study investigated is a AUD$380 million magnetite iron ore processing plant, which is located in the Pilbara region of WA and covers an area of approximately 5141 ha. The project comprises two main facilities:

1. An iron ore mine area: approximately 1230 km north–north-east of Perth and 110 km south–south-east of Port Hedland.
2. Iron ore processing plant.

The new open-pit mine is approximately 4.5 km in length and 1 km wide. The mine comprises a waste rock dump, tailings storage facility, low-grade ore stockpile, process rejects waste landform, crushing and screening hub, magnetic separation processing plant, power station, roads, and other associated mine infrastructure. The project aimed to process up to 30 million tons of magnetite ore per year by extracting up to 107 Mtpa of ore and waste rock over a mine life of 45 years. The ore undergoes crushing, screening, and magnetic separation. Up to 15 Mtpa of product will be sent to Port Hedland for export as magnetite concentrate. The ore mining methodology employed for the project involved conventional drill and blast, followed by hydraulic excavation and haulage to processing facilities and stockpiles by off-road haul trucks. The iron ore processing procedure consists of the following elements, which are identified in Fig. 1:

1. run of mine (ROM) pad;
2. primary crushing and secondary crushing;
3. stockpile and reclaim;
4. high-pressure grinding;
5. air classification;
6. dry magnetic separation;
7. wet magnetic separation;
8. concentrate thickening and tailing thickening; and
9. concentrate dewatering.

The processing procedure commences from the primary crushing plant, which is located at the top right corner of Fig. 1. The ROM ore is taken from the ROM stockpile via haul truck and fed into a primary gyratory crusher. Then, the crushed ore will be fed into a secondary circuit of three cone crushers to further reduce the size of ore. This ore is then transferred to the primary stockpile.

Ore is then recovered from the primary stockpile via an apron feeder and delivered via conveyors to a High Pressure Grinding Roll (HPGR) to further reduce the size of ore to a diameter of less than 150 μm. The obtained ore particles are sent to the Air Classification (AC) building such that they can be separated: (1) particles greater than 3 mm will be returned to the HPGR feed bin; (2) particles with diameter between 3 mm to 150 μm will be delivered to Dry Magnetic Separation (DMS) building; (3) particles less than 150 μm are further split into oversize (150 μm to 50 μm) and undersize (less than 50 μm). Oversize particles will report to coarse Wet Magnetic Separation (WMS) circuit and undersize particles will be sent to fine WMS. The DMS building services is an iron ore separator, which separates the ore particles into magnetic and non-magnetic fractions. The magnetic fraction is transported to the HPGR feed bin for further size reduction. The non-magnetic fraction will report to the tailing stockpile via tailing conveyors.

Particles with less than 150 μm diameter discharged from the AC building are sent to the WMS facility to be slurried by water. The iron ore slurry will be put through a series of drums and mills by which it is separated into concentrate and tailing and delivered to Concentrate Thickener (CT) and Tailing Thickener (TT), respectively. The discharge from the CT is pumped at a nominal wet solid content of 62% to a Concentrate Dewatering (CD) plant and filtered to produce a final product concentrate cake at 8% weight to water residual moisture. The discharge from the TT is transported and disposed to the tailing storage facility.

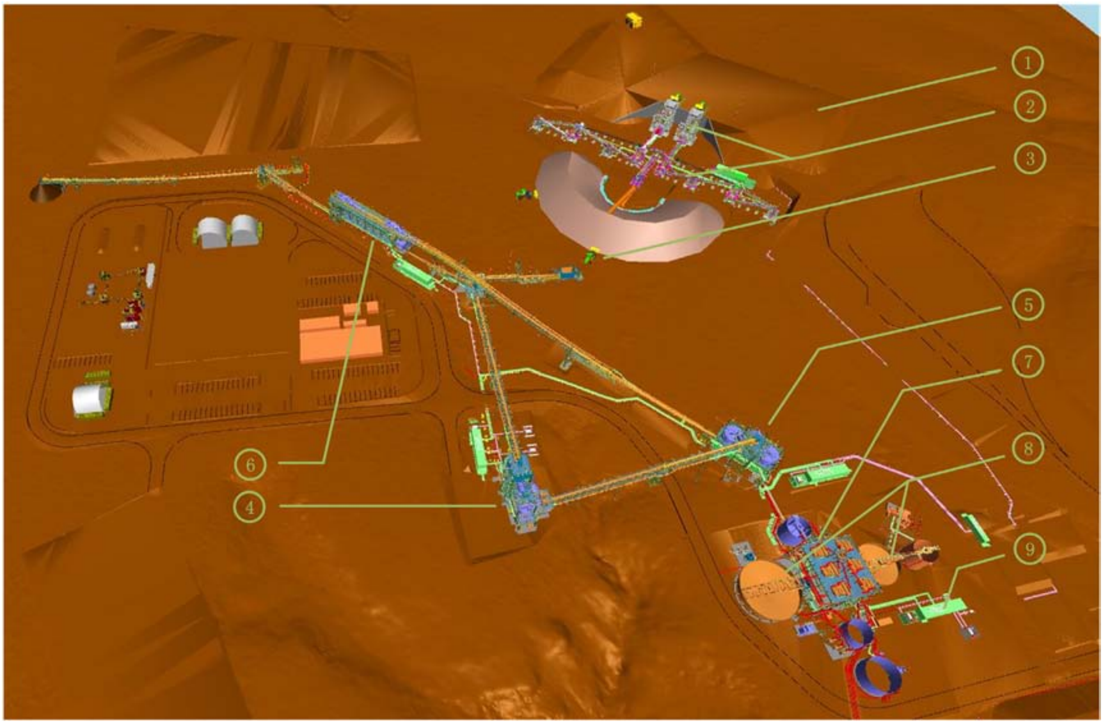


Fig. 1. Iron ore processing plant.

2.2. Engineering electrical instrumentation and control systems

A Perth-based project management and engineering company XY was contracted to design and engineer the EICS of the processing plant with a steel fabricator (Steel) employed to produce a 3D model for the whole processing plant (Fig. 1). An instrumentation and electrical (I&E) systems company was then contracted to

- document the EICS design;
- coordinate the Structure Mechanical Piping (SMP);
- design the lighting and small power;
- design and engineering the fiber optic network;
- import the reference documents (e.g., vendor manuals, certificates) into a SIM and link to relevant objects and folders.

The total cost of the EICS was $43.5 million, with design and engineering accounting for $2.3 million. Instead of using CAD to conduct the above tasks, the I&E contractor developed a SIM. A SIM is a generic term used to describe the components, along with their attributes and relationships with each other, which when aggregated comprise a complex system. A SIM is usually created using appropriate software such as Dynamic Asset Documentation (DAD: see http://www.dad.net.au/). A SIM is a digital representation of real-world components in a connected system, such as electrical control, or power and communication systems. When a SIM is applied to the design of a connected system, all physical equipment and the associated connections to be constructed can be modeled in a database. Thus, each component only needs to be modeled once and a SPOT for the design is established.

There are two methods that can be used to construct a SIM using software such as DAD: (1) manually and (2) automatically. The manual method is appropriate for new projects or where a complete cable schedule is not available. In such circumstances, engineers are required to manually create a digital model of each real-world component and cable within the SIM to form a connected system. If complete cable schedules are available, then the modeling process is a straightforward process as software such as DAD it is equipped with a function that can generate a SIM automatically based on the information presented in them. In this case study project, a SIM was manually created for EICS of the iron ore processing plant as the design progressing. The obtained digital SIM could be effectively utilized throughout the asset's entire life cycle (e.g., design, procurement, construction, commissioning, operation, and maintenance). Noteworthy, no drawings were issued, and as a result, the propensity for errors, omissions, and information redundancy that are typically associated with the production of drawings was reduced [13]. The vision of a paperless project became a reality in this instance and the ensuing benefits that were acquired by the digital SIM are identified in Table 1.

The 3D model, developed by Steel, was linked to the SIM to enable the acquisition of data and visualization of the EICS. With this linking, through a “Waypoint” function, cable routes were visualized in the 3D model. Typically, the estimation of cable lengths has been and remains a problematic issue in EICS projects, but by linking the SIM to the 3D

Table 1
Benefits of a digital SIM.

Stage	Benefit
Design	EICS modeled in a digital environment Creation of a digital workflow throughout the project Information redundancy is eliminated No drawings were issued A reduction in errors and omissions No draftsmen were required Online design review was enabled Flexibility for change of design was provided
Construction management	Procurement is made easier as material quantity list is readily available Cable schedules are directly generated from the SIM Construction schedules/progresses are recorded and monitored Material data report readily available
Construction and installation	Site engineers have direct access to design information using PC Tablets

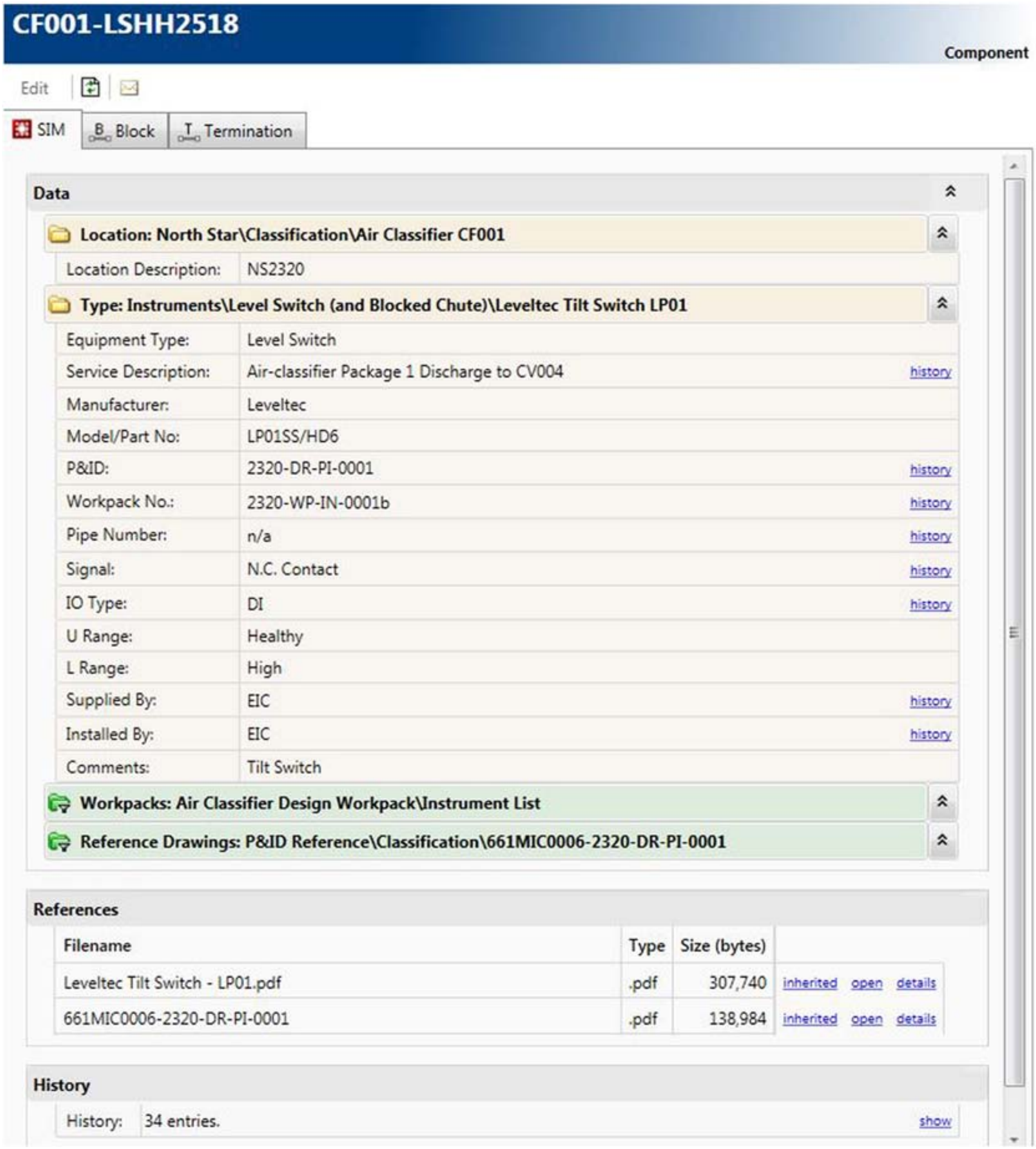
model provided site engineers with the ability to visualize the routing of cables between instruments therefore reducing "wastage" and improving their installation efficiency.

3. Application of the systems information model in practice

At the heart of the SIM is the concept of a "Function Module," which provides a gateway to the information contained within the model. Within the "Design Module," each individual physical instrument to be constructed in the real world was modeled as a digital component. Two general attributes "Location" and "Type" were assigned to each component. The "Location" describes the physical position of the component within the plant. The "Type" defines the functionality to be performed by the component. Private "Attributes" of a component defined information such as manufacturer, model, signal type, and I/O type. Authorized users were granted the rights to edit, add, or delete the attributes to suit each individual type of instrument. Cables between instruments were modeled as connectors. Private "Attributes," such as type, size, and length were then assigned to each of them. Reference documents, such as user manuals, certifications, installation instructions, and pictures were imported into the "Reference Library" and linked to the corresponding component or connector. A typical example of a "level switch" CF001-LSHH2518 used in the project is illustrated in Fig. 2.

The "level switch" is used in the AC building to detect if an iron ore feed bin is blocked or not. The block and terminal connections are shown in Fig. 3. Fig. 2 can be used to locate "where it is" and "what it is" by displaying the information for the "Location" and "Type" of the level switch. It can also reveal other detailed design information that is listed within the "Type" attribute. Fig. 3 displays "how it is connected." It can be seen from Fig. 3 (a) that the "level switch" is connected to a field junction box PU001-JB003 through a local junction box LSHH2518-JB01. Its terminal connections are shown in Fig. 3 (b) indicating that the signals are fed into a remote I/O card ST1214, which is located in the "field junction box" PU001-JB003. The signals are further transmitted by a network adaptor and sent to a Programmable Logic Controller (PLC) control system *via* a Process Field Bus (Profibus) Decentralised Peripherals (DP) network. The Profibus DP is typically used to operate sensors and actuators *via* a centralized controller in production automation applications.

As all the components and connectors were digitally modeled in the SIM, it enabled the Bill of Quantity (BOQ) to be readily generated. For



CF001-LSHH2518

Data

Location: North Star\Classification\Air Classifier CF001

Location Description: NS2320

Type: Instruments\Level Switch (and Blocked Chute)\Leveltec Tilt Switch LP01

Equipment Type:	Level Switch	
Service Description:	Air-classifier Package 1 Discharge to CV004	history
Manufacturer:	Leveltec	
Model/Part No:	LP01SS/HD6	
P&ID:	2320-DR-PI-0001	history
Workpack No.:	2320-WP-IN-0001b	history
Pipe Number:	n/a	history
Signal:	N.C. Contact	history
IO Type:	DI	history
U Range:	Healthy	
L Range:	High	
Supplied By:	EIC	history
Installed By:	EIC	history
Comments:	Tilt Switch	

Workpacks: Air Classifier Design Workpack\Instrument List

Reference Drawings: P&ID Reference\Classification\661MIC0006-2320-DR-PI-0001

References

Filename	Type	Size (bytes)	
Leveltec Tilt Switch - LP01.pdf	.pdf	307,740	inherited open details
661MIC0006-2320-DR-PI-0001	.pdf	138,984	inherited open details

History

History: 34 entries. show

Fig. 2. Design details of "level switch" LSHH2518.

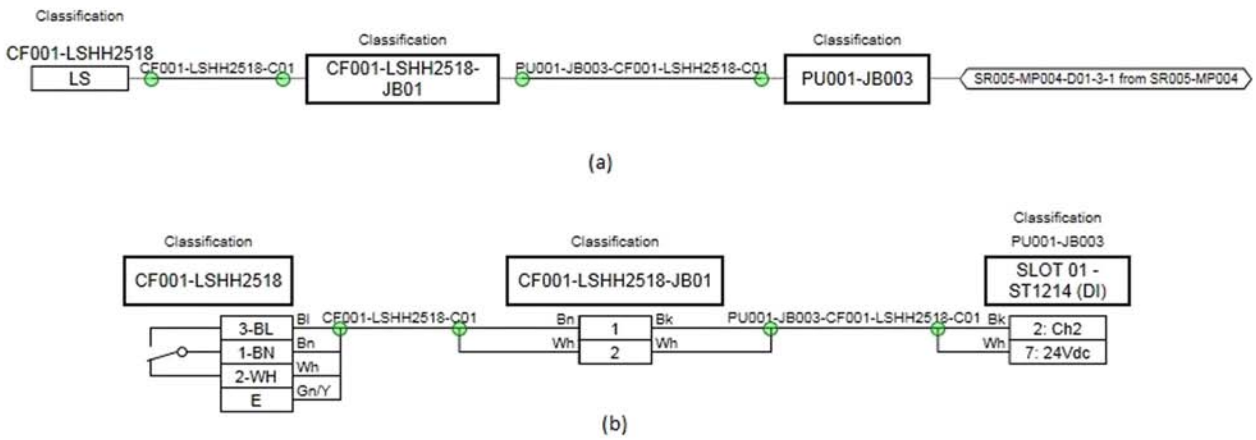


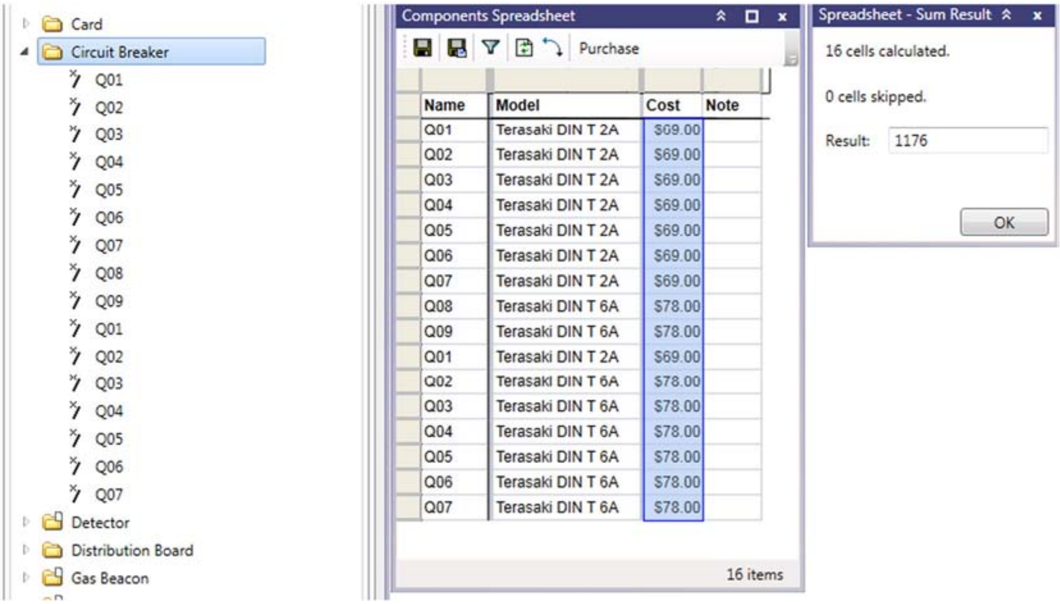
Fig. 3. Connections of level switch LSHH2518.

example, in determining the technical specification and quantity of circuit breakers for the control system of a conveyor, an engineer can first locate all "Circuit Breaker" components and then filter out those that do not belong to the conveyor control system using the in-built "Filter" function. Results can then be exported to a spreadsheet for analysis. Technical specifications such as model, number of poles, interrupting capacity and tripping current, as well as price information can be included in the results. A list containing the detailed information including total quantities and cost of equipment to be procured can be readily generated either in "pdf" or "excel" format (Fig. 4). The procurement status of each individual piece of equipment was recorded and managed within the model.

A complete history log was provided for each component within the SIM. Whenever a modification was undertaken, the person undertaking this task was identified and the changes were automatically and chronologically recorded. This created an audit trail that was used to trace the revision history and assisted engineers to compare previous with current design versions. For example, it can be seen in Fig. 2 that 34 historical records were registered since the creation of the object in the SIM. Yet, in a drawing-based design, these revisions would have to be maintained manually. This can be a tedious and costly process when a revision requires a number of drawings to be found, modified, re-checked, and re-issued to all relevant parties. Moreover, all the revised versions of a drawing and its original copy would need to be categorized and archived in order to enable the design to be traceable.

3.1. Electrical devices and cables

During the design of the magnetite iron ore processing plant, it was revealed that a total of 5834 electrical devices formed part of its electrical engineering design. These devices were classified according to their different functionalities: (1) Communications & Networks, (2) Control System, (3) Electrical, (4) Instrument, (5) Junction Box, (6) Panel and Cabinet, and (7) Terminal Strip. The distribution of the devices among various areas of the plant are presented in Table 2. It was also found that 5780 cables were used in the engineering design ranging from high voltage power to low voltage signal cables (Table 3). During the engineering design phase, a senior electrical engineer from I&E contractor collaborated with the XY engineering team. The I&E contractor engineer received design information from both the XY team and the vendors who supplied the prefabricated devices for the project. These were gradually modeled as the design progressed as digital components of a SIM using the DAD software. Once the components were modeled, cables were connected to each individual terminal according to the



Name	Model	Cost	Note
Q01	Terasaki DIN T 2A	$69.00	
Q02	Terasaki DIN T 2A	$69.00	
Q03	Terasaki DIN T 2A	$69.00	
Q04	Terasaki DIN T 2A	$69.00	
Q05	Terasaki DIN T 2A	$69.00	
Q06	Terasaki DIN T 2A	$69.00	
Q07	Terasaki DIN T 2A	$69.00	
Q08	Terasaki DIN T 6A	$78.00	
Q09	Terasaki DIN T 6A	$78.00	
Q01	Terasaki DIN T 2A	$69.00	
Q02	Terasaki DIN T 6A	$78.00	
Q03	Terasaki DIN T 6A	$78.00	
Q04	Terasaki DIN T 6A	$78.00	
Q05	Terasaki DIN T 6A	$78.00	
Q06	Terasaki DIN T 6A	$78.00	
Q07	Terasaki DIN T 6A	$78.00	

16 items

16 cells calculated.

0 cells skipped.

Result: 1176

Fig. 4. Cost of circuit breakers.

Table 2
Distribution of electrical devices.

Type Location	Communications and networks	Control system	Electrical	Instrument	Junction box	Panel and cabinet	Terminal strip	Total
Air classifier	6	68	175	160	30	0	29	**468**
Concentrate handling	5	59	333	198	19	3	22	**639**
Crushing and screening	7	140	157	386	28	18	46	**782**
Dry magnetic separation	5	60	349	149	40	1	58	**662**
Lower plant control room	1	0	1	0	0	0	0	**2**
Primary grinding	5	64	200	193	38	2	52	**554**
Process plant control room	2	0	2	0	0	0	0	**4**
Site service	1	32	38	62	3	3	12	**151**
Switchroom 1	1	0	34	0	0	1	0	**36**
Switchroom 2	7	35	235	1	1	3	62	**344**
Switchroom 3	16	19	459	2	1	3	59	**559**
Switchroom 4	9	15	93	1	0	2	3	**123**
Switchroom 5	19	18	439	2	1	3	72	**554**
Switchroom 6	15	18	337	2	0	3	52	**427**
Switchroom 7	3	11	4	0	0	1	0	**19**
Tailings dewatering	3	28	33	113	11	2	12	**202**
Wet magnetic seperation	4	32	182	64	8	0	18	**308**
Total	**109**	**599**	**3071**	**1333**	**180**	**45**	**497**	**5834**

Table 3
Number of cables.

Type	Power 11KV	Power 6.6KV	Power LV	Power VSD	Control	Instrument	DATA	Fibre optic	Vender	Wire link	Internal link	Earth	Total
No.	7	8	1541	106	51	1131	374	16	188	1810	484	64	**5780**

engineering specifications, forming a dynamically interconnected electrical control system.

Within the SIM, all users were inter-visible and could concurrently edit the design. Having an advanced history tracking function in place provided users with an awareness of the modifications made by others and thus enabled them to also work asynchronously.

As a result of using a SIM the traditional role of the draftsman (e.g., preparing the outline of schematics drawings) became redundant. Instead, the I&E engineer worked collaboratively and simultaneously with the XY team to document the EICS, as the design and engineering was undertaken. The designs received from the XY team were sketches of Piping and Instrumentation Diagrams (P&ID) and electrical wiring diagrams. Noteworthy in this project, vendors were not required to use the SIM to document design and produce deliverables. Instead, information obtained from the vendors was used to model the component types using the design module. Vendor drawings, manuals, specifications, and all other auxiliary documents were uploaded into the database and linked to their corresponding components.

Fig. 5 illustrates the components history during the design process. It can be seen from Fig. 5 that as the design progressed, components were gradually modeled into the database. From week 1 to week 33, a total of 9537 components were modeled. Yet, a number of components were removed from the design each week. It was found that during the 33-week period, a total of 2661 components were deleted from the database, which clearly reflected the iterative nature of the design process.

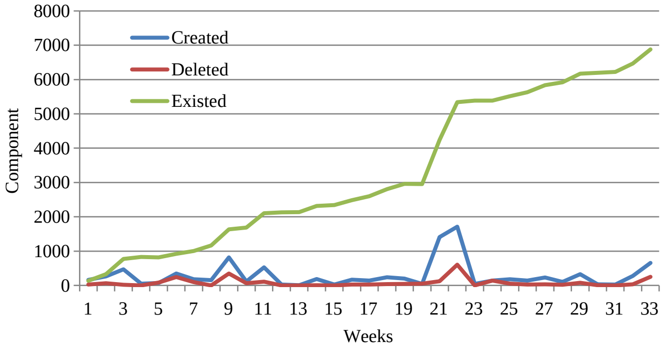


Fig. 5. Component history during the design process.

For example, there were 33 “under-speed” switches modeled in an early version of the design, which were used to monitor the speed of the conveyor belts and trip the corresponding PLC control signal if any were running below their rated speed. However, due to design changes, all the “under-speed” switches were removed from the design in week 24. Consequently, their related remote I/O cards in the field junction boxes and cables also needed to be removed. At the end of week 33, there were 6876 components left in the model. Fig. 6 illustrates the history log of connectors that had been created and deleted during the design process. It can be seen that from week 1 to week 33, a total of 8857 connectors had been modeled among which 3111 had been removed from the design, leaving 5746 connectors left in the model. In a previous study undertaken by Love et al. [13]), it was revealed that an average of five components and five cables (10 objects in total) required one document. Thus, assuming this would have been the case in this project if traditional CAD drawings had been used, then approximately 1260 documents would have been required to document the electrical design. Love et al. [13] also reported that 40 man-hours, on average, were required to produce each CAD drawing of an electrical engineering design. Bearing this in mind and with a market pay rate for a draftsman at AUD $130/h in WA, it would cost approximately AUD $6,552,000 (i.e. a total of 50,400 man-hours) to produce the 1260 documents. Noteworthy, this is merely the cost for the draftsman to produce the initial version of the drawings. If any error or omission is found on a drawing during construction, for example, it would need to be revised and reissued, adding further costs and impacting productivity levels, especially if the contractor is unable to proceed with their work. The plant is currently under construction and the electrical engineers on site are using PC tablets to instantly and remotely access the SIM database (Fig. 7).

3.2. Publish module

The SIM provided users with a “Publish Module” in order to share it with other stakeholders. In this module, the design information stored

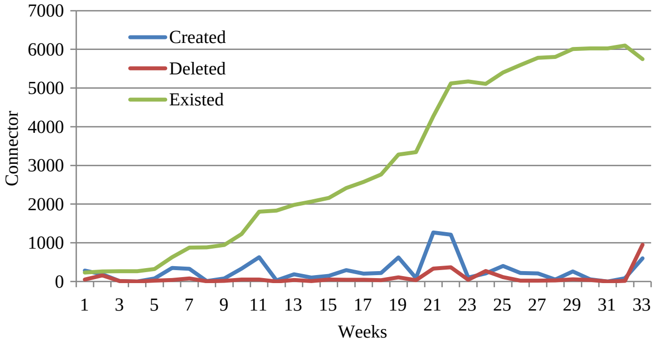


Fig. 6. Connector history during the design process.

in the SIM was accessed through various formats (e.g., pdf or excel files). The published documents were presented as block diagrams, terminal diagrams, or cable schedules, which identify the relationships between devices (Fig. 8). These were generated based on the information attached to each component or cable modeled in the SIM database. A cable schedule of the two cables connecting equipment can be generated automatically, showing their destination and specification needed to finish the site work. As the electrical cables usually have multi-cores, a spreadsheet could also be produced showing how each individual core should be terminated (Fig. 9). The cable schedule and core spreadsheet were also available in an excel file format, which enabled the information to be exported and utilized by other third party software packages.

3.3. Spatial Module

A "Spatial Module" which is a functional block embedded in DAD was provided to edit spatial information such as coordinates and dimensions for each individual component. The "Spatial Module" forms an interfacing layer between the users and the SIM. It enables the users to access the detailed design information that was created in the "Design Module." However, users are not authorized to modify the design through the "Spatial Module." Any modification to the design can only be done within the SIM "Design Module." This is to avoid any unauthorized change made to the design by unauthorized users. By using the "Spatial Module," users are able to attach and edit the spatial information to the components modeled in the SIM. The spatial information forms an extra layer of information of the components and is linked to the SIM. This information was then used to visualize the equipment in 3D when the SIM was linked to other third party software packages such as Google Earth or Navisworks®. Fig. 10 demonstrates the electrical marshalling panel SR002-MP001 with dimensions and coordinates defined, shown in the "Spatial Module." From the coordinate information provided by the engineers, the physical position of the marshalling panel within the plant can be conveniently located. The dimension information can be used to assist engineers to determine the arrangement of the equipment/cables installed within the marshalling panel. As small components such as cards, rails, and switches can also have their individual dimensional information defined, the spatial portal enables users to perform a trial arrangement of those installed within the marshalling panel (Fig. 11). Using this method, engineers are able to determine the number of components that the marshalling panel can contain, their arrangement and the

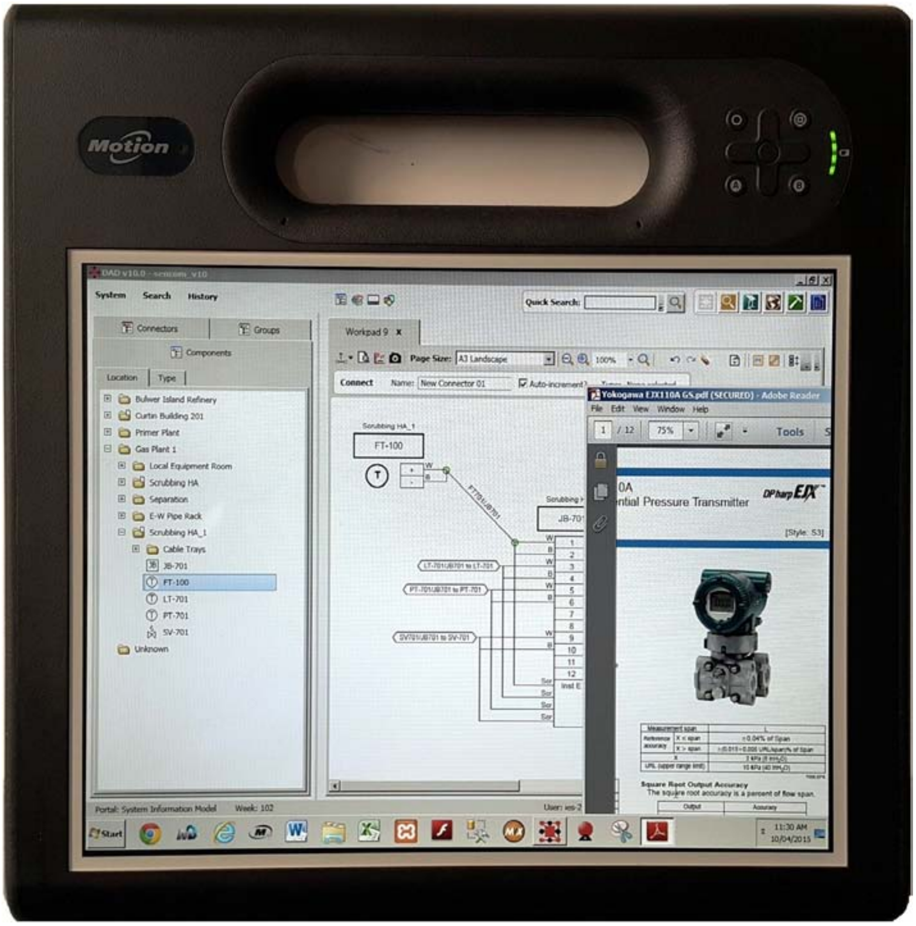
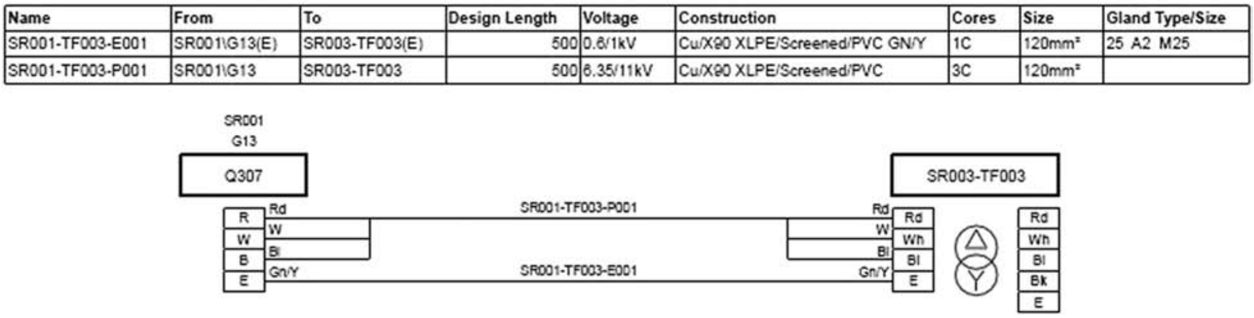


Fig. 7. PC tablet used during construction.



Name	From	To	Design Length	Voltage	Construction	Cores	Size	Gland Type/Size
SR001-TF003-E001	SR001\G13(E)	SR003-TF003(E)	500	0.6/1kV	Cu/X90 XLPE/Screened/PVC GN/Y	1C	120mm^2	25 A2 M25
SR001-TF003-P001	SR001\G13	SR003-TF003	500	6.35/11kV	Cu/X90 XLPE/Screened/PVC	3C	120mm^2	

Fig. 8. “Publish Module.”

Name	Core	Screen	Wiremarker From	Wiremarker To	From	To
SR001-TF003-E001	Gn/Y	☐	Q307-E	TF003-E	Q307(E)	SR003-TF003(E)
SR001-TF003-P001	Rd	☐	Q307-R	TF003-Rd	Q307(R)	SR003-TF003(Rd)
SR001-TF003-P001	W	☐	Q307-W	TF003-Wh	Q307(W)	SR003-TF003(Wh)
SR001-TF003-P001	Bl	☐	Q307-B	TF003-Bl	Q307(B)	SR003-TF003(Bl)

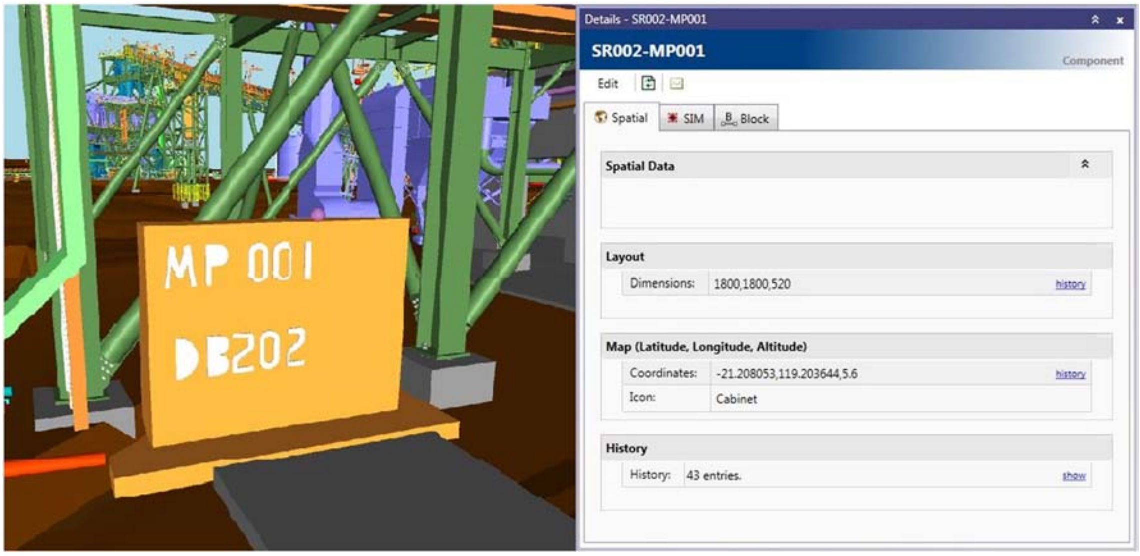
Fig. 9. Core spreadsheet.

wirings among the components. This can assist engineers to determine if the size of the current marshalling panel is sufficient to hold all the required components. If not, a larger marshalling panel may be required or an additional one may need to be purchased.

As the number of electrical components in this project were significant, an issue of concern was to ensure components were accurately identifiable in the SIM (i.e., using DAD) and Navisworks®. For example, the marshalling panel shown in Fig. 10 is modeled both in the SIM and the 3D model of the plant; a challenge posed was to ensure a mutual connection between both pieces of software could be achieved.

Before addressing this linking issue, it is worth mentioning that two numbering systems are used in the SIM: (1) “Tag Name” system; and (2) the “Unique ID” system. The “Tag Name” of an object is the name that will be used for reference by engineers and in documents. For example, SR002-MP001 is the “Tag Name” of the marshalling panel shown in Fig. 10. The “Tag Name” of an object is usually not fixed throughout a project for various reasons such as change in location or design. As the “Tag Name” of an object is subject to changes, it is not suitable to be used for the linking between the SIM and other software applications as the linking will be broken once the tag name is changed. To address such a difficulty, a “Unique ID” numbering system was developed for each module so that information can be accessed by other software applications. For example, the ID for the “Design Module” is 10001, for the “Costing Module,” 9975, and for the “Review Module,” 9900. These IDs are fixed and remain identical for all databases. Then, each object (component/connector) modeled is automatically allocated a “Global Unique ID” (GUID) when the object is created, e.g., the ID for marshalling panel SR002-MP001 in this case is 330057. The object unique ID is identical across different function modules and remain fixed regardless of any changes made to the object. Thus, with the two IDs (one for the module and one for the object), a precise identification of any object in the model to other software applications is provided. Accessing the information of any object modeled was achieved by executing the following command through other software applications:

```
<dadv1100 : //ServerAddress sqlexpress/DatabaseName/ObjectID/ModuleID>
```



SR002-MP001

Spatial Data

Layout

Dimensions: 1800,1800,520

Map (Latitude, Longitude, Altitude)

Coordinates: -21.208053,119.203644,5.6

Icon: Cabinet

History

History: 43 entries.

Fig. 10. Equipment in “Spatial Module.”

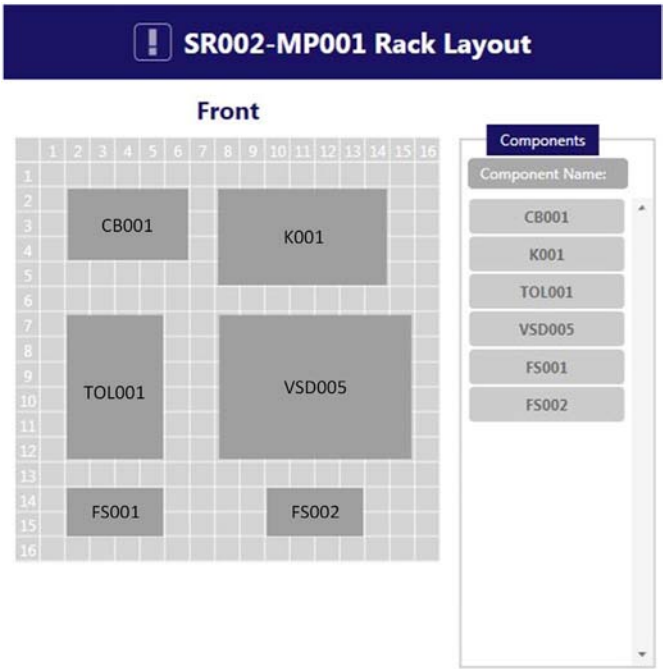


Fig. 11. Trial arrangement of components.

where 1100 is the version number of DAD being used. ServerAddress, DatabaseName, ObjectID, and ModuleID need to be supplied by the users. For example, to access the marshalling panel SR002-MP001 through the SIM "Design Module" on a local database which is named as Magnetite Processing, the above command was set as:

<dadv1100 : //localhost sqlexpress/MagnetiteProcessing/330, 057/10, 001>

Once this command is executed, the SIM "Design Module" opens with a pop-up window showing the detail information of the target marshalling panel. Above shows the method how other third-party software applications could access the information stored in the SIM; this also allows users to access information stored in other software applications by simply adding a command tag in the dropdown menu shown in Fig. 12. By clicking the tag, a query will be sent containing the unique ID of the corresponding object and other required information such as coordinates to other software applications for handling. Development of an interface between the SIM and other software application may be required depending on the software used.

In the case of the magnetite iron ore processing project, a third-party interface was developed to create a bi-directional link between the SIM and the 3D model in Autodesk Navisworks®. Such an interface enabled any component in the SIM to be located in a 3D model and *vice versa*. Thus, users were able to access the detailed design data stored in the SIM and explore the interconnected devices. Fig. 12 provides an example of the link between the SIM and Navisworks®. In the SIM, a "pull wire" switch HSZ2102 is selected. By choosing "Show in 3D" from the menu, Navisworks® is automatically launched and the corresponding "pull wire switch" is shown and identified in the 3D model. Linking objects from Navisworks® to the SIM follows a similar process. First, an object is chosen in the 3D model, and then by selecting the "ShowDAD" button, the corresponding object is displayed.

Reducing material waste such as cables in EICS project posed a challenge for engineers, as electrical engineering drawings typically describe connected relationships between devices rather than spatial information such as scale, dimensions, or distance. As a result, it is difficult for the engineers to determine critical aspects of the design such as cable run lengths. Such a problem is compounded in resource projects as the area of a single plant can cover tens of kilometers. Thus, a miscalculation in distance may result in significant cable waste.

In this case study project, there were 5834 devices and 5780 cables modeled in the SIM database. The power cables and signals cables joining these devices formed a very complicated network. Determining the route of cables from one device to another and calculating the cable length were critical tasks that confronted the engineers. The electrical devices were modeled in 3D. However, the cable network between them was too complicated to be modeled, so the cable trays were modeled instead. As multiple cables converged into or split out of a cable tray, it is impossible to trace the cable routes. To overcome this difficulty, DAD, through the interface with Navisworks®, provided the users with a "Waypoint" tool. This therefore enabled each individual geometric cable tray section in Navisworks® to be modeled as a semantic waypoint. Thus, a 1:1 relationship was maintained between the cable

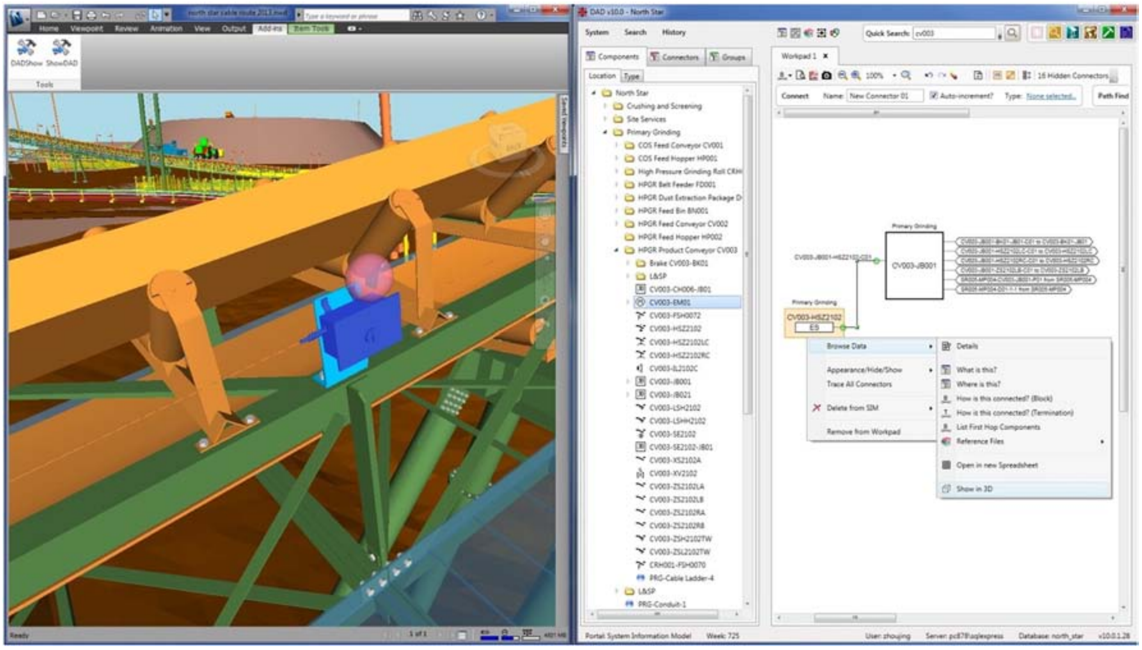


Fig. 12. Object linking between DAD and 3D model.

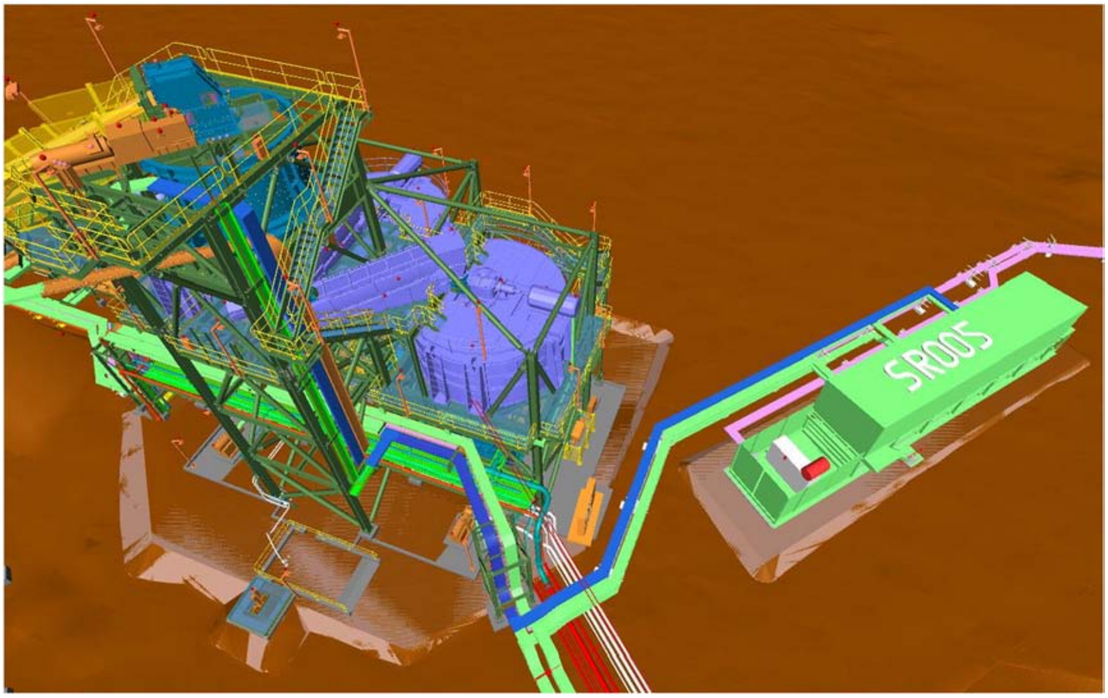


Fig. 13. Waypoint cable route.

tray section and the corresponding waypoint. Waypoint or multiple waypoints can subsequently be attached to any cable in the SIM forming a cable route. By selecting the waypoints attached to a cable, the corresponding cable tray sections in the 3D model can be highlighted. Fig. 13 identifies the cable route from a motor CV003-EM01 to the motor control center MCC05 located at "switch room" SR005. Its corresponding connection in the SIM is shown in Fig. 14. As the length of each cable tray section is readily available, the information can be passed to the waypoints in the SIM, which in turn enables cable length to be accurately calculated.

Fig. 15 shows that the cable route highlighted in blue in Fig. 13 consists of 24 cable tray sections. The total length of the cable route, and therefore the three cables between CV003-EM01 and SR005-MCC05, is calculated as 85.49 m.

4. Discussion

The development and application of object-oriented technologies such as a SIM can help to facilitate collaboration and overcome communication problems that often exist in projects [7]. Transforming the established document-oriented information exchanges that are typically used in EICS projects to a more collaborative data-sharing environment enables the processes to be streamlined and errors, as a result of duplication and inconsistency, to be prevented from occurring. While still working within the restriction of discipline-specific models, the creation of a SIM is the first step towards integrated and interoperable data without a reliance on drawings and contributes to the transition from Level 1, on the Bew–Richard maturity model, towards the as yet unsupported Level 3 [16] (Fig. 16).

The SIM presented here is essentially a definition of a discipline-specific view and the DAD tool provided all the mechanisms required by the subject expert to create and manipulate the EICS. The use of mining industry-specific software is, in this case, essential for efficient design, allowing systems to be designed and presented without the need for redundant information, in particular the modeling of geometry. In addition, the ability to share data, through the use of robust GUIDs, allowed data to be coordinated and shared across software platforms without the need for complex data exchanges.

4.1. Future research

This reliance, however, on discipline-specific models, each needing to be created and maintained, while without doubt removing errors within the discipline, can also result in redundant and inconsistent data that may not be usefully integrated with other systems. Thus, in the future, protocols will need to be agreed and maintained in order to ensure that information held in more than one model does not diverge or result in a duplication of effort. When the number of disciplines

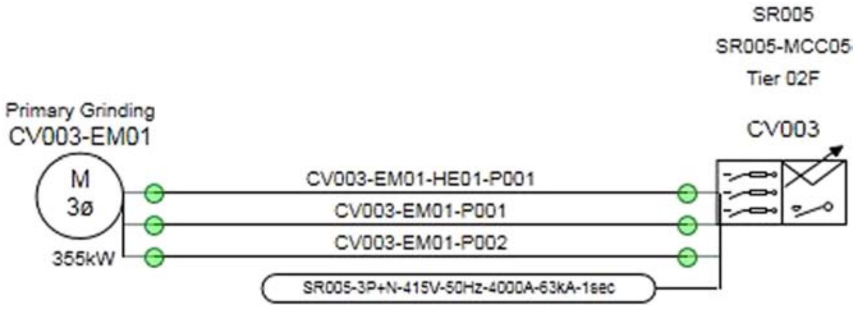
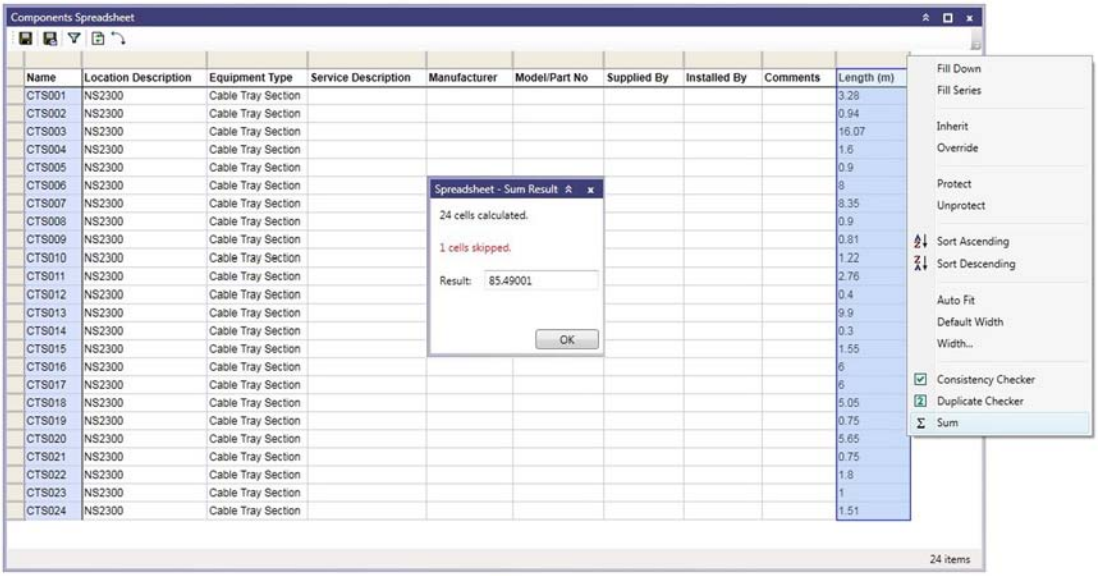


Fig. 14. Connections shown in SIM.



Name	Location Description	Equipment Type	Service Description	Manufacturer	Model/Part No	Supplied By	Installed By	Comments	Length (m)
CTS001	NS2300	Cable Tray Section							3.28
CTS002	NS2300	Cable Tray Section							0.94
CTS003	NS2300	Cable Tray Section							16.07
CTS004	NS2300	Cable Tray Section							1.6
CTS005	NS2300	Cable Tray Section							0.9
CTS006	NS2300	Cable Tray Section							8
CTS007	NS2300	Cable Tray Section							8.35
CTS008	NS2300	Cable Tray Section							0.9
CTS009	NS2300	Cable Tray Section							0.81
CTS010	NS2300	Cable Tray Section							1.22
CTS011	NS2300	Cable Tray Section							2.76
CTS012	NS2300	Cable Tray Section							0.4
CTS013	NS2300	Cable Tray Section							9.9
CTS014	NS2300	Cable Tray Section							0.3
CTS015	NS2300	Cable Tray Section							1.55
CTS016	NS2300	Cable Tray Section							6
CTS017	NS2300	Cable Tray Section							6
CTS018	NS2300	Cable Tray Section							5.05
CTS019	NS2300	Cable Tray Section							0.75
CTS020	NS2300	Cable Tray Section							5.65
CTS021	NS2300	Cable Tray Section							0.75
CTS022	NS2300	Cable Tray Section							1.8
CTS023	NS2300	Cable Tray Section							1
CTS024	NS2300	Cable Tray Section							1.51

Spreadsheet - Sum Result

24 cells calculated.

1 cells skipped.

Result: 85.49001

Fig. 15. Cable length calculation.

involved increases, along with the amount of software platforms supported, the maintenance of these protocols soon becomes unwieldy. It has been suggested that to move forward and achieve Level 3 maturity, the data contained within a discipline specific model view such as this SIM needs to interoperate with a standardized "model view" of an open standard pan industry and vendor-neutral data schema such as the Industry Foundation Classes (IFC) [7,11]. This will provide a mechanism to interoperate across all disciplines and ensure that data can be exchanged robustly in a standardized (and therefore checkable) format, across multiple software platforms. The data created in platforms such as a SIM provide valuable real-world scenarios that can be applied as use cases to feed into existing model view definitions such as COBie [2,3,5] to ensure that such schemas meet the needs of the mining industry [23].

The model servers required for full multi-disciplinary, Level 3 collaboration, on object-oriented data models such as SIMs and BIMs, do not yet exist [19]. Discipline-specific information platforms such as a SIM provide instant and measureable benefits to their users without major disruption to those project participants utilizing the information that is contained in the model. The data collected and structures used in such practical examples must feedback to the experts in organizations such as buildingSMART to ensure that future model servers are developed in a way that meets the needs of all parties involved with the delivery of a mining project, thus enabling the espoused benefits of

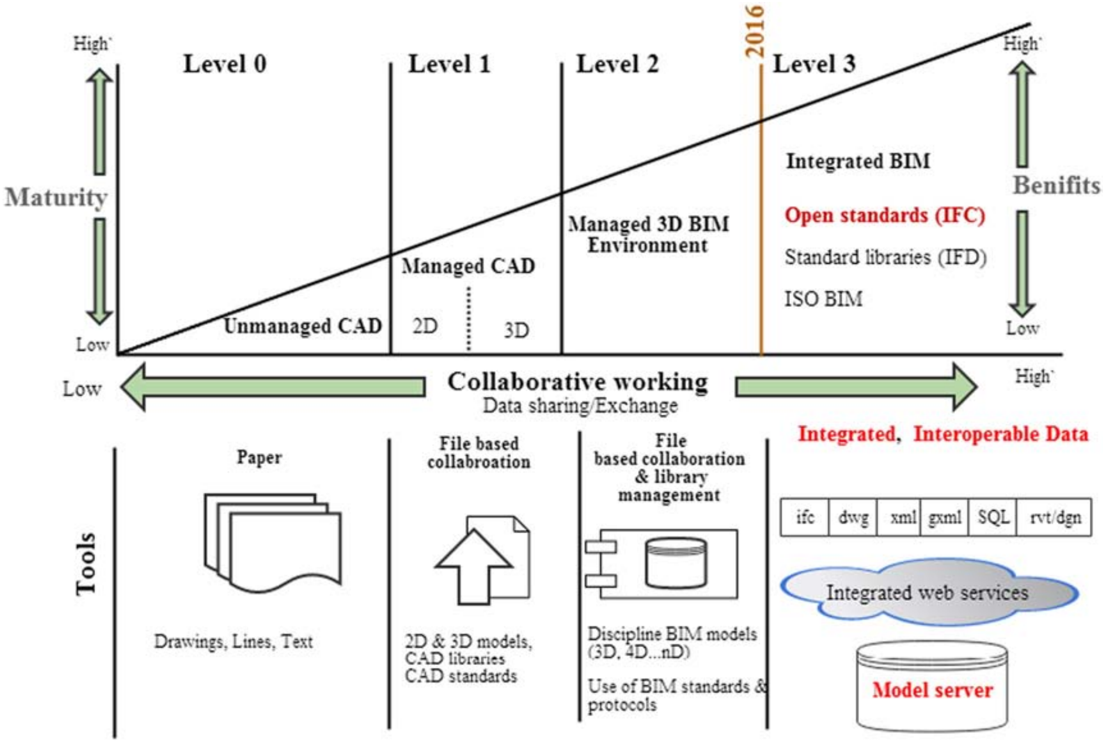


Fig. 16. Collaborative working and BIM maturity levels.

collaborative BIM and SIM to be mutually realized, particularly during the operations and maintenance of assets.

5. Conclusion

The mining industry needs to re-examine its business practices and the processes used to deliver and manage assets if productivity and the competitiveness of the industry in the global marketplace is to improve in the long run. Significant CAPEX overruns have jeopardized the viability of future projects and adversely influenced the return on investment of assets constructed, particularly considering the fall in price of commodities such as iron ore as a result of emerging economies such as China which have experiencing lower levels of domestic growth.

Several companies in Australia have recognized the need and urgency to re-examine the way in which they deliver and manage their assets in order to remain competitive. In addressing this issue, a major iron ore mining company re-examined the way it engineered, constructed, and implemented its EICS for a magnetite iron ore processing plant to ensure the operations and maintenance of its asset could be managed efficiently and effectively.

Previous research undertaken by the authors has demonstrated the potential of using a SIM to significantly reduce the costs associated with engineering and documentation. This provided an impetus for the iron ore company to adopt a SIM rather than using CAD, which has been often used within the mining industry for EICS. Working in a collaborative environment, the mine operator, engineers, and contractor engineered and documented the EICS. Rather than exchanging files between participants, a single-sever model was developed and modified accordingly when changes were required. Notably, no drawings were issued and the contractor installed the EICS using the digital model through the use of a PC tablet on-site; the project was paperless with regard to EICS.

By transforming the established document-oriented information exchanges a collaborative data-sharing environment was established, which enabled the engineering and documentation process to be streamlined and errors, as a result of duplication and inconsistency, to be prevented. While still working within the restriction of discipline-specific models, the creation of a SIM is the first step towards an integrated and interoperable data without a reliance on drawings.

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References

[1] R. Baskerville, Distinguishing action research from participative case studies, J. Syst. Inf. Technol. 1 (1) (1997) 25–45.
[2] BIM Guides. (2014). Available from http://bimguides.vtreem.com/bin/view/Main/WebHome, Accessed 17th February 2015.
[3] Blis-project, http://www.blis-project.org/IAI-MVD/2009.
[4] T.R. Black, Evaluating Social Science Research: An Introduction, Sage Publications, London, 1993.
[5] buildingSMART, 2011 Available from http://www.buildingsmart-tech.org/specifications/ifc-view-definition (Accessed 17th February, 2015).
[6] N.K. Denzin, The Research Act: A Theoretical Introduction to Sociological Methods, third ed. Prentice-Hall, Englewood Cliffs, 1988.
[7] C. Eastman, P. Teichol, R. Sacks, K. Liston, BIM Handbook—A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors, second ed. John Wiley & Sons Inc., 2011
[8] A.S. Hanna, F. Boodai, M. El Asmar, State of practice of building information modelling in mechanical and electrical construction industries, ASCE J. Constr. Eng. Manag. **139** (10) (2013) (pp.).
[9] A.S. Hanna, M. Yeutter, D.G. Aoun, State of practice of building information modelling in the electrical construction industry, ASCE J. Constr. Eng. Manag. **140** (12) (2014) (pp.).
[10] B. Israel, S. Schurman, M.K. Hugentobler, Relationships between organization members and communities, J. Appl. Behav. Sci. 28 (1992) 74–101.
[11] ISO 16739, Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries, ISO Central Secretariat, 2013.
[12] NBIMS-US™, The National BIM Standard-United States™ Accessed 15th December, http://www.nationalbimstandard.org/faq.php#faq12014.
[13] P.E.D. Love, J. Zhou, C.-P. Sing, J.T. Kim, Documentation errors in instrumentation and electrical systems: toward productivity improvement using system information modelling, Autom. Constr. 35 (2013) 448–459.
[14] P.E.D. Love, J. Zhou, J.T. Kim, Assessing the impact of requests for information in electrical and instrumentation engineering contracts, J. Eng. Des. 25 (4–6) (2014) 177–193.
[15] A.J. Mills, G. Durepos, E. Wiebe, Encyclopaedia of Case Study Research, SAGE Publications, 2010.
[16] PAS 1192–2:2013, PAS 1192–2:2013 Specification for information management for the capital/delivery phase of construction projects using building information modelling. British Standards, BSI Standards Limited, 2013.
[17] M. Peters, V. Robinson, The origins and status of action research, J. Appl. Behav. Sci. 20 (2) (1984) 113–124.
[18] C. Robson, Real World Research: A Resource for Social Scientists and Practitioner-Researchers, Blackwell Publishers, Oxford, 1993.
[19] Shafiq, M. T. (2014). *Managing Iterative Changes in Building Information Models in Collaborative Work Environments*. Unpublished PhD thesis, Northumbria University, Newcastle upon Tyne.
[20] L. Smith, L. Bratini, A. Chambers, R.A. Jensen, L. Romero, Between idealism and reality: meeting the challenges of participatory action research, Action Res. 8 (4) (2010) 407–425.
[21] G. Susman, R. Evered, An assessment of the scientific merits of action research, Adm. Sci. Q. 23 (4) (1978) 582–603.
[22] S.J. Taylor, R. Bogdan, Introduction to Qualitative Research Methods(2nd) Wiley-Interscience Publications, USA, 1984.
[23] C. Zhang, J. Beetz, B. de Vries, An ontological approach for semantic validation of IFC models, Proceedings of the 21st International Workshop on Intelligent Computing in Engineering (EG-ICE) 2014 - July 16th -18th, 2014 Cardiff, UK, 2014.