ENGINEERING MANAGEMENT AND BUSINESS INTELLIGENCE: THE IMPORTANCE OF PLANT DESIGN BASE

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ABSTRACT

Most popular business improvement models center their framework and approaches around ***business process*** improvement – thus on people, process and technology aspects of the business. They tend to drive business process improvement cycle elements, and seldom evaluate the impact of not using high quality critical plant design and control data effectively. As a result, these business models generally struggle to quantify their value proposition as they lack the plant and process data needed to demonstrate/prove value. This paper highlights the importance of understanding and using the plant design base as a primary input to process plant business improvement models and initiatives.

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1. INTRODUCTION: THE IMPORTANCE OF THE PLANT DESIGN BASE

Most of the popular business improvement models centers their framework and approaches around ***business process*** improvement. Very few of these models, if any, evaluate the impact of not using critical plant design and control data effectively. Limited focus is therefore placed on the ideal set of plant data and information required for business improvement and analytics. As a result, these business models generally find it difficult to quantify the value proposition sold to the business as it lacks the supporting plant and process data that can be used to demonstrate and prove the value proposition.

According to Biehn[2], data scientists believe that as little as 5% of the "big data" gathered results in 95% of the value contribution of the data. And herein lies one of the biggest problems with data in business today – ***effectively identifying, modelling and analysing the 5% critical data to improve business operations***. Many companies gather vast amounts of data, but rarely take the effort to analyse the data or even asking the basic question of *WHY* they are gathering the data. Although data storage costs have significantly reduced, the impact of analysing critical business and plant data when it is buried in 95% of "low value data" has a significant impact on productivity, situational analysis capability, incident response and decision times.

The research study has developed an integrated plant information (IPI) framework and Business Improvement Model (IPI-BIM) depicted below in Figure 1. At the core of this model is the Plant Design Base Data contained in an IPI system environment, with the design base content supported by the required engineering processes and advanced analytics capability to manage it.

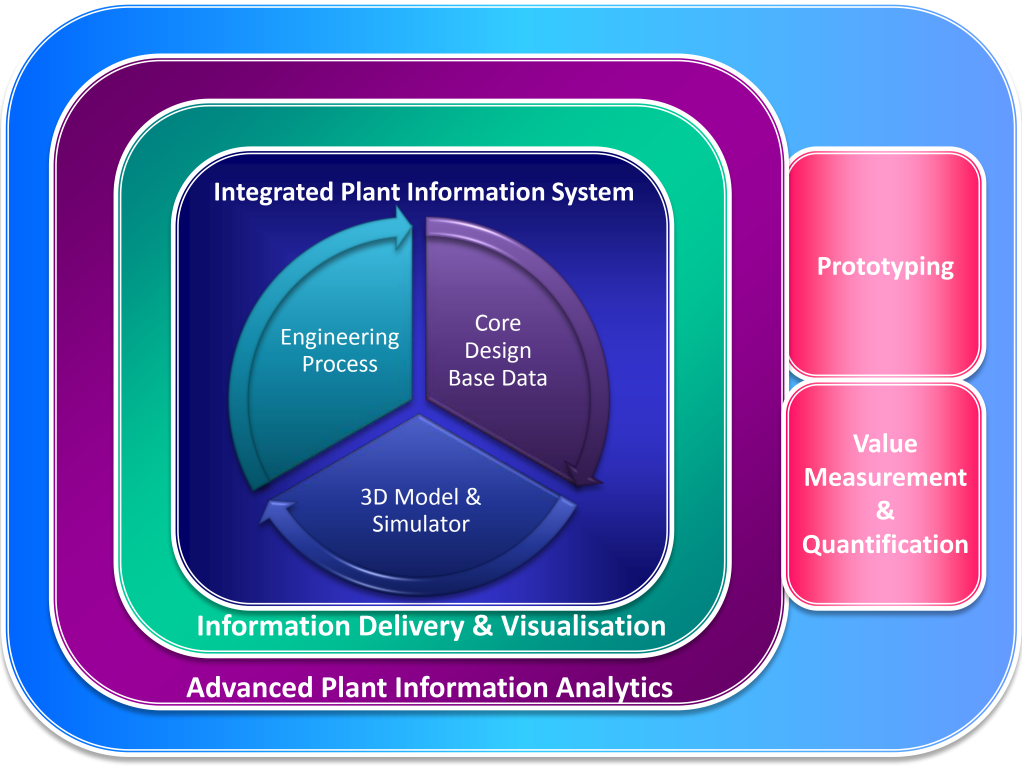


Figure 1: The Integrated Plant Information Business Improvement Model (IPI-BIM)

The research study scope included the identification, sourcing, validation and information management requirements of the most critical and core design base content needed for advanced analytics and decision making. Although the research study was focused on the Power Utility environment, any process plant owner would be able to identify with the core design base content listed in Table 3.

Most of the current Power Utility Generation fleet are either mid-design life or post this midpoint in terms of the asset lifecycle (Figure 2). The research scope is thus of great interest to the Utility that is currently undertaking a process of Validating and Verifying (V&V) their plant design base and implementing more extensive configuration control capability for the management of the plant design base. V&V of the entire potential design base can come at significant cost to the Power Utility, so if a reduced critical and core design base can be identified, there is significant cost saving potential for the Power Utility in a very funding-constrained environment.

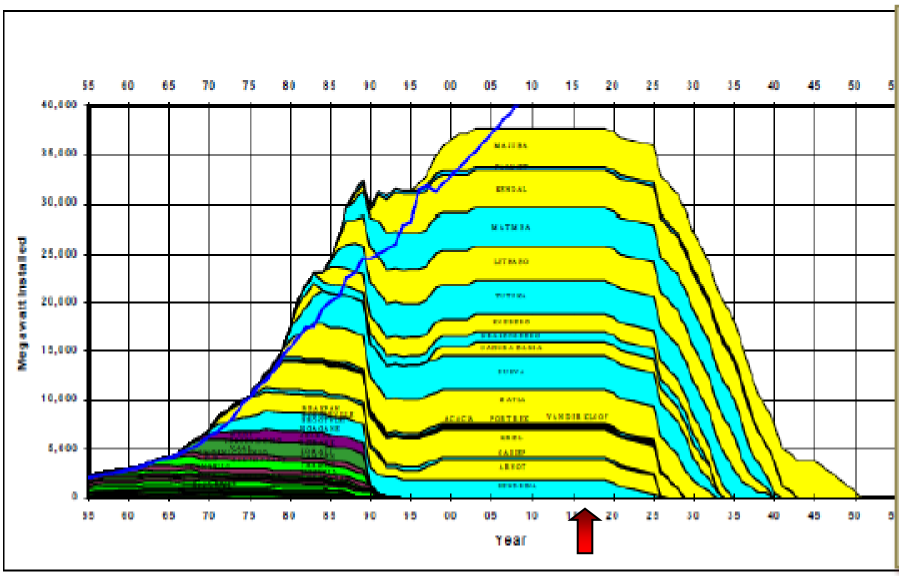


Fig 2: Shows the current age profile of the Eskom Power Generation fleet, red arrow indicates current year (2015). The utility face a significant decline in generating capability in the next 10-15 years due to ageing plant, making it more crucial to improve reliability and prediction of performance risks.

Figure 2: Eskom Generation Fleet Age [4]

The operational research and prototyping further evaluated whether the identified core design base proposed for the IPI-BIM would support predictive analysis of plant behaviour in order to increase reliability of plant. Proposed system integration, core design base identified, the required data interaction, validation and visualisation capability, all formed part of the operational research effort to prove the IPI-BIM elements and implementation approaches suggested.

The research included an evaluation of information delivery options and technology within the Power Utility to define the most cost efficient, intuitive and effective/productive way to make the information available. More integrated design base data management would also support business improvement by supplying consistent, validated and verified design base data in one central information repository. This paper focuses on a sub-set of the overall research undertaken to build and prove the IPI-BIM Model and Approach. It specifically covers the core design base definition and operational prototyping/research undertaken to prove that it is sufficient to support business improvement initiatives in process plant environments.

2. PLANT DESIGN BASE AS THE FOUNDATION FOR ADVANCED ANALYTICS

The IPI-BIM Framework works on the premise that a systematic and integrated approach to configuring and building the required Integrated Plant Information (IPI) infrastructure and architecture can set up the organisation for success in driving more informed decision making and improved business operations (Figure 3).

Research into the building of Artificial Intelligence (AI) capability and algorithms clearly indicated that it is a research study field in its own right, and the aim of this study was not to build or establish this AI capability and was thus excluded from the research scope. The research aimed to establish the framework capability stack to enable predictive analytics capability level, with the premise that AI would be a natural outflow from the initial predictive analytics frameworks and fault models built during the research prototypes.

Figure 3 indicates how the Plant Design Base ***is the most fundamental requirement for advanced plant analytics***. The challenge is to define the core design base data set, specifically on plants that were built before the electronic information era, and confirming that what has been sourced is sufficient to support the advanced analytics capability required for business improvement using plant information.

Searches of the Electrical Power Research Institute (EPRI) research database (www.epri.com) returned very limited information on exactly what is deemed prescribed design base information and scope, and rather focused on actual design examples - confirming the need to define the core design base data set needed for advanced analytics in the proposed Business Improvement Model.

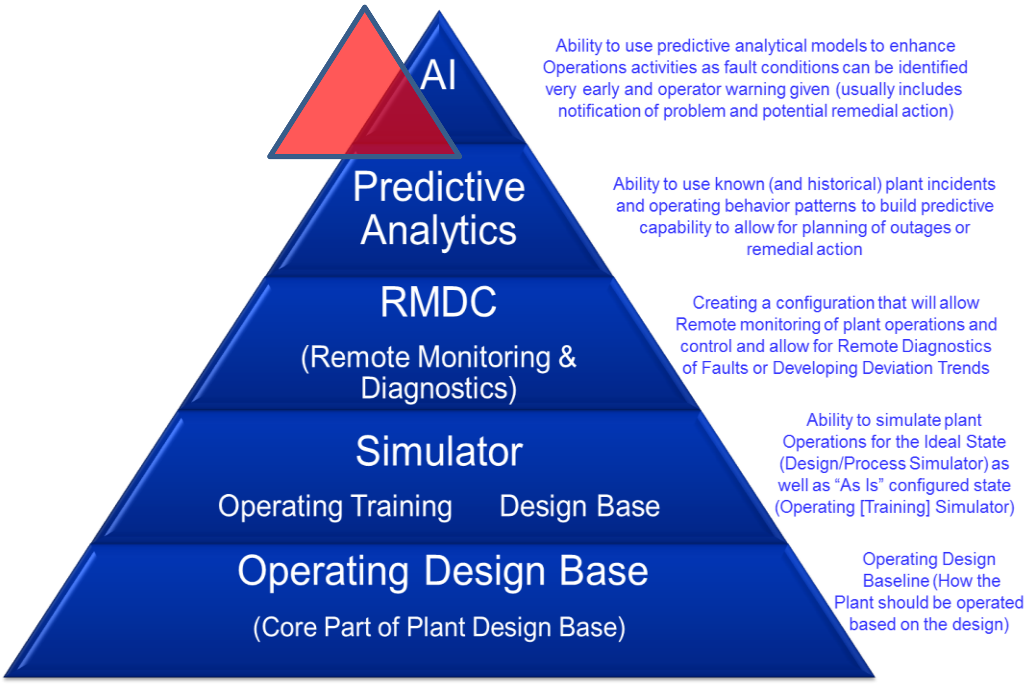


Figure 3: Advanced Analytics Capability Building Blocks [15]

The PAS-55 [10] framework makes it clear that good decisions should be balanced between deterministic ***and*** probabilistic analysis to provide the required insights, perspective, comprehension and balance in the decision making process. **The PAS-55 framework also emphases the importance of a well-managed design base information and data-set to assist in decision making.**

The Nuclear industry study on advanced AI on control systems [18] sees the development of advanced algorithms and fault models as exciting new future trends that can have a major impact on operator efficiency in dealing with plant upsets. **This industry study confirms the crucial importance of a well-managed, integrated plant database where all critical plant design base information is contained.** The study also supports the view that it is key to apply rule sets in the management of information and when dealing with the ordering of large data-sets for analytical analysis.

3. RESEARCH SCOPE AND OUTCOMES

Part of the overall operational research performed aimed to define the scope, effort, establishment methodology and extent of design base information in an integrated plant information system (IPIS) hub for a Brownfields plant. As indicated, it is considered a core capability needed to deploy and use more advanced predictive plant information analytical capability to enhance and improve business efficiency and decision making. It is also a key input to achieve the Power Utility SmartUtility Strategy [8] desired outcomes.

Part of the research process was to understand and characterise the core elements that make up the critical plant design base for a Brownfields power utility plant and investigating whether there is any difference in content and methodology of establishing the critical plant design base between Greenfield and Brownfields Plants.

Although there is obvious benefit with a reduced core design base (reduced validation and verification [V&V] effort and cost if only the most critical information has to be subjected to this process), it remains important to ensure that the scaled down design base information set is still sufficient to support asset management, advanced analytics and Business Intelligence (BI).

The research effort further included an investigation into the viability of reverse engineering data and plant process design base content. This was required in cases where original design base data-sets could not be sourced with conventional data mining/sourcing processes. Reverse engineering results were subjected to a three-way process of V&V using Plant Operating Simulator, Engineering Simulator/Flow Simulation and Actual Plant performance data evaluation to ensure its correctness.

Subsequent prototyping was then conducted to confirm that the core design base elements identified in the Plant Information System hub is extensive enough in nature to support efficient asset management and predictive diagnostics.

The research also aimed to identify the most efficient methods of information delivery based on user needs, type of user and specific business requirements. The engineering design base is very data-centric in nature and options for delivering it in a more user-friendly and intuitive manner was prototyped.

3.1 Software System Implementation Methodology

The research developed a templatised, standardised, balanced implementation methodology and system configuration that contains the required elements of data content, workflow, engineering business processes and information integration needed to enable and support the engineering organisation and core engineering processes required across the asset lifecycle (Figure 4).

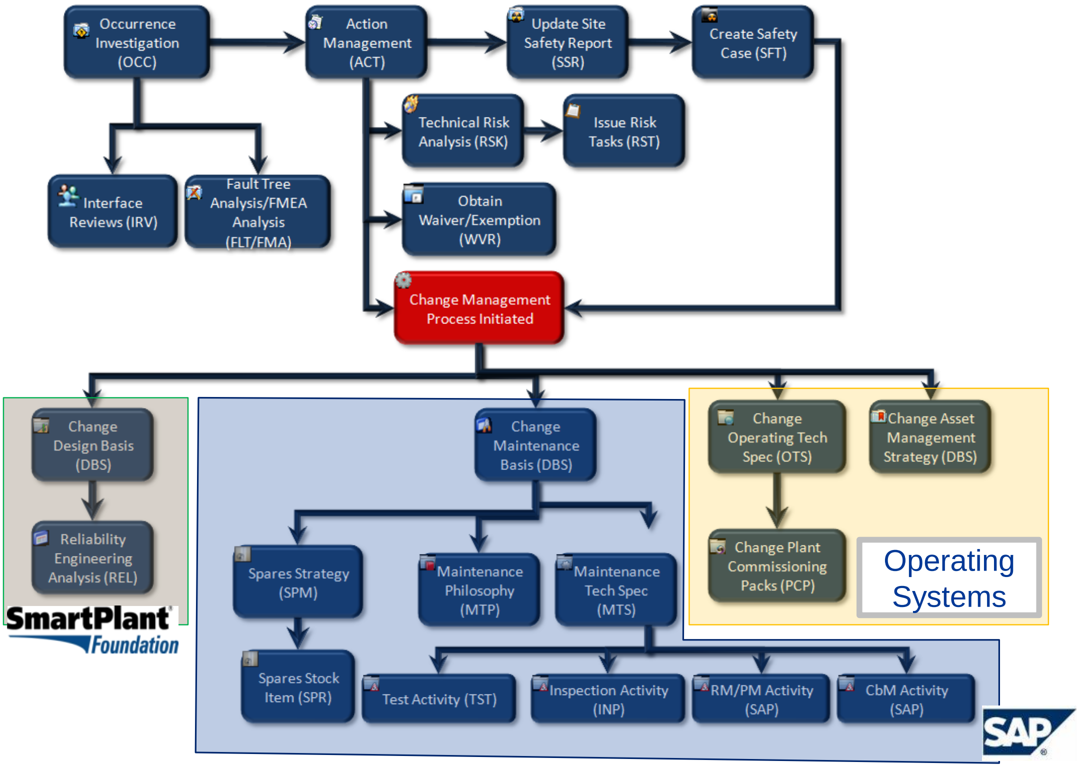


Figure 4: IPI Engineering Business Process Integration [16]

This implemented configuration and capability forms part of the core system framework in the IPI-BIM and acts as the integrated repository for engineering processes (with their associated BI meta-data for analytical purposes), design base data and the 3D plant visualisation platform.

Four Engineering Information Management System Project implementation methodologies were evaluated during the research study (Table 1). The four projects all had the same intent – the implementation of an integrated engineering information management system for the Power Utility that can manage the plant design base and associated workflows.

Although these projects had the same intent and intended outcomes, they followed very different approaches and execution methods. The biggest impact on system implementation timelines are the engineering business process configuration scope and implementation methods. Delays on Projects 2, 3 and 4 were primarily caused by challenges on engineering process workflow configuration. These configurations generally ended up being the critical path items defining/ affecting the project timeline. Enabling a more optimal method to define and configure workflows would therefore add significant value in system implementation scopes of work.

Table 1: Research Findings – IPI System Implementation Methodologies

	PROJECT 1 METHOD	**PROJECT 2 METHOD**	**PROJECT 3 METHOD**	**PROJECT 4 METHOD**
Implementation Timeframe (Planned) {9}	6 Months	24 Months	9 Months	6 Months {2}
Implementation Timeframe (Actual)	6 Months	36 Months	24 Months {1}	42 Months (Still Ongoing) {2}
Deployment Timeframe	4 Weeks	2 Years	8 Weeks (Prototype)	52 Weeks (Still Ongoing)
Number of Eng. Processes Enabled	6	4	22	8
Extent of 2D Intelligence{7}	30%{4}	0%	60%	40%{5}
Extent of 3D Intelligence{8}	25% (Point Cloud, Limited 3D Model) {4}	10% (Only 3D Review models, no intelligence)	60% (Limited 3D use due to reference data availability) 3D-Pact Ops Simulator Implemented	30% (Reference 3D Models only – reference data still an issue to enable full intelligence 3D Models)
Operational Use	Full operational use of all functionalities created – Used at Power Station for 7 years	Partial – 1 New Build Project, no use in Brownfields Generation plants. No 2D/3D deployed in operational use.	Prototype implementation only – SPO OOTB implementation favored and GEDI Project closed out at feasibility study and concept delivery phase.	Limited use as it is still in deployment phase. Partial Implementation at 2 sites. A number of functionality additions still required for full operational use.
Implementation Cost	R9M{3}	R60M	R15M{3}	R120M+{6}

Notes:

{1} Increased timeframe caused by scope creep in number of business processes required. (7 core processes were defined at the start of the project to prove the concept – a total of 22 processes were eventually implemented under the full project scope).

{2} "Out of the Box" (OOTB) Timeframe of 6 months was claimed by vendor. The OOTB implemented solution was not accepted or signed off by business as it did not meet business requirements.

{3} Implementation cost included the proof of concept implementation of 2D and 3D design base deliverables for Project 3. The other 3 projects only focused on ***enabling*** the capability to create intelligent 2D/3D deliverables.

{4} The initial project scope excluded 2D & 3D Deliverables but was added subsequent to initial project scoping.

{5} The 2D/3D design-base related work undertaken in Project 3 was re-used in Project 4's Implementation.

{6} Implementation cost for this project *excludes* extensive design base data migration. The project's scope only covers legacy EDMS system replacement efforts.

{7} Two-dimensional (2D) intelligence implies the conversion of conventional drawings into data-centric "intelligent drawings" where design base content is related to objects on the drawing and available on "query" of the object on the drawing.

{8} Three-dimensional (3D) intelligence implies the use of visual/three-dimensional information datasets to display the plan design base in a visual format. As with 2D intelligence drawings, 3D model "objects" can be queried for design base information like design criteria, specification values, etc.

{9} The engineering process workflow configuration would typically dictate the anticipated project timeframe and on all four projects was the "critical path" scope.

From evaluation, the Project 3 Implementation Method was found to be preferred baseline to establish the IPI System implementation approach for the IPI-BIM. Enhancement of this method and the development of a templatised 6-step implementation methodology in the research study resulted in a well-documented rapid application development (RAD) approach to integrated engineering system implementation.

3.2 Engineering Business Process Implementation Methodology

To prove the methodology developed, the enhanced implementation methodology was used on Project 3 to configure and implement the 15 additional engineering processes identified in addition to the original 6 core processes. Table 2 below demonstrates how the structured and templatised approach and methodology developed by the research significantly reduced business process implementation cycle time and configuration error rates.

Table 2: Engineering Business Process Implementation Method Findings

	COMPLEX ENGINEERING PROCESS	**AVERAGE COMPLEXITY ENGINEERING PROCESS**	**SIMPLISTIC ENGINEERING PROCESS**
Target Processes	**1st Pass:** Engineering & Project Change Management (Design & Field Changes) **2nd Pass:** Technical Risk Analysis **3rd Pass:** Technical Documentation Management	**1st Pass:** Occurrence & Incident Management **2nd Pass:** Non-Conformance Management **3rd Pass:** Authorisation Management	**1st Pass:** Action Management **2nd Pass:** Interface Management **3rd Pass:** Spares Strategy Management
No of Workflow Steps	>20	10-20	<10
First Pass Process Configuration & Implementation Cycle Time	42 Days	14 Days	6 Days
2nd Pass Process Configuration & Implementation Cycle Time	29 Days	11 Days	4 Days
3rd Pass Process Configuration & Implementation Cycle Time	21 Days	7 Days	2 Days
Error Rate (UAT/FAT NCR - % rework)	1st Pass: 22% 2nd Pass: 19.8% 3rd Pass: 13%	1st Pass: 15% 2nd Pass: 7.8% 3rd Pass: 4.5%	1st Pass: 11% 2nd Pass: 6.3% 3rd Pass: 2.8%

The projected business process system configuration time for the additional 15 processes was reduced from 9 months to 6 months (with the resulting benefits of reduced project cost and earlier project scope delivery).

3.3 Identifying the Core Design Base

An Intergraph study [3] states the goals of having core design base information available as being:

- Reduced Time-to-Market (TTM)
- Maximised Time-in-Market (TIM)
- Optimised Operating Parameters (OOP)

The study very aptly shows how certain information creates a cascading negative business effect later in the asset lifecycle when it is not available, as well as the inter-relatedness of the TTM, TIM and OOP elements.

Numerous examples were sourced from industry players in the EPC space [3, 6, 11, 13, 14, 17] to establish the typical Design Base Handover scope that Owner/Operators ask for and measure at handover of plant into commercial operation.

The challenges with obtaining a full design base were demonstrated on the Greenfields Power Plant Project as well as the Brownfields Power Station that formed part of the research study. The research study concluded that the ability to source a full-on design base data set is problematic if a proper and extensively detailed handover information specification was not issued to the Design Authorities/Contractors.

Given the analysis of information sourced/available against the full design base, the research study theorised that it will be possible to identify the set of core design base information most needed by the Owner/Operator to manage, operate and maintain the asset for the design asset lifecycle timeframe. And to demonstrate that supply/sourcing and validation of this core design base data-set is both possible and feasible.

The research study also theorised that it may be more difficult to source such design base content on an old Brownfields plant, and that there would be a need to do reverse engineering of missing design base content. To prove this hypothesis, design base sourcing was therefore conducted in both a Greenfields and Brownfields scenario to compare the availability of information and determine the need for reverse engineering.

The research study concluded that the design base elements and content needed for a full C&I control system refurbishment (Figure 5) would be the closest requirements definition of what plant and technical information should be deemed ***CORE*** design base content for a power plant asset (in this case the plant Operating Design Baseline). Further detailed analysis of the typical design artefacts that would define the Operating Design Baseline, is provided in Table 3.

This Operating Design Baseline is typically augmented by a Maintenance Design Baseline for the plant asset, defining the maintenance strategy and tasks for plant equipment based on its criticality classification, operating duty and operating environment conditions.

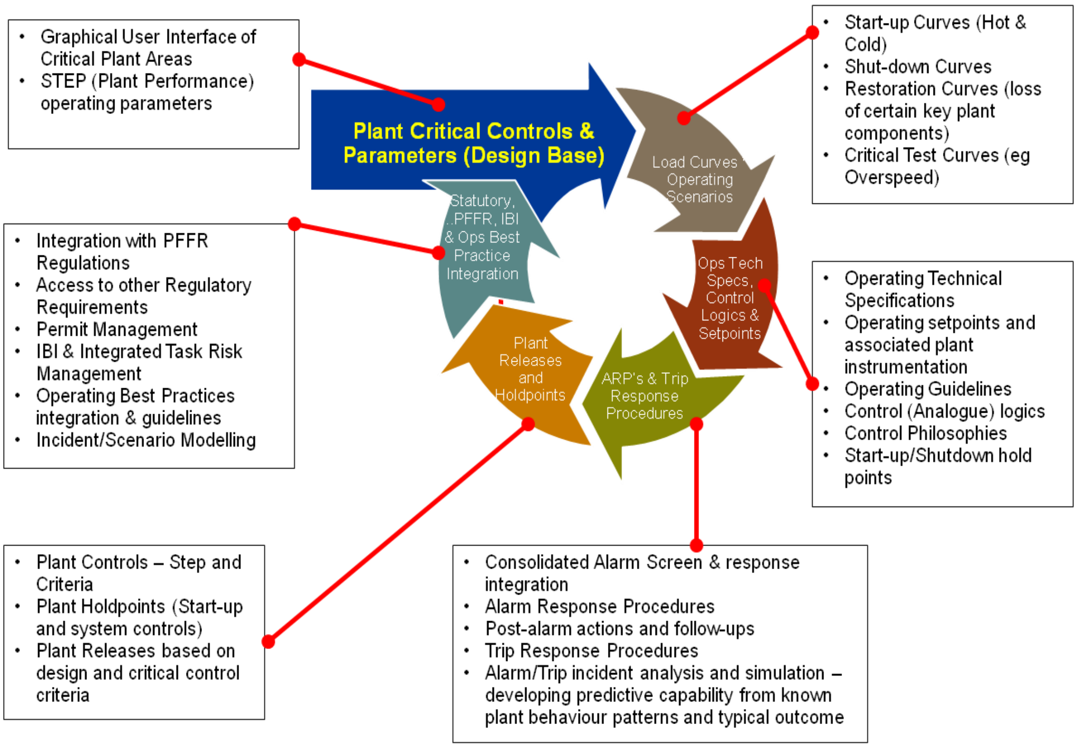


Figure 5: Core Design Base Content needed for C&I Upgrades

The research study focused further data sourcing and evaluation of design base artefacts listed in Table 3. Although the research study was focused in the Power Utility environment, the commonality of these design base artefacts to most process industries should be evident. This view is confirmed in the numerous examples sourced from industry players in the EPC space [3, 6, 11, 13, 14, 17].

Operational research was used to determine completeness and availability of this information in a Greenfields Power Plant Project, as well as an operational Brownfields Power Plant, to confirm that this is a viable hypothesis and design base scope.

Table 3 indicates the actual volumes of design base artefacts sourced for each core design base element. It demonstrates that the information is indeed available, and can be sourced successfully for the Greenfields as well as Brownfields plant scenarios.

Interpretative notes at the end of Table 3 explain anomalies or large differences found with the comparative analysis done in the research study.

Table 3: Core Design Base Content Value - Brownfields vs Greenfields Plant

CORE DESIGN BASE CONTENT	QUANTITIES OF DESIGN BASE ARTEFACTS	
	GREENFIELDS PLANT	BROWNFIELDS PLANT
Process Flow Diagrams (PFD's)	144	122
Process & Instrumentation Diagrams (P&ID's)	4,467	3,198
Material, Mass & Energy Balances	2	4
Plant Process Set-point Lists	95	1{8}
Operating Envelopes	135	13{1}
Operating Curves (Start-up, Shutdown, Specific Conditions)	0	16
Single Line Diagrams	869	1,321
Control & Operating Philosophies	1	7
Control Functional Specifications	272	32
System Functional Specifications	793{9}	42
Operating Manuals	0	135
Process Alarms List – Alarm Response Procedures	2	1,578
Plant Trip & Interlock Schedule	2,817	12,695{2}
C&I Setpoint List	165	55
SIL Report (Safety Instrumentation List)	17	1
Instrument Schedule (Preferably including Locations)	101	304
Plant Control & Protection Logic (Including Interlocking)	0{2}	0{2}
Automation Concepts/Strategy	0	2
3rd Party Control Systems Connectivity to SCADA Systems	0	1
Interface Bus Requirements (IT Level)	0	1
Electrical Settings Documents (Including Protections)	244{3}	373{3}
Drive & Actuator Schedule	38	373
Switchgear Schedules	244	1,696
Equipment Datasheets/Data-lists	2,404	970{4}
Maintenance Philosophies/Strategy	0{13}	8
Maintenance Technical Specifications	0{13}	145
Layout Drawings (Plant Control/Switchgear Rooms)	15,213	4,978
Test & Inspection Plans	723	399{5}
Operating Technical Specifications	0{13}	33
Operating Check sheets	591{11}	202

Commissioning Check sheets (Running, Start-up & Shutdown)	1,750	833
Panel Standby Check sheets	0{6}	0{6}
Control Panel Releases	51{6}	0{6}
Plant Simulation / Simulator Strategy	0	1
Simulator User Requirement Specification	0	1
Technical Procedures – Operating	584	893
Technical Procedures – Maintenance	563	199
Plant Occurrences History	0	6,944
Plant FMECA Analysis (Occurrence Statistics)	90{12}	0{7}
Plant Modifications History & Detail	355{10}	1,726

Notes:
{1} Operating Envelopes are typically described in the OTS and not found as a stand-alone/separate document. Some Operational/Performance Requirements documents were identified that to some extent provided the information needed to define the operating envelope.
{2} Does not exist as unique entities, but part of the set of Logic Diagrams of the Control System.
{3} Some of the information was contained in the electrical load list, and some of it in the Control Logic Diagrams.
{4} Number reflects the unique datasheet entities. This ***excludes*** equipment data contained in MSExcel format spreadsheets extracted from manuals and other sources.
{5} Excludes 177 actual test specifications for the Brownfields plant (content defines test specifics and not just test frequency and high level criteria) and 383 for the Greenfields Project.
{6} Panel Standby checks forms part of the Commissioning Check sheets and not separate entities.
{7} Statistics derived from Occurrence History captured in the Occurrence Management Process. Data mined and analysed on "as/when required basis"
{8} Information exists as "Process Design Criteria".
{9} Delivered as System Descriptions on Greenfields Project
{10} Greenfields Project still under construction, changes handled under Project Engineering Change Notice (ECN) or Field Change Notice (FCN) process. Number reflects the quantities of these registered under the project.
{11} Issued as Operating Instructions.
{12} Safety Study artifacts, feeding into FMECA process.
{13} Normally a document compiled by the System Engineer for the Plant system once all commissioning, maintenance guidelines and operating information is provided and signed off at hand-over.

A low volume of information & data was found on operating envelopes and expected plant process response behaviours on the Brownfields Plant. This design base content was therefore earmarked as the ideal candidates for the reverse engineering scope of the research study.

3.4 Structuring Design Base content

The research study theorised that it is crucial to implement a structured classification system to identify and manage the plant design base and its associated artefacts more effectively. The Power Utility implemented the IEC 61355 Document Classification standard[9] in 2008 and this standard was used to define and group the design base artefacts listed in Table 13. Prior to this standardisation, very little consistent structuring or classification methods were employed in the Power Utility to order engineering design base artefacts and content, making assessment of design base artefact maturity and completeness problematic.

The first pass assignment of design base artefacts to the IEC classification standard was done manually for the research study Greenfields Project. It was found to be very time consuming, and the research theorised that it should be possible to define and utilise data analytics rule-sets to assign IEC classes to the documents automatically. The data-mining would focus on the titles of documents and drawings and sometimes internal content (if Optical Character Recognition [OCR] technology was executed on the documents).

The first data-mining algorithmic rule-set was defined and executed as "Iteration 1" on the Greenfields Project data-set. This was then compared against the manual IEC allocation done previously to determine the accuracy of the automated rule-set. A success rate of 53.7% accuracy on IEC level 4 assignments was achieved.

Table 4 summarises how the data-mining and analytical success rate was improved using further iterations and enhancements to the rule-set (and using both Brownfields and Greenfields plant documentation).

Iteration 2 significantly enhanced the success rate, mostly due to the fact that a mature Brownfields Power Station data set was used to enhance the set developed using the Greenfields Project. Many design base artefacts were not available on the Greenfields Project during Iteration 1, reducing the number of artefacts automated (57 artefact types). With Iteration 2, the IEC artefact types were expanded to 107 instances.

Iteration 3 used data from a second Brownfields plant (with additional new data mining keywords and search terms), which resulted in a further notable improvement.

Table 4: Automated Data Analytics Mining Tool Success Rate

ITERATION 1	ITERATION 2	ITERATION 3*
Greenfields Rule-set	Greenfields enhanced with Brownfields design base data and naming conventions used on older plants	Greenfields enhanced with design base data from 2 Brownfields plants
53.7%	83%	90.3%

**Note: For the final iteration, the remainder of the document types was manually assigned by evaluating the document titles in batches and allocating the correct IEC document classes*

The productivity benefit and thus usability of this automated classification tool in an operational environment was confirmed by the research – a previously labour intensive, manual IEC class assignment process of nearly 9 months was reduced to 2 months by applying the automated data-mining rule-sets on another power plant of the Power Utility.

3.5 Reverse Engineering Core Design Base content

The research study scope included an element of reverse engineering using the Brownfields Plant Operating Simulator content to re-build and validate the missing design base content identified. This allowed the re-creation of the operating envelopes and the expected plant process response behaviours of the Brownfields Plant. The research process and methodology is indicated below, and Figure 6 is an example of the typical process followed by the research study (this process may differ depending on the scope of the reverse engineering exercise).

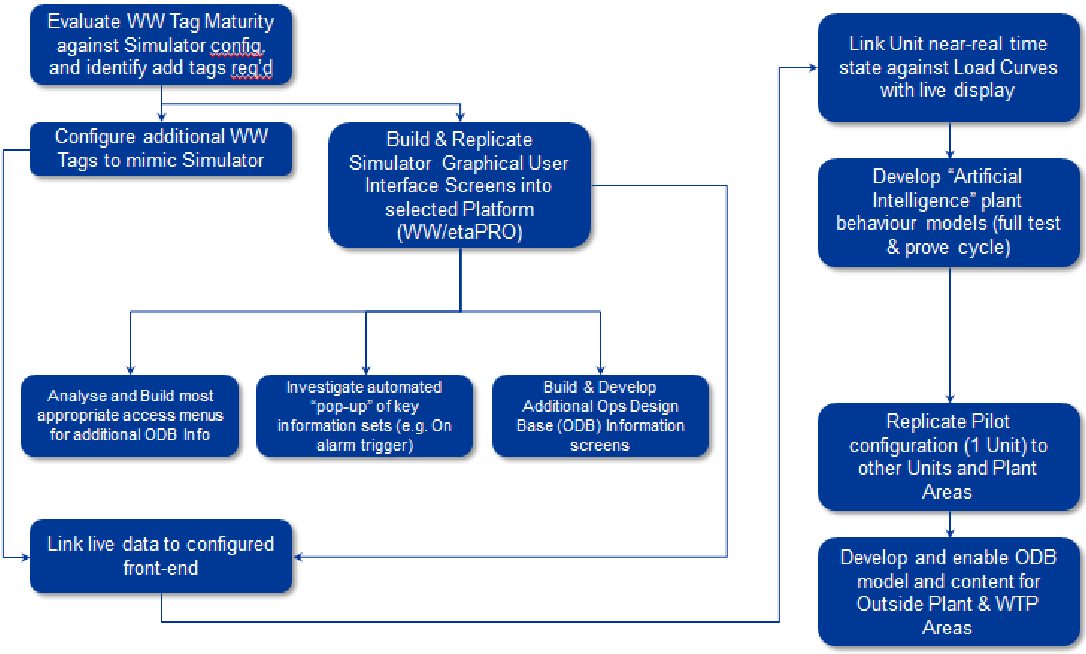


Figure 6: Reverse Engineering Design Base using Plant Operating Simulator

Notes on Figure 6:

1. *WW = Invensys WonderWare technology deployed as Plant Data Historian platform.*
2. *etaPRO = engineering simulation software deployed by the Power Utility at the Brownfields Power Station of the research study.*
3. *ODB =Operating Design Base.*
4. *WTP = Water Treatment Plant.*

Research data analysis also revealed that there was a significant number of missing or mismatched data-points between the 3 systems used in the reverse engineering process (plant control system, the Operating Simulator and Engineering Simulator). Resolving this data quality issue resulted in a notable improvement in the outcome of the advanced analytics (as certain values in the engineering simulator previously used "interpreted" or estimated values instead of real-time data values from the plant).

Research efforts included alignment of the Engineering and Operator simulator systems in terms of design base content, and then comparison to actual plant performance monitoring data-sets to confirm re-engineered datasets and expected behaviour observed in the two simulators.

The research proceeded to evaluate the load curves (that only existed in unverified paper format) and automated these in the Operating Simulator. Using actual plant data-sets and start-up scenarios, the operating curve was evaluated and confirmed against control system data (confirming that the simulated configuration and outputs mimic real life conditions and behavior). This reverse engineered and developed plant operating curve and analytical model can therefore be used with confidence for further analytics and measurement of plant reliability and availability.

The advanced analytics model built of the Brownfields Plant Rankine cycle (and the outcomes achieved running analytical scenarios on this cycle model), created a useful plant process design baseline.

Introduction of transient process analytics using the Flownex^{TM} software platform further enhanced the simulation capability in the research study. A drawback of the etaPRO Virtual Plant system^{TM} is that it provides a static analysis of plant process conditions and does not cover transient conditions and the subsequent process condition normalisation usually experienced when plant process conditions change.

3.6 Reducing Information Delivery Complexity

Gentile [7] states from his research that there are notable benefits from using data visualisation in an effort to reduce perceived and actual information/data complexities.

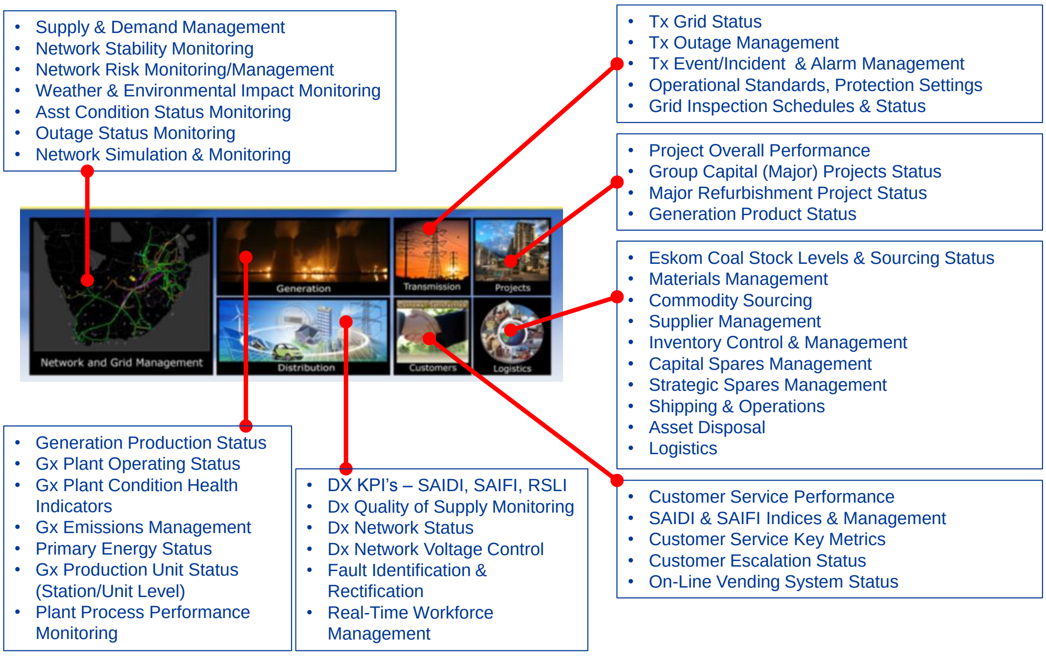
Typical benefits listed are:

- Understanding and absorbing complex technical engineering concepts when visually described.
- Better visualisation and understanding of relationships and behavior patterns for operational and business activities.
- Emerging trends and patterns can be recognised and acted on faster.
- The ability to directly interact and manipulate data.
- Complex business concepts can be better implemented in a visual format to enable a new business langue or bring about a change in business paradigms.

Part of the IPI-BIM operational research entailed the evaluation of the various information delivery technologies available within the Utility and defining the most appropriate infrastructure to use. Due to funding constraints, the research brief was to contain the research and data sources prototyped within the realm of the Power Utility's approved software technology stack, and as such research was not undertaken into alternative systems or software solutions.

The research study prototyping scope proposed and proved portal technology as a preferred medium of information delivery in a diverse organisation with different needs and uses for the information contained in business systems. The diversity of information covered is depicted in Figure 7.

The research and prototype scope considered both static and dynamic data sources within the Utility organisation. The frequency of data storage in the source systems varied from continuous on-line data capturing systems to systems where data is captured and trended on a monthly (or infrequent/"as and when required") basis.



- Supply & Demand Management
- Network Stability Monitoring
- Network Risk Monitoring/Management
- Weather & Environmental Impact Monitoring
- Asst Condition Status Monitoring
- Outage Status Monitoring
- Network Simulation & Monitoring

- Tx Grid Status
- Tx Outage Management
- Tx Event/Incident & Alarm Management
- Operational Standards, Protection Settings
- Grid Inspection Schedules & Status

- Project Overall Performance
- Group Capital (Major) Projects Status
- Major Refurbishment Project Status
- Generation Product Status

- Eskom Coal Stock Levels & Sourcing Status
- Materials Management
- Commodity Sourcing
- Supplier Management
- Inventory Control & Management
- Capital Spares Management
- Strategic Spares Management
- Shipping & Operations
- Asset Disposal
- Logistics

- Generation Production Status
- Gx Plant Operating Status
- Gx Plant Condition Health Indicators
- Gx Emissions Management
- Primary Energy Status
- Gx Production Unit Status (Station/Unit Level)
- Plant Process Performance Monitoring

- DX KPI's – SAIDI, SAIFI, RSLI
- Dx Quality of Supply Monitoring
- Dx Network Status
- Dx Network Voltage Control
- Fault Identification & Rectification
- Real-Time Workforce Management

- Customer Service Performance
- SAIDI & SAIFI Indices & Management
- Customer Service Key Metrics
- Customer Escalation Status
- On-Line Vending System Status

Figure 7: Implemented Portal Technology and Scope of Business Information Visible

Further research undertaken demonstrated the ease with which modern 3D CADD Models could be used to enable 3D visualisation capabilities in a portal environment. Being an integral part of the plant design base, the 3D Model of the plant could be enabled as a prototype research to demonstrate the ease of creating an interactive, virtual plant 3D environment on the Greenfields Project (Figure 8) from where design base information can be interrogated.

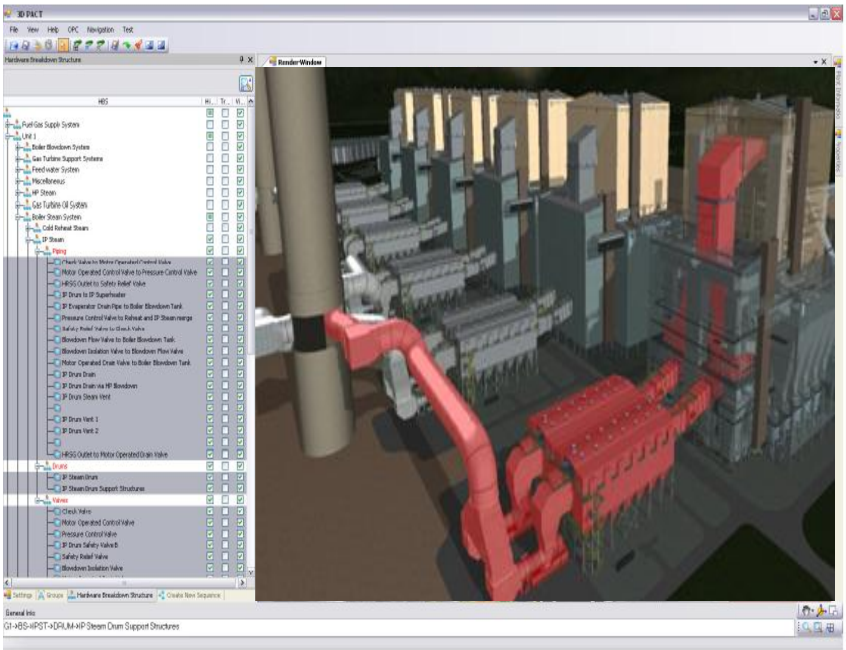


Figure 8: Visualisation of Design Base Content in 3D interactive plant model

As part of the information delivery research portion, a Proof of Concept (PoC) study demonstrating the integration of the 2D advanced analytics Flownex^{TM} capability into the 3D Plant Operating & Engineering Simulator was undertaken. The PoC focused on the Flue Gas Desulpherisation portion of the plant on the Greenfields Project that formed part of the research study. The reason for the choice was two-fold:

- A more mature 3D model of the Plant Design Base existed.
- A business need for Operating Staff to be trained on a very complex and intricate plant process technology that has not been implemented on a power generation plant in the Utility before.

Figure 9 below shows the outcome of this PoC - controllable parameters linked to a dynamic process simulator (Flownex^{TM}) was enabled (on the right hand side of the User Interface) allowing the end user to make changes to these parameters and evaluate the impact on plant performance and outputs. In the same visual interface it also exposed the end user to the integrated design base information system (on the left hand side of the User Interface) where more design base content can be accessed to evaluate the impact of plant control and parameter changes.

The plant breakdown structure of the Plant Design Base becomes the integration lever to expose more design base information and data when required by the operator/user, creating an “information on demand” capability and reducing potential information overload by exposing too much information in one user interface.

Design Base Information Link via Plant Breakdown Structure

Controllable Plant parameters enabled in the 3D Virtual model

3D Plant Virtual Model of FGD Plant (Scrubber highlighted and showing controllable parameters

01_HAD_1AA

01_HAD_1AA	
Power Plant Parameters	
Unit install capacity	8E+08
Plant efficiency	0.5
Combustion Parameters	
Superfluous combustion ...	1.2
Coal unburnt C mass fra...	0.01
Bottom ash fraction	0.1
Coal Parameters	
Calorific value (Nett)	18330
Ash mass fraction	30.6
C mass fraction	47.7
Cl mass fraction	0.1
H mass fraction	3
N mass fraction	0.8
O mass fraction	7.2
S mass fraction	1.4
Moisture mass fraction	9.2
Ambient Conditions	
Air humidity	0.3
Air temperature	298.2

10_HTD_10_BB_001

10_HTD_10_BB_001	
Chemistry	
Gas synthesis Mass source	5.787946
Liquid synthesis Mass so...	-5.787946
SO2 removal efficiency	0.95
Gypsum synthesis Mass ...	6.242045
Gas Flow Results	
Pressure loss	164.95842
Gas Inlet Mass flow	0
Gas Outlet Mass flow	0
Flow velocity	2.516052
Energy and Heat Transfer	
Evaporation Heat	-17212098
Gas-Liquid Heat transfer	3.709868E+07
Liquid Flow Results	
Liquid Inlet Mass flow	0
Liquid Outlet Mass flow	0

Figure 9: Integrating Advanced Analytics with the 3D Information Delivery and Design Base

It also evaluated of methods to simplify complex plant process models by focusing on core operating design base content known as "Controllable Parameters" in the process plant control environment. Work done in the reverse engineering phase of the research project added significantly to this evaluation.

The research study scope included an evaluation of the viability of creating a similar virtual, interactive and 3D visualisation capability enabled environment for the Brownfields Plant using 3D Laser scanning technology and data outputs.

The research study scope was extended to include a small prototype to prove that the same 3D virtual environment capability can be enabled using 3D laser point cloud scanning technology on top of which design base content can be enabled for a Brownfields plant that does not have access to a modern CADD 3D Model. The prototype outcome confirmed that similar results were achievable and feasible.

4. BENEFITS OF A WELL MANAGED DESIGN BASE

4.1 Better identification of "Plant Hot Spots" and addressing performance issues

The research prototyping showed how effective management, ordering of design base data and analysing plant historical information allowed the Brownfields Plant in the research study to focus on problem plant areas.

The Brownfields Plant could identify the top 10 problem plant areas using improved plant design base data and information classification and management approaches, and it also assisted the research study in the identification of candidate plant areas to use for advanced analytics prototyping.

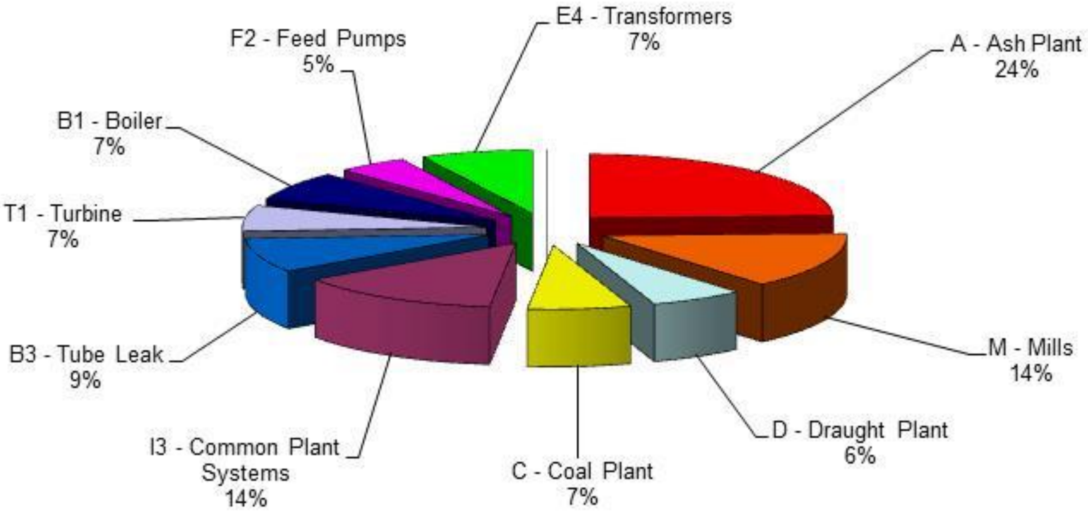


Figure 10: Top 10 Problem Plant Areas (Brownfields Research Plant) [19]

4.2 Improving Plant Abnormal Condition Analytics

The Design Base information contained in the Integrated Plant Information System platform, will enable the organisation to effectively build, test and refine analytical fault models.

An Emerson study [5] confirms that some of the biggest challenges in process plant are overwhelmed operators and complex plant operations that demand a new approach to managing plant more efficiently and predictively. The study confirms that abnormal situation ***prevention*** is one of the biggest potential productivity gains in the Process Plant operating space.

The research postulated that the IPI Design Base content can be used to efficiently and correctly define, build and prototype advanced analytical models that will make it possible to:

- Measure efficiency of current operating practices against operating design base and make recommendations on remedial action where there is room for improvement.
- Demonstrate that improved early warning failure detection is possible using big data and advanced analytics capabilities to analyse plant operating and control data.
- Measure efficiency of operations during abnormal and/or test conditions of process plant.
- Improve operator training outcomes – if training can be integrated with design base simulation capability and predictive capability it will create a highly efficient operator workforce that has the tools and means to timeously act on plant deviations to prevent trips and load losses.

The research outcome confirmed the theory postulated that a combination of analytical methods will most likely be required to provide a holistic plant improvement framework. The analytical methods employed in the overall research study was found to cover all 3 types of analytical techniques - descriptive, predictive and prescriptive[12].

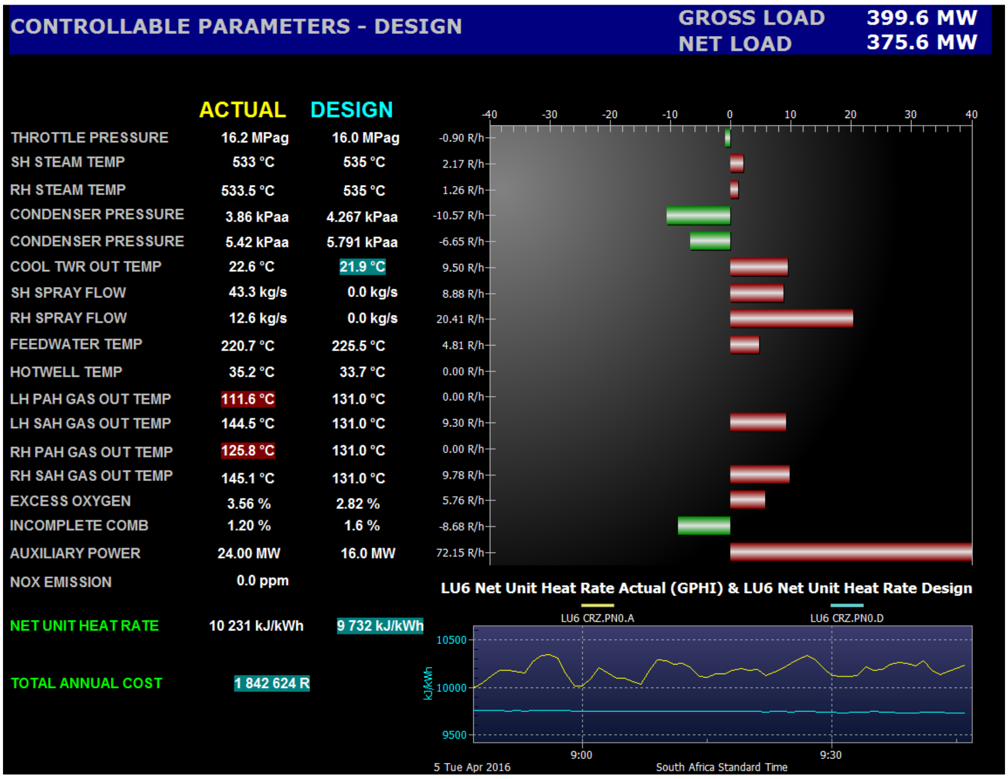
From the research study literature survey, it was suggested that Angeli[1] most aptly describes the basic research methodology and elements that made up the advanced analytics models of this research study.

The researcher could find practical application of this method already employed on the Brownfields Plant that formed part of the research study, so it made sense to leverage the method further when it came to defining more advanced analytical models on the plant.

Several derivations of the plant ideal state with regards to the Rankine cycle were developed and evaluated in the research. This allows an analysis of the impact when plant operations and maintenance do not align with the requirements of the design base.

Identification of controllable parameters in the Plant Operating Design Base further allowed online continuous trending of plant operations to evaluate how well it is operated within this baseline, and identify areas of continuous improvement where further technical training can enhance the Operator's ability to better control and manage plant within the required design base parameters.

Fig. 12 shows an example of how the performance comparison was done and trended in the Brownfield Plant's boiler system area.



CONTROLLABLE PARAMETERS - DESIGN

GROSS LOAD 399.6 MW
NET LOAD 375.6 MW

	ACTUAL	DESIGN	
THROTTLE PRESSURE	16.2 MPag	16.0 MPag	-0.90 R/h
SH STEAM TEMP	533 °C	535 °C	2.17 R/h
RH STEAM TEMP	533.5 °C	535 °C	1.26 R/h
CONDENSER PRESSURE	3.86 kPaa	4.267 kPaa	-10.57 R/h
CONDENSER PRESSURE	5.42 kPaa	5.791 kPaa	-6.65 R/h
COOL TWR OUT TEMP	22.6 °C	21.9 °C	9.50 R/h
SH SPRAY FLOW	43.3 kg/s	0.0 kg/s	8.88 R/h
RH SPRAY FLOW	12.6 kg/s	0.0 kg/s	20.41 R/h
FEEDWATER TEMP	220.7 °C	225.5 °C	4.81 R/h
HOTWELL TEMP	35.2 °C	33.7 °C	0.00 R/h
LH PAH GAS OUT TEMP	111.6 °C	131.0 °C	0.00 R/h
LH SAH GAS OUT TEMP	144.5 °C	131.0 °C	9.30 R/h
RH PAH GAS OUT TEMP	125.8 °C	131.0 °C	0.00 R/h
RH SAH GAS OUT TEMP	145.1 °C	131.0 °C	9.78 R/h
EXCESS OXYGEN	3.56 %	2.82 %	5.76 R/h
INCOMPLETE COMB	1.20 %	1.6 %	-8.68 R/h
AUXILIARY POWER	24.00 MW	16.0 MW	72.15 R/h
NOX EMISSION	0.0 ppm		
NET UNIT HEAT RATE	10 231 kJ/kWh	9 732 kJ/kWh	
TOTAL ANNUAL COST	1 842 624 R		

Figure 12: Plant Controllable Parameter Monitoring

The research also successfully demonstrated the impact of design base decisions during plant design, and the long term impact it can have on product output and plant efficiency.

As an example, the original Brownfields Plant design base was one where steam-driven feed pumps formed the basis for both normal as well as stand-by duty. The final implemented design configuration however, was one Steam-turbine driven feed pump with two electrically driven feed pumps as back-up in emergencies when the main pump is not available.

The research prototype evaluated the impact of using the two Electric Feed pumps (EFP) for feed water supply (normally reserved for standby/emergency purposes). This would be contrary to the ideal design base scenario of using the steam-turbine feed pump (SFP) for normal operations.

The impact of this decision on available output generation and GTCHR is significant – higher fuel consumption and heat transfer rate requirements for less MW's output to the electricity grid (Table 5) – which can be a significant impact considering a plant design life of at least 40 years.

Table 5: SFP vs EFP feedwater Supply Impact on Generation and Heat Rate

PROCESS SCENARIO	GROSS GENERATION (MW)	HEAT RATE - GTCHR (Btu/kWh)
BFPT providing feedwater to Boiler	619.384	7,683
EFP's providing feedwater to Boiler	604.309	7,876

5. CONCLUSION

The research has provided a practical and workable methodology and framework within the overall IPI-BIM to identify, source, validate and implement the core design base information data-set required for plant asset management and advanced analytics to improve business efficiency. It confirmed the importance to have engineering business processes to support the management of the design base content over the plant asset lifecycle. The research study further showed that the choice of system implementation methodology can have a significant impact on cost and timelines involved to implement the IPI system and associated design base contents of the IPI-BIM.

The research demonstrated the benefit of design base data and information structuring into a well-controlled classification system. This greatly assisted in evaluation and identification of core design base candidates. Using the research to introduce an effective and very accurate automation document type classification tool sped up the process of this classification exercise significantly. This was shown to significantly improve the productivity of staff involved with any Design Base back-fit or V&V exercise.

The research managed to successfully define a core set of design base information required for advanced plant condition analytics and associated improved business intelligence. The research hypothesis was proven that C&I Control System Upgrade design base requirements make up the core Operating Design Base content. It was shown to be a feasible scope for design base V&V, regardless of whether it is a Greenfields Project or Brownfields Process Plant.

Where identified core design base content could not be sourced, sufficient alternative information was available to reverse engineer and/or re-build the missing information.

The advanced analytics and plant process modelling/simulation portion of the research study further confirmed that the identified core design base set was sufficient for the research scope of work. The data set could be successfully used to identify opportunities for business improvement using the integrated plant information.

By undertaking the design base definition and additional reverse engineering exercise in the research, and enabling it in Portal technology and 3D visual/interactive format, opened up significant value propositions for the business:

- Improved visibility of plant performance and design base data.
- Increased understanding of plant behavior in upset conditions, and the impact of this on plant output and reliability.
- Online and continuous monitoring of performance against design base values.
- Timeous management of performance deviations in cases where the plant deviates from the target or expected operating envelopes.
- Increased usage (and thus better Return-on-Investment) for the advanced analytics software investment made in the Utility.

By bringing together critical business, plant process and design base information into a single integrated plant information platform, a powerful business improvement capability is enabled using integrated plant information. It empowers business users to make plant and process decisions in the fastest and most efficient manner.

REFERENCES

[1] **Angeli, C.** 2004. On-Line Fault Detection Techniques for Technical Systems: A Survey. Department of Mathematics and Computer Science. Technomathematics Research Foundation. Greece

[2] **Biehn, N.** May 2013. The Missing V's in Big Data: Viability and Value. PROS. www.wired.com/insights.

[3] **Botterill.** 19 January 2007. SmartPlant Technical Specification Guide: Capitalising on a "Smart Handover" Strategy – for the Engineering Enterprise. PPM-05-063. Intergraph Corporation,

[4] **Department of Minerals and Energy.** 2010. Integrated Resource Plan for Electricity 2010-2030, Revision 2, Final Report. South Africa.

[5] **Emerson. September 2003.** White Paper: Reducing Operations & Maintenance Costs. .

[6] **Fallon, K.K. and Palmer, M.E.** January 2006. EPISTLE Facilities Information Handover Guide, Part I. NISTIR7529. National Institute of Standards and Technology, US Department of Commerce.

[7] **Gentile, B.** 29 September 2014. The Top 5 Business Benefits of using Data Visualisation. TIBCO Analytics Product Group, TIBCO Software Inc.

[8] ***Hales, K.*** *2013. Eskom Smart Strategy.* Eskom Holdings (Pty) Ltd.

[9] **International Electricity Commission.** 2008. IEC 61355: Classification and Designation of Documents for Plants, Systems and Equipment. www.iec.com. Geneva, Switzerland.

[10] **ISO/PC251, ISO Standards Organisation**. 15 January 2014. ISO 55001: Asset Management Systems: Requirements. 1st Edition. Switzerland.

[11] **Lewis, S and Thomson, A.** 10 September 1998. EPISTLE Process Industries Data Handover Guide, Part II. Issue 2.2

[12] **Lustig, I, Dietrich, N. Johnson, C. and Dziekan, C.** 2004. The Analytics Journey. Institute for Operations Research and the Management Sciences.

[13] **Port, Dr. S.** 2002/2007. Plant Information Management in Offshore Projects: an e-Engineering/e-Business Implementation. Statoil and Intergraph Process, Power & Marine, Intergraph publication DDPP244EA0, Intergraph Corporation.

[14] **Smit, M.J.** June 2009. Completion of Power Plant Projects, Commissioning, Take-over from Contractors and Hand-over to the Generation Business. Eskom Holdings (Pty) Ltd.

[15] **Swanepoel, H.F**. October 2014. Lethabo Plant Information System Concept: Supporting the Eskom Smart Utility Drive. Eskom Holdings (Pty) Ltd.

[16] **Swanepoel, H.F**. October 2012. SmartPlant GEDI Implementation: Training Guideline. Eskom Holdings.

[17] **Smit, M.J.** November 2008. Generation Project Management. Eskom Holdings.

[18] **Sun, B.K.H., Kossilov, A. and Negoyan, V**. July 1997. Advanced Control Systems to Improve Nuclear Power Plant Reliability and Efficiency. International Atomic Energy Association. Vienna, Austria.

[19] **Wegener, R. & Sinha, V.** 2013The Value of Big Data: How Analytics Differentiates Winners. Bain & Company. Atlanta.