

Plant information management towards business improvement

HF Swanepoel
27360989

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Promoter: Prof JH Wichers

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It all starts here TM



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®

This Thesis is dedicated to the team of colleagues and peers who assisted me over many years of operational research to develop the business improvement model I share with this research study. Their belief in my vision of a working integrated plant information business improvement model and their assistance and willingness to test my model concepts and implementation methodologies were invaluable in achieving the final outcome.

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Living a life that matters is not something that happens by accident, nor is it a matter of circumstance. It is a choice.

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TABLE OF CONTENTS

PREFACE	I
ABSTRACT	XII
OPSOMMING	XIV
ACKNOWLEDGEMENTS	XVI
LIST OF SYMBOLS AND ABBREVIATIONS	XVII
DEFINITION OF TERMS	XX
LIST OF TABLES	XXVIII
LIST OF FIGURES	XXX
CHAPTER 1	1
INTRODUCTION	1
1.1 Problem Statement	5
1.1.1 Current Business Improvement Models (BIM's)	5
1.1.2 Integration of Advanced Analytics into Business Improvement Models.....	6
1.1.3 Access to Information	8
1.1.4 Complexity of a Process Plant Environment	8
1.1.5 Impact of Inadequate Design Base Management and Change Control.....	11
1.2 Research Hypothesis	13
1.3 Research Aims, Objectives, Approach and Deliverables	14
1.3.1 Research Aims.....	14
1.3.2 Research Approach.....	16
1.3.3 Research Objectives	17
1.3.4 Research Deliverables.....	19
1.4 Delimitations of the Study	19
1.5 Assumptions	20
1.6 Importance of the Study	20
1.6.1 Importance to Industrial/Process Plants	21
1.6.2 Academic Importance.....	21
1.7 Explanation for using the V–Systems approach for the Research Study	21
1.8 Structure of the Thesis	23
1.9 Summary	25

CHAPTER 2.....	27
LITERATURE SURVEY.....	27
2.1 Business Environment Changes challenging existing Business Models	27
2.1.1 Global Business Sustainability	27
2.1.2 African and South African Business Pressures.....	28
2.1.3 Advent of the Smart Grid and Smart Utility	30
2.1.4 Ageing Plant and Performance Deterioration.....	32
2.2 Business Improvement Models (BIM's)	36
2.2.1 The Most Common BIM Frameworks.....	36
2.2.2 The Baldrige Model	38
2.2.3 The European Foundation for Quality Management (EFQM) Excellence Model™	39
2.2.4 Information Management Models.....	40
2.2.5 Challenges with the Common BIM Frameworks	41
2.3 Integrated Plant Information Management Systems	44
2.3.1 The Need for Integrated Plant Information Management.....	44
2.3.2 The Challenges of Integrated Plant Information Management.....	44
2.3.3 Plant Information Relationship Complexity	46
2.3.4 Plant Information Volumes and Structure	47
2.3.5 The Integrated Nature of Engineering Business Processes	49
2.3.6 The Value and Benefits of Integrated Plant Information Management	50
2.3.7 Integrated Plant Information Management System Approaches.....	51
2.3.7.1 Business Strategy	51
2.3.7.2 Development Methods.....	52
2.3.7.3 System Configuration Approach.....	55
2.3.7.4 System Design Approach	56
2.3.7.5 Asset Lifecycle Impact.....	58
2.4 Design Base Definition.....	63
2.4.1 The Importance of the Plant Design Base	63
2.4.2 Consequences of inadequate Design Base Management.....	64
2.4.3 The Need for Managing the Design Base in an Integrated Solution.....	65
2.4.4 Design Base Definition and Maturity Levels.....	65

2.4.5	Design Base Classification Systems	67
2.4.6	The Ideal versus a <i>Practical</i> /Achievable Plant Design Base.....	68
2.5	Information Delivery Technology.....	69
2.5.1	Value of Integrated Information Delivery.....	69
2.5.2	3D Visualisation Technology for Information Delivery	70
2.5.3	3D Laser Scanning for 3D Visualisation Platforms.....	72
2.5.4	3D Visualisation Technology Information Delivery Complexity	72
2.5.5	Portal Technology Advances and Benefits	74
2.5.6	The Nerve Centre Concept.....	74
2.6	Advanced Analytics	75
2.6.1	The Drivers for Advanced Analytics	76
2.6.2	ERP versus SCADA System Analytics	78
2.6.3	Potential Analytical Methods and Usage	79
2.6.4	Using Analytics for Plant Asset Condition decision-making	81
2.6.5	Advanced Analytics and AI Maturity	82
2.6.6	Availability of Plant Historical Information and FMECA Data	88
2.6.7	The Key Role of Failure Statistics in Advanced Analytics.....	89
2.6.8	Data Quality Requirements for Advanced Analytics.....	91
2.6.9	Data Availability Requirements for Advanced Analytics	91
2.7	Defining the Value Proposition for the Business Improvement Framework.....	92
2.7.1	Business Drivers that Unlock the Value Proposition.....	92
2.7.2	The Training Value Proposition.....	93
2.7.3	Construction Management Value Proposition.....	93
2.7.4	Maintenance Management Proposition	93
2.7.5	Engineering Productivity Value Proposition	94
2.7.6	Information Integration Value Proposition.....	94
CHAPTER 3.....	THE INTEGRATED PLANT INFORMATION SYSTEM PLATFORM	96
3.1	Introduction	96
3.2	Research Hypothesis Relevant to the IPI System Platform	97
3.3	Scope of the Research Undertaken to evaluate IPI System Implementations.....	97

3.4	Evaluation of Integrated Plant Information System Implementation Approaches	99
3.5	Developing an IPI System RAD Implementation Approach for the IPI–BIM Framework.....	101
3.6	Confirming the Engineering Processes Required for Design Base Management.....	106
3.7	Validating and proving the new IPI–BIM System RAD Implementation Methodology.....	107
3.8	Research Findings Summary.....	108
3.9	Optimisation/Rationalisation Opportunities regarding IPI System Platform.....	109
3.10	Conclusion	110
CHAPTER 4.....		113
	DESIGN BASE REQUIREMENTS FOR THE IPI–BIM FRAMEWORK.....	113
4.1	Hypothesis Relevant to the Design Base	114
4.1.1	Core Design Base Definition.....	114
4.1.2	Reverse Engineering Missing Design Base Content.....	114
4.1.3	Brownfields versus Greenfields Design Base Establishment Methodologies ..	115
4.2	Research Scope for Core Design Base Validation	115
4.3	Phase 1 Related: Defining the Core Design Base Content.....	116
4.3.1	The Ideal Design Base Scope.....	116
4.3.2	Defining an Achievable Core Design Base Scope	119
4.4	Phase 1 Related: Improving the Efficient Structuring of Core Design Base Content.....	121
4.4.1	Development of the Data Mining Automation Tool	121
4.4.2	Testing and Validating the Data Mining Automation Tool	123
4.4.3	Data Mining Automation Tool Success Rate.....	126
4.5	Phase 1 Related: Comparing Greenfields versus Brownfields Plant Methodology.....	127
4.6	Phase 2 Related: Design Base Content Sourcing and Completeness Evaluation.....	128
4.6.1	Greenfields Project Design Base Sourcing.....	128
4.6.2	Brownfields Power Station Design Base Sourcing.....	129
4.6.3	Sourcing Core Design Base Content.....	130

4.7	Phase 3 Related: Design Base Reverse Engineering.....	133
4.7.1	Reverse Engineering Design Base Candidate(s).....	133
4.7.2	Reverse Engineering Methodology and Research Scope	133
4.7.3	Design Base Data Quality Challenges and Enhancements Required	135
4.7.4	Operating Envelope and Alarm Criteria Limitation Challenges	136
4.7.5	Research-based Enhancements to the Engineering Simulator	137
4.7.6	Reverse Engineering Results: Design Base Candidates.....	138
4.7.7	Reverse Engineering Outcome Validation and Verification	141
4.8	Research Findings Summary.....	142
4.8.1	Design Base Classification System.....	142
4.8.2	Core Design Base Definition.....	143
4.8.3	Design Base Data Sourcing – Greenfields vs Brownfields Comparison.....	143
4.8.4	Core Design Base Reverse Engineering	144
4.9	Optimisation/Rationalisation Opportunities regarding the Plant Design Base	145
4.10	Conclusion	145
4.10.1	Design Base Classification System.....	145
4.10.2	Core Design Base Content.....	147
4.10.3	Design Base Reverse Engineering.....	148
CHAPTER 5.....		149
INFORMATION DELIVERY AND VISUALISATION OPTIONS.....		149
5.1	Hypothesis Relevant to Information Delivery and Visualisation.....	149
5.2	Research Approach regarding Information Delivery and Visualisation ...	150
5.3	Information Delivery Research Scope	150
5.3.1	User–Driven Information Delivery.....	150
5.3.2	Information Delivery Options.....	151
5.4	Scope of Information Visualisation Prototyping	151
5.4.1	Integrated Information Delivery Option Research Scope Constraints	151
5.4.2	Integrated Information Delivery Options	152
5.4.3	3D Information Delivery Capability Evaluation	152
5.4.4	Evaluation of Advanced Analytics Capability in Portal Technology.....	153
5.4.5	Plant Data Availability for Online Monitoring	154

5.4.6	Complex Information Simplification and Increased Plant Information Visibility.....	154
5.5	Information Technology and Infrastructure Constraints.....	154
5.6	Research Prototyping Methodology.....	155
5.6.1	SmartPortal Capability.....	155
5.6.2	3D Visualisation Capability Evaluation	156
5.7	Information Delivery and Visualisation Prototyping Results	157
5.7.1	Portal Capability Evaluation	157
5.7.2	On-line Plant Condition Data Visibility in the Portal Technology	161
5.7.3	3D Information Delivery Capability Evaluation	163
5.7.4	Advanced Analytics in the Portal Technology	165
5.7.5	Simplification of Complex Engineering Information	166
5.8	Information Delivery and Visualisation Prototype Research Findings	169
5.8.1	Portal Capability	169
5.8.2	Plant Analytics and Monitoring in the Portal.....	170
5.8.3	3D Visualisation Technology for the Portal.....	170
5.8.4	Portal Value Proposition	171
5.8.5	Portal versus Nerve Centre Comparison	172
5.9	Conclusion	173
CHAPTER 6		175
ADVANCED ANALYTICS IN THE IPI-BIM FRAMEWORK.....		175
6.1	Postulated Theories regarding Advanced Analytics.....	176
6.2	Advanced Analytics Building Blocks for Asset Management Optimisation	177
6.3	Research Methodology.....	178
6.3.1	Type and Scope of Advanced Analytics Required	178
6.3.2	Advanced Analytics Prototyping Use Cases	179
6.3.3	Identifying the Best Research Methodology.....	184
6.3.4	Advanced Analytics System Technology and Validation Methods used.....	185
6.4	Scope of Advanced Analytics Research and Prototyping	186
6.4.1	Use Case 1: Plant Rankine Cycle Scenarios – Design Base versus Actual...	186
6.4.2	Use Case 2: Evaluate Impact of Design Base Integrity and Changes on Plant Reliability.....	187

6.4.3	Use Case 3: Evaluate Operational Efficiency of Statutory Plant Tests.....	187
6.4.4	Evaluate Integration of Advanced Analytics capability into Operating Simulators.....	188
6.5	Advanced Analytics Prototyping Preparatory Work	188
6.5.1	Creating the Comparative Analytics Baseline	189
6.5.2	Identifying the Controllable Parameters.....	190
6.5.3	Enabling Advanced Analytics in new Process Plant Technologies on the Operating Simulator Platform.....	192
6.6	Prototyping Results	194
6.6.1	Use Case 1 Related: Plant Design Base – Operational Adherence	194
6.6.2	Use Case 1 Related: Operating within Design Base Operating Start-up Curves.....	195
6.6.3	Use Case 2 Related: Impact of Optimal Design Base Deviations/Integrity Challenges.....	197
6.6.4	Emerging Patterns indicating Failure Triggers	199
6.6.5	Use Case 3 Related: Operational Compliance to Design Base Test Conditions.....	201
6.6	Research Findings Summary.....	202
6.6.1	Advanced Analytical Methods Used	202
6.6.2	Core Design Base Suitability for Advanced Analytics.....	202
6.6.3	Benefits of Advanced Analytics for Plant Operations	203
6.6.4	Effects of Ageing Plant and Deteriorating Plant Conditions on Analytics of Plant Performance.....	204
6.6.5	Advanced Analytics as a Core Element to SmartUtility Strategy Execution.....	204
6.7	Conclusion	205
CHAPTER 7		207
	THE IPI–BIM FRAMEWORK VALUE PROPOSITION.....	207
7.1	Value Proposition Hypothesis	207
7.2	Value Proposition Model Development	208
7.2.1	Basis of the Value Proposition Model.....	208
7.2.2	Core Principles in Defining the Value Proposition Model.....	208
7.2.3	Standardisation Elements within the Value Proposition Model	209
7.3	Production Cost Input Impact on the Value Proposition Model.....	209

7.4	Value Proposition Model – Business Drivers	210
7.4.1	Regulatory Compliance and Risk Management	210
7.4.2	Safety and Health of Staff, Contractors and the Public.....	210
7.4.3	Safety and Health of Staff, Contractors Operational Efficiency and Cost Management.....	210
7.4.4	Environmental Management and Compliance	210
7.4.5	Inventory and Supply Chain Management.....	211
7.4.6	Technical Performance (Plant Reliability and Availability)	211
7.4.7	ICT and Infrastructure Cost Savings	211
7.4.8	Engineering Capability and Productivity	211
7.4.9	Maintenance Efficiency and Cost Containment.....	211
7.4.10	Construction and Commissioning Efficiency	212
7.4.11	Knowledge and Human Capital Management.....	212
7.4.12	Non–Monetary Value Proposition.....	212
7.5	Cost Model Inputs	212
7.5.1	Power Utility Production–Related Costs.....	212
7.5.2	Other Cost Elements	214
7.5.3	Probability Factor	214
7.5.4	Industry Cost Saving Benefits – Relevance Considerations.....	215
7.5.5	Use Cases to Support Value Proposition Calculations.....	215
7.6	Value Proposition Model Development Outcome.....	215
7.7	Applying the Value Proposition Model to prove IPI–BIM Framework Value	216
7.7.1	Plant Load Loss Prevention Value Contribution.....	216
7.7.2	Typical Value Proposition Elements – Engineering Productivity and Risk Management.....	217
7.7.3	Typical Value Proposition Elements – Operator Training Improvement	218
7.7.4	Typical Value Proposition Elements – Maintenance Practices	219
7.7.5	Typical Value Proposition Elements – Reliability/Availability Improvements....	220
7.7.6	Typical Value Proposition Elements – Construction/Project Execution Efficiency	220
7.7.7	Typical Value Proposition Elements – IT Infrastructure.....	221
7.8	Value Proposition Model – Research Findings Summary.....	222

7.9	Conclusion	222
CHAPTER 8.....		224
OPERATIONALISING THE IPI–BIM FRAMEWORK.....		224
8.1	Hypothesis Relevant to IPI–BIM Framework Operationalisation	224
8.2	Business Need Considerations during Operationalisation.....	225
8.2	Scope and Status of IPI–BIM Framework Validation on Research Study Projects	226
8.3	Operationalisation Results on Research Study Projects	228
8.3.1	Brownfields Power Station IPI–BIM Framework Implementation	228
8.3.2	Greenfields Project IPI–BIM Framework Implementation	229
8.4	Actual IPI–BIM Framework Benefits Realisation	230
8.5	IPI–BIM Framework External Validity and Relevance.....	231
8.5	Recognition of IPI–BIM Framework Research Work	233
8.6	Conclusion	234
CHAPTER 9.....		235
HYPOTHESIS CONFIRMATION AND INTERPRETATION		235
9.1	Interpretation and Evaluation – Hypothesis 1	235
9.2	Interpretation and Evaluation – Hypothesis 2	237
9.3	Interpretation and Evaluation – Hypothesis 3	238
9.4	Interpretation and Evaluation – Hypothesis 4	240
9.5	Interpretation and Evaluation – Hypothesis 5	241
9.6	Interpretation and Evaluation – Hypothesis 6	242
9.7	Interpretation and Evaluation – Hypothesis 7	245
9.8	Interpretation and Evaluation – Hypothesis 8	246
9.9	Interpretation and Evaluation – Hypothesis 9	248
9.10	Interpretation and Evaluation – Hypothesis 10	249
CHAPTER 10.....		251
CONCLUSION		251
10.1	Further Research Areas	254
10.1.1	Advanced Analytics.....	254
10.1.2	Reliability Engineering Framework.....	254
10.1.3	Extension of Information Delivery Capability.....	255
10.1.4	3D Laser–scanning Technology Advancements	256

10.1.5	Value Proposition Model Use Cases	256
10.2	Failed Theories.....	257
10.2.1	A single Integrated Plant Information System for both EPC and O&M Lifecycle.....	257
10.2.2	A Phased System approach can allow for an “as/when required” Phased Engineering Business Process Implementation	257
10.2.3	Interoperability of the SharePoint Portal with External data sources.....	258
10.2.4	Conversion of 3D Point Cloud content to solid 3D CADD models would be viable for Information Delivery.....	258
10.2.5	Static Process Analysis as a holistic solution.....	259
10.3	Final Thoughts on Business Improvement as a Driver for Social Change.....	260
	BIBLIOGRAPHY	262
	ANNEXURES	274
	ANNEXURE A – The ideal Plant Engineering Baseline.....	274
	ANNEXURE B – Verification and Validation of Rankine Cycle reverse engineering	276

The World Energy Council [World Energy Council, 2007/2013] defines numerous challenges in the global energy arena pressuring Owner/Operators to operate existing plant better and more efficiently. Internal Power Utility research by Jones confirms that the current business model is no longer sustainable [Jones, 2015]. Operating challenges, rising operating costs and deteriorating plant availability are creating a perfect storm that demands radical changes in the way the Utility is managing its business operations and how it addresses the challenges.

The current electricity-constrained South African environment and challenges are not unique, as is shown by the PWC Survey on Energy Sector business models, which covered 53 utilities in 35 countries. The study confirms similar business environment triggers that will initiate business model changes [Schwieters et al., 2015].

As such there is increasing focus on the use of business- and technical plant information and data to make better, more integrated and informed decisions on the plant. Biehn states in his research that data scientists believe as little as 5% of the “big data” gathered results in 95% of the value contribution of the data [Biehn, 2013]. 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.**

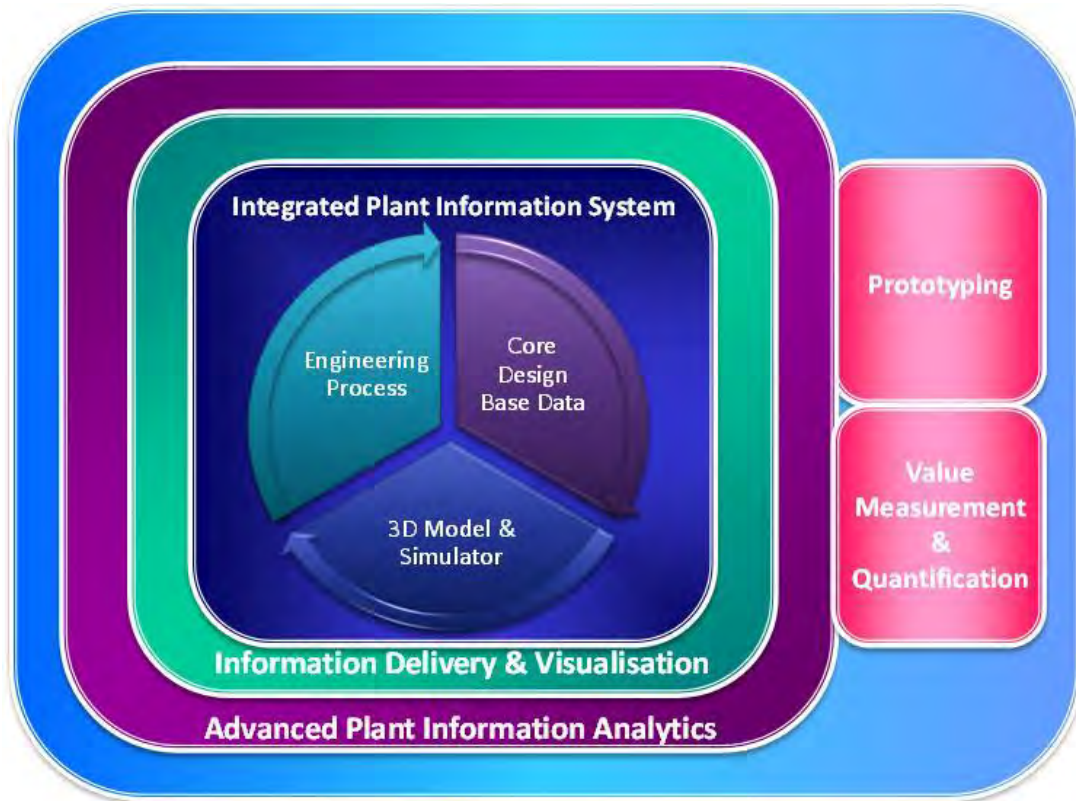
Many companies gather vast amounts of data, but rarely take the effort to analyse the data or even asking the basic question of *WHY* they are gathering the data. Although data storage costs have significantly reduced, the impact of analysing critical business and plant data when it is buried in 95% of “low-value data” have a significant impact on productivity, situational analysis capability, incident response and decision times.

Most popular business improvement models centre their framework and approaches on **business process** improvement – thus on people, process and technology aspects of the business. They tend to drive business process 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 and return-on-investment.

The research study developed and refined an integrated plant information (IPI) framework and Business Improvement Model (IPI-BIM) (Figure 0–1) and used operational research between 2007 and 2016 to validate and prove how this BIM Framework and implementation approach can be used to improve business operations and provide decision-making insight.

The IPI-BIM Framework differs from well-known business improvement framework models (e.g. the Baldrige Business Model Review Framework [NIST, 2015] and the European Foundation for Quality Management (EFQM) Excellence Model Review Framework™ [Von Rompuy, 2012]) in that it does not focus on process, core values and/or concepts, but rather integrated plant information and data analytics as the foundation for business improvement in a Process Plant/Utility.

Figure 0–1: The Integrated Plant Information Business Improvement Model (IPI-BIM)



Validation of the IPI-BIM Framework was done as a comparative study – evaluating and documenting the benefits of implementing it on the two power stations that formed part of the research study, and comparing the outcome against other power stations of similar size and complexity in the Power Utility where the IPI-BIM and implementation approaches were not used. The outcome confirmed that the proposed IPI-BIM is an operationally ready business improvement model. ***It is, however, a complex undertaking and the effort required to fully establish this framework should not be under-estimated.***

Although operational research focus was Power Utility focused, the IPI-BIM and implementation approaches are generic enough in nature to be applicable to other process plant environments.

Key Terms: Business Improvement Models; Integrated Plant Information Management; Business Intelligence; Design Base; Advanced Analytics; Value Proposition

Die Wêreld Energie Raad [World Energy Council, 2007/2013] definieer talle uitdagings in die globale energie arena wat druk uitoefen op Eienaar / Operateurs om bestaande aanlegte beter en meer doeltreffend bestuur. Interne Kragvoorsiener navorsing bevestig dat die huidige sake-model nie meer volhoubaar is nie [Jones, 2015]. Bedryfs uitdagings, stygende bedryfskoste en 'n afname in aanleg-beskikbaarheid skep 'n perfekte storm wat radikale veranderinge verg in die manier waarop die Kragvoorsiener sy sake bedryf. Die huidige elektrisiteit tekorte in Suid-Afrika en die meegaande uitdagings is nie uniek nie, soos blyk uit die PWC-opname oor Energie Sektor sake-modelle wat 53 kragvoorsieners in 35 lande ondervra het – hulle bevindinge bevestig soortgelyke besigheids-drywe wat sakemodel veranderinge sal inisieer. [Schwieters et al., 2015]

Daar is dus toenemende fokus op die gebruik van sake- en tegniese aanleg inligting en data om beter, meer geïntegreerde en ingeligte besluite te neem oor die aanleg en besigheid. Biehn maak die stelling dat data wetenskaplikes van opinie is dat so min as 5% van "groot data" bydra tot 95% van die waarde wat verkry word uit die data. [Biehn, 2013] **En hierin lê een van die grootste uitdagings met data in besigheid vandag – hoe om die 5% kritieke data effektief te identifiseer, te modelleer en te ontleed om sakebedrywighede te verbeter.**

Baie maatskappye versamel groot hoeveelhede data, maar ontleed selde al die data of vra selfs die basiese vraag van *HOEKOM* hulle die data insamel. Hoewel data stoor-koste aansienlik verminder het, verminder dit nie die die impak van 'n soektog na, en moeitevolle ontleding van kritieke sake- en aanleg data wanneer dit versteek is in 95% "lae waarde data" nie – dit het 'n beduidende negatiewe impak op produktiwiteit, situasie-analise vermoë, insident-reaksie tyd en besluitnemings effektiwiteit.

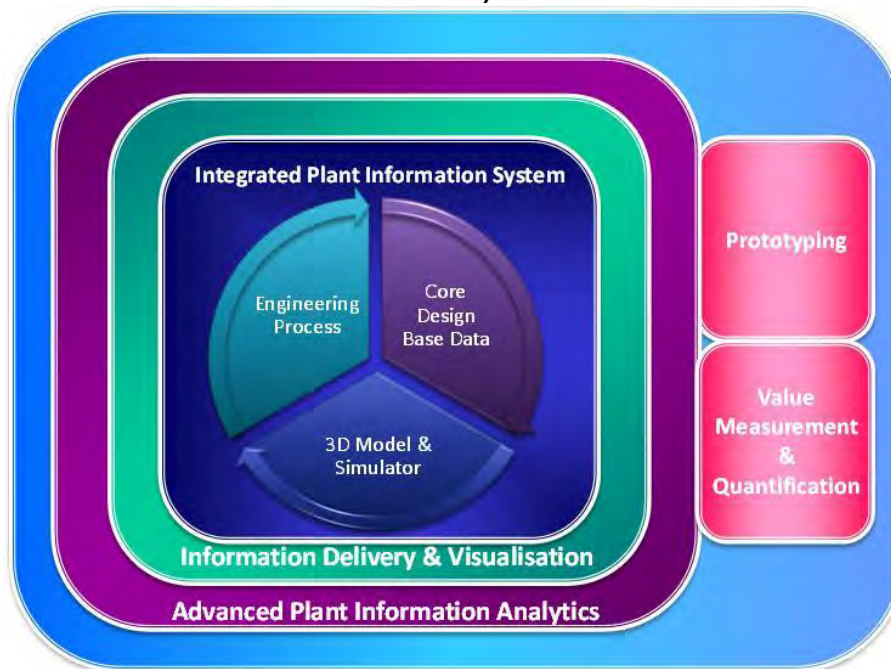
Die mees gewilde besigheid verbetering modelle sentreer hul raamwerk en benaderings rondom **besigheid proses** verbetering – dus op mense, proses en tegnologie aspekte van die besigheid. Hulle is geneig om op besigheid proses elemente te fokus en evalueer selde die impak wat 'n tekort aan hoë gehalte kritieke aanlegontwerp en beheer data het op besigheid effektiwiteit en verbetering. As gevolg hiervan, sukkel hierdie besigheid verbetering-modelle gewoonlik om hul waarde te kwantifiseer omdat hulle die aanleg en besigheid data kort wat nodig is om die verbeterings waarde te kan demonstreer/bereken.

Die navorsingstudie het 'n geïntegreerde aanleg inligting (IPI) raamwerk en Besigheids Verbetering Model (IPI-BIM) (Figuur 0–2) ontwikkel en verfyn. Operasionele navorsing en prototipes vir die periode 2007 tot 2016 is gebruik as 'n validasie meganisme om die Model en

implementering metodiek te bewys en te demonstreer hoe hierdie Raamwerk en benadering kan gebruik word om sakebedrywigheide te verbeter en besluitneming insig te verhoog.

Hierdie model verskil van die mees bekende besigheid verbetering raamwerk modelle (bv. die Baldrige Besigheids Model verbeterings raamwerk [NIST, 2015] en die Europese Stigting vir Kwaliteitsbestuur (EFQM) Uitnemendheids Model hersieningsraamwerk™ [Van Rompuy, 2012]) in die sin dat dit nie fokus op proses, kernwaardes en / of konsepte nie, maar eerder geïntegreerde aanleg inligting en data analise as die grondslag om besigheids aktiwiteite te verbeter in 'n proses aanleg.

Figuur 0–2: Die Geïntegreerde Aanleg Inligting Besigheids Verbeterings Model (IPI–BIM)



Validasie van die IPI–BIM raamwerk was gedoen as 'n vergelykende studie. Dit het die evaluering en dokumentering behels van die voordele wat implementering van die raamwerk gehad het op die twee kragstasies wat deel uitgemaak het van die navorsing studie, en die uitkoms te vergelyk met ander kragstasies van dieselfde grootte, konstruksie en kompleksiteit waar die raamwerk en implementering metodiek nie toegepas was nie. Die vergelykende studie het bevestig dat die voorgestelde IPI–BIM raamwerk operasioneel gereed is. ***Die implementering van die voorgestelde model is egter 'n komplekse onderneming en die insette en werk nodig om hierdie raamwerk te implementeer moet nie onderskat word nie.***

Hoewel operasionele navorsing gefokus was op die Kragvoorsiener omgewing, is die IPI–BIM Raamwerk en implementering benaderings generies genoeg om van toepassing te wees op die meeste proses aanleg omgewings.

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LIST OF SYMBOLS AND ABBREVIATIONS

Abbreviation	Meaning
2D	Two-Dimensional
3D	Three-Dimensional
A.I./AI	Artificial Intelligence
B&V	Black and Veatch
B2B	Back-To-Basics (in the context of this research study). B2B is also used to abbreviate the term “Business to Business” information exchange.
BFPT	Boiler Feed Pump Turbine
BI	Business Intelligence
BIM	Business Improvement Model (in the context of this research study). BIM is also used to abbreviate the term “Building Information Modelling”
BLR	Boiler
BPP	Business Productivity Program
BPP MS/MW	Business Productivity Program – Maintenance Strategy/Maintenance Work Project
BTLM	Boiler Tube Leak Management
C&I	Control and Instrumentation
CAD	Computer Aided Design
CADD	Computer Aided Design and Draughting
CAPCO	Chief Air Pollution Control Officer
CARAT	Complete, Accurate, Reliable, Available, Timely (Data Criteria)
CMBG	Configuration Management Business Group
COBIT	Control Objectives for Information and Related Technology
CoE	Centre of Excellence
CRM	Customer Relationship Management
DBBF	Design Base Back-Fit
DCS	Distributed Control System
DI	Disabling Injury
DMBOK	Data Management Book of Knowledge
DTM	Digital Terrain Model
EAF	Energy Availability Factor
eHPUM	Eskom High Performance Utility Model
EBP	Engineering Business Process
ECM	Engineering Change Management
ECN	Engineering Change Notice
EDMS	Electronic Document Management System
EEMUA	Engineering Equipment Material Users Association
EFP	Electric-Driven Feed Pump
EFQM	European Foundation for Quality Management
EKF	Extended Kalman Filter
EPC	Engineer, Procure, Construct (Asset Lifecycle – Build Phase)
EPRI	Electrical Power Research Institute
ERP	Enterprise Resource Planning (Software Systems)

Abbreviation	Meaning
ES	Expert System
FAT	Factory Acceptance Testing
FCN	Field Change Notice
FEED	Front End Engineering Design
FGD	Flue Gas Desulphurisation
FL	Fuzzy Logic
FMEA	Failure Mode Effect Analysis
FMECA	Failure Mode Effect Criticality Analysis
GA	Genetic Algorithms
GEDI	Generation Engineering Design Infrastructure (Project)
GEXCO	Generation Division Executive Committee
GIS	Geospatial Information System
GTCHR	Gross Turbine Cycle Heat Rate
HAZOP	Hazardous Operations (Study)
HP	High Pressure
IAEA	International Atomic Energy Agency
IBI	Integrated Business Improvement (business improvement methodology)
ICT	Information and Communications Technology
IEC	International Electricity Commission
IM	Information Management
INPO	International Nuclear Producers Organisation
IP	Intermediate Pressure or Intellectual Property (refer to context)
IPI	Integrated Plant Information
IPI-BIM	Integrated Plant Information – Business Improvement Model
IPIS	Integrated Plant Information System
IPP	Independent Power Producer
IT	Information Technology
KPI	Key Performance Indicator
LP	Low Pressure
LTPH	Long Term Plant Health
LTPHI	Long Term Plant Health Indicator
MOC/MoC	Management of Change
MTS	Maintenance Technical Specification
MS/MW	Maintenance Strategy– Maintenance Work
MW	Mega–Watt
MYPD	Multi–Year Price Determination
NDT	Non–Destructive Testing
NERSA	National Energy Regulator of South Africa
O&M	Operate and Maintain (Asset Lifecycle – Operational Phase)
O/O	Owner/Operator
OCGT	Open Cycle Gas Turbine
OCR	Optical Character Recognition

Abbreviation	Meaning
OOTB	Out of the Box
OOP	Optimise Operating Parameters
OTS	Operating Technical Specification
P&ID	Piping and Instrumentation Diagram
PBS	Plant Breakdown Structure
PCM	Process Control Manual
PSM	Power Station Manager
PWC	Price Waterhouse Coopers™
QC	Quality Control
RACI	Responsibility, Accountability, Consulted, Informed
RAD	Rapid Application Development
RAM	Reliability, Availability, Maintainability
RCM	Reliability Centred Maintenance
RFID	Radio Frequency Identification
RMDC	Remote Monitoring Diagnostic Centre
ROA	Return-on-Asset
ROI	Return on Investment
ROR	Rate of Return
RTF	Run-To-Failure
S/BY	Standby
SCADA	System Control and Data Acquisition
SCM	Supply Chain Management
SDLC	System Design Lifecycle
SLD	Single Line Diagram
SPE	Intergraph SmartPlant Enterprise™ (software)
SPF	Intergraph SmartPlant Foundation™ (software)
SPO	Intergraph SmartPlant Owner/Operator™ (software)
TIM	Time-In-Market
TOGAF	The Open Group Architecture Framework
TPM	Total Productivity Management
TQM	Total Quality Management
TTM	Time-To-Market
UAT	User Acceptance Testing
URS	User Requirement Specification
U.S	United States
V&V	Validation and Verification
WEC	The World Energy Council
WTP	Water Treatment Plant
WW	WonderWare™

DEFINITION OF TERMS

Term	Definition	Source
Advanced Analytics	The use of plant information and data beyond the conventional realm of monitoring and control. Applying analytical models and advanced/complex data analysis and processing to analyse plant condition and make decisions based on these analytical outcomes. Advanced Analytics is a grouping of analytic techniques used to predict future outcomes. Advanced Analytics produce insights that traditional approaches to business intelligence (BI) –such as query and reporting– are unlikely to discover	www.searchbusinessanalytics.techtarget.com http://birtanalytics.actuate.com
Approach	1. A way of dealing with a situation or problem. “we need a whole new approach to the job”	Wikipedia
Artificial Intelligence (AI)	1. a branch of computer science dealing with the simulation of intelligent behaviour in computers 2. the capability of a machine to imitate intelligent human behaviour	http://www.merriam-webster.com/dictionary
AKZ	Plant codification system used to uniquely denote plant, systems and equipment/components in power generating plant. The predecessor of the VGB KKS system.	VGB and Lethabo Information Manual (LIM 103)
Back To Basics (B2B)	Definition: iii. Stressing simplicity and adherence to fundamental principles: <i>The movement suggests a back-to-basics approach to living for those whose lives have become complicated.</i> 2. Emphasizing or based upon the teaching of such basic subjects as reading, arithmetic, grammar, or history in a traditional way.” In the business context used in this research study, it means a return to the fundamental teachings and principles of business operations and focusing on the core elements of a business model to improve business efficiency.	<i>Random House Unabridged Dictionary</i>
Bell Curve	A symmetrical bell-shaped curve that represents the distribution of values, frequencies, or probabilities of a set of data. It slopes downward from a point in the middle corresponding to the mean value or the maximum probability. Data that reflect the aggregate outcome of large numbers of unrelated events tend to result in bell curve distributions. The “ Gaussian ” or “ normal distribution ” is a mathematically well-defined bell curve used in statistics and in science generally.	www.dictionary.com

Term	Definition	Source
Brownfields	An existing onshore or offshore facility, e.g. 'brownfield modification' is an upgrade to an existing facility. Brownfield land (Civil Engineering) means places where new buildings may need to be designed and erected considering the other structures and services already in place.	Wood Group – Definitions for Industry and Technical Terms and Wikipedia
Business Improvement	Business improvement is a systematic approach to help an organization optimize its underlying processes to achieve more efficient results. Process improvement is an aspect of organizational development (OD) in which a series of actions are taken by a process owner to identify, analyse and improve existing business processes within an organization to meet new goals and objectives, such as increasing profits and performance, reducing costs and accelerating schedules. These actions often follow a specific methodology or strategy to increase the likelihood of successful results. Process improvement is also a method to introduce process changes to improve the quality of a product or service, to better match customer and consumer needs.	Wikipedia and University of Cambridge.
Configuration	An arrangement of parts or elements in a particular form, figure, or combination. In the case of software, arrangement of a system configuration implies setting it up to meet unique and specific business needs. In software engineering , software configuration management (SCM or S/W CM) is the task of tracking and controlling changes in the software , part of the larger cross-disciplinary field of configuration management . SCM practices include revision control and the establishment of baselines.	Wikipedia
Customisation	Custom software (also known as bespoke software or tailor-made software) is software that is specially developed for some specific organization or user. As such, it can be contrasted with the use of software packages developed for the mass market, such as commercial off-the-shelf (COTS) software, or existing free software. Since custom software is developed for a single customer it can accommodate that customer's particular preferences and expectations.	Wikipedia
Design Basis (Base)	Set of conditions, needs, and requirements taken into account in designing a facility or product.	www.businessdictionary.com

Term	Definition	Source
EKF	The extended Kalman filter (EKF) is probably the most widely used estimation algorithm for nonlinear systems	https://en.wikipedia.org/wiki
Energy Availability Factor (EAF)	The “ availability factor ” of a power plant is the amount of time that it is able to produce electricity over a certain period, divided by the amount of the time in the period. Occasions, where only partial capacity is available, may or may not be deducted. Where they are, the metric is titled <i>equivalent availability factor</i> (EAF). The availability factor should not be confused with the capacity factor. The capacity factor for a period will always be less than the equivalent availability factor for the same period. The difference depends on the utilization of the power plant.	https://en.wikipedia.org/wiki
Framework	a : A basic conceptual structure (as of ideas) <i><the framework of the United States Constitution></i> b : a skeletal, openwork, or structural frame In the context of this research study, (a) applies	Merriam–Webster Dictionary (www.merriam-webster.com)
Greenfields	A new field development requiring new facilities, either onshore or offshore. A greenfield project is one that lacks constraints imposed by prior work. The analogy is to that of construction on greenfield land where there is no need to work within the constraints of existing buildings or infrastructure	Wood Group – Definitions for Industry and Technical Terms and Wikipedia
Information Management	Information management (IM) concerns a cycle of organisational activity: the acquisition of information from one or more sources, the custodianship and the distribution of that information to those who need it, and its ultimate disposition through archiving or deletion. Information management is closely related to, and overlaps, the management of data systems, technology, processes and – where the availability of information is critical to organisation success – strategy.	Wikipedia
ISO 14001	ISO 14000 is a series of environmental management standards developed and published by the International Organization for Standardization (ISO) for organizations. The ISO 14000 standards are not designed to aid the enforcement of environmental laws and do not regulate the environmental activities of organizations. Adherence to these standards is voluntary. ISO 14001 covers the implementation of an environmental management system and the criteria defined to achieve those objectives performance of an organization systematic, independent and documented process for obtaining audit evidence and evaluating it	http://whatis.techtarget.com/

Term	Definition	Source
	objectively to determine the extent to which the environmental management system audit criteria set by the organization are fulfilled.	
ISO 55001	Following the use of PAS 55 that was increasingly recognised as a generically applicable definition of good practices in the optimized management of physical assets, it was transformed to become an international standard, which is available in three parts: • ISO 55000 provides an overview of the subject of asset management and the standard terms and definitions. • ISO 55001 is the requirements specification for an integrated, effective management system for asset management. • ISO 55002 provides guidance for the implementation of such a system.	http://www.assetmanagementstandards.com/
IT–OT	While there are no industry–standard definitions of IT and OT in the electric power industry, it is possible to delineate the two → 1 – 2. OT is typically associated with field–based devices connected to the distribution system, and the infrastructure for monitoring and controlling those devices. This includes control centre based systems such as Supervisory Control and Data Acquisition (SCADA) and Distribution Management Systems (DMS). Most communications are performed device–to–device, or device–to–computer, with relatively little human interaction. IT is traditionally associated with back–office information systems used for conducting business–type transactions, such as cost and tax accounting, billing and revenue collection, asset tracking and depreciation, human resource records and time–keeping, and customer records. Manual data entry is often involved, and the computing resources have tended to be centred in offices, server rooms, and corporate data centres.	http://tdworld.com/sponsored–articles/itot–convergence/
Maintenance Base	A formal process of defining the maintenance tasks, frequencies and scope of work required to maintain a plant according to the prescribed Design Basis. A standardised methodology, rule–set, and definitions would be used to build the maintenance basis.	Own Definition in context of Research Study
Meta–data	Defined as “data about data” – a set of data that describes and gives information about other data.	www.ibm.com/
Model	1. A standard or example for imitation or comparison. 2. A representation, generally in miniature, to show the construction or appearance of something.	http://www.dictionary.com

Term	Definition	Source
	In the context of this research study, standard activities grouped together to form standard examples that can be used for the implementation of an integrated plant information system to improve business efficiency.	
MYPD	NERSA began developing a regulatory methodology in 2003 called the Multi-Year Price Determination (MYPD). This incorporates some of the Rate of Return (RoR) and incentive-based principles through the introduction of the transmission and distribution service incentive schemes and the energy efficiency demand side management (EEDSM) schemes. The RoR methodology states that “the revenue to be earned by Eskom should be equal to the efficient cost to supply electricity plus a fair return on the rate base”. This methodology was the subject of separate consultations which NERSA had with the stakeholders since the first MYPD in 2006. The MYPD2 will apply during a crucial period of the implementation of Eskom’s expansion program with a need to ensure a stable regulatory approach.	NERSA Multi-Year Price Determination (MYPD) Methodology
Open Standards	"Open Standards" are standards made available to the general public and are developed (or approved) and maintained via a collaborative and consensus driven process. "Open Standards" facilitate interoperability and data exchange among different products or services and are intended for widespread adoption.	www.itu.int/en/ITU
Operating Base	The operating envelope as defined by the Plant Design Base indicating safe operating values, operating criteria and requirements to be met in order to ensure operations within the design life and parameter limits.	Own Definition in context of Research Study
Operating Load Curves (Load Curves)	Power Generating plants are designed to start up in a very controlled fashion and require the introduction of process elements in a very sequential manner and sequence. The common term used for this sequence and start-up shut-down criteria is termed the “Load Curve”.	
Optimised Operating Parameters (OOP)	Defined as the process of making the most of the things you have least of [time, resources, and schedule] for the things you want more of [throughput, safety, and profit].	Intergraph
Organisational Effectiveness	A measurement of how effective the organisation manages its operations compared to Industry and Best Practice Principles. This is the efficiency with which an association is able to meet its objectives. The main measure of organisational effectiveness for a business will generally be expressed in terms of how well its net profitability compares with its target profitability.	http://www.businessdictionary.com/definition/

Term	Definition	Source
	Additional measures might include growth data and the results of customer satisfaction surveys.	
Out of The Box (OOTB)	“Out of the Box” – An out of the box feature or functionality (also called OOTB or Off the shelf), particularly in software, is a feature or functionality of a product that works immediately after installation without any configuration or modification. It also means that it is available for all users by default, and is not required to pay additionally to use those features, or needs to be configured.	Wiktionary/ Wikipedia
PAS–55	PAS 55 is the British Standards Institution's (BSI) Publicly Available Specification for the optimized management of physical assets – it provides clear definitions and a 28–point requirements specification for establishing and verifying a joined–up, optimized and whole–life management system for all types of physical assets.	http://pas55.net/
PCA	Principal component analysis is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components.	https://en.wikipedia.org/wiki/
Plant Information Management	Also defined as Production Information Management System. Also known as a “process information management system,” a PIMS is a client/server application for the acquisition, display, archiving and reporting of information from a wide variety of control, plant and business systems. A critical component in a manufacturing enterprise’s application architecture for creating a common repository of plant information that can be effectively leveraged in enterprise and supply chain management applications.	Gartner IT Glossary
PLS	Partial least squares regression (PLS regression) is a statistical method that bears some relation to principal components regression.	https://en.wikipedia.org/wiki/
QTA	Query Tree ALOHA (QTA) anti-collision algorithm	ieeexplore.ieee.org
Reliability Base	Defining the reliability requirements (Reliability, Availability, and Maintainability) based on the Design Basis of a plant or system. This includes the use of Reliability engineering tools and advanced software and methodologies to define failure modes and recommending/implementing the required actions to maintain the reliability to levels as originally used in defining the Design Base.	Own Definition in context of Research Study

Term	Definition	Source
ROA (Return on Assets)	Return on assets (ROA) is an indicator of how profitable a company is relative to its total assets. ROA gives an idea as to how efficient management is at using its assets to generate earnings. Calculated by dividing a company's annual earnings by its total assets, ROA is displayed as a percentage. Sometimes this is referred to as "return on investment".	http://www.investopedia.com/terms
ROI³	A term coined by Bentley Systems International in 2008 to define projects that display the maximum value proposition for infrastructure projects. It considers 3 elements – return-on-investment, return-on-infrastructure, and return-on-innovation, thus the ROI ³ term.	www.Bentley.com
SmartGrid	A smart grid is an electrical grid which includes a variety of operational and energy measures including smart meters, smart appliances, renewable energy resources, and energy efficiency resources. A smart grid is an electricity network based on digital technology that is used to supply electricity to consumers via two-way digital communication. This system allows for monitoring, analysis, control and communication within the supply chain to help improve efficiency, reduce energy consumption and cost, and maximize the transparency and reliability of the energy supply chain. The smart grid was introduced with the aim of overcoming the weaknesses of conventional electrical grids by using smart net meters.	Wikipedia and Technopedia
Smart Meters	A “ smart meter ” is an electronic device that records consumption of electric energy in intervals of an hour or less and communicates that information at least daily back to the utility for monitoring and billing. Smart meters enable two-way communication between the meter and the central system.	https://en.wikipedia.org/wiki/Smart_meter
Smart Technology	Self-Monitoring, Analysis and Reporting Technology ; often written as SMART , is a monitoring system included in computer hard disk drives (HDDs) and solid-state drives (SSDs) that detect and reports on various indicators of drive reliability, with the intent of enabling the anticipation of hardware failures.	https://en.wikipedia.org/wiki/S.M.A.R.T.
SmartUtility	There is no general consensus on a definition, but the research author from research defines this term as follows: “The utilization of smart technologies across the entire utility landscape, including smart use of all resources like water, energy, fuel, electricity, resource planning.” This is based on views like those of Silverspring networks:	Silverspring Networks

Term	Definition	Source
	Utilities, like cities, deliver vital services to large numbers of people across vast geographic areas. By leveraging their experience using advanced technology to deliver safe, reliable and secure energy, utilities can also help cities modernize their infrastructure, establish a platform for economic growth, and empower the communities which they serve. So what makes utilities a natural 'smart city' partner in areas such as smart energy and water networks, intelligent street lights and traffic controls, pollution and disaster sensor, transportation networks, and more. a "smart city."	
SmartStrategy	A term coined internally to the power utility to describe the integrated effort (beyond "SmartGrid" concepts) in all areas of the business to bring about business improvements and efficiency.	
Time-In-Market (TIM)	The process and steps taken to mitigate unplanned outages, minimize engineering turnarounds and obviate safety, hazard and regulatory risks which would otherwise halt production.	Intergraph
Time-To-Market (TTM)	Defined as the process of getting the plant asset designed and constructed ahead of schedule, within budget and operating at designed capacity to meet a market window of opportunity.	Intergraph
Utility	In the context of this research study, Utility implies the South African Power Generation utility.	
V-Model	The V-model is a term applied to a range of models, from a conceptual model designed to produce a simplified understanding of the complexity associated with systems development to detailed, rigorous development lifecycle models and project management models. The V-model is a graphical representation of the systems development lifecycle. It summarizes the main steps to be taken in conjunction with the corresponding deliverables within computerized system validation framework.	Wikipedia
Wet FGD	Flue-gas desulfurization (FGD) is a set of technologies used to remove sulfur dioxide (SO ₂) from exhaust flue gases of fossil-fuel power plants, and from the emissions of other sulfur oxide emitting processes. Wet FGD uses a wet scrubbing approach using a slurry of alkaline sorbent, usually limestone or lime, or seawater to scrub gases.	Wikipedia

LIST OF TABLES

Table 2–1:	World Energy Council 3A's vs Key Business Drivers [Jain, 2007].....	27
Table 2–2:	Business and Operational Challenges for Power Utilities (2008/9) [Swanepoel, 2011a]	28
Table 2–3:	Baldrige Evaluation Outcome – Showing a “Process Centric” improvement mode [NIST, 2015].....	42
Table 2–4:	EFQM Radar Model Outcome Evaluation [Van Rompuy, 2012]	42
Table 2–5:	Typical Technical Design Base Content Volume Profile: 3,600 MW Power Station.....	48
Table 3–1:	Integrated Engineering System Implementation Approaches Evaluated.....	98
Table 3–2:	Evaluation Findings – IPI System Implementation Methodologies	99
Table 3–3:	Engineering Business Process Implementation Cycle Times Using Developed Implementation Methodology.....	107
Table 3–4:	Implementation Methodology Benefits [Swanepoel, 2010a].....	111
Table 3–5:	Implementation Methodology Benefits.....	112
Table 4–1:	Comparison of Design Base Definition Approach and Scope	117
Table 4–2:	Brownfields Design Base Artefact Volumes per Discipline	118
Table 4–3:	Greenfields Design Base Artefact Volumes per Discipline.....	118
Table 4–4:	Greenfields vs. Brownfields Data Volumes.....	118
Table 4–5:	Typical example of a data mining rule–set developed in this research study [Tullis, 2013].....	122
Table 4–6:	Automated Data Analytics Mining Tool Success Rate.....	126
Table 4–7:	Core Design Base Content Value – Brownfields vs Greenfields Plant	130
Table 4–8:	Core Design Base Content Value – Brownfields vs Greenfields Plant	146
Table 4–9:	Core Design Base Content Value – Brownfields vs Greenfields Plant	147
Table 6–1:	Evaluation of Managing Controllable Parameters in line with Design Operating Envelopes	194
Table 6–2:	Evaluation of Adherence to Operating Envelopes	196
Table 6–3:	BFPT vs EFP Feed–water Supply Impact on Generation and Heat Rate	197
Table 6–4:	Evaluation of HP Heater Fouling on Feedwater Temperature and Heat Rate	198

Table 6–5:	Evaluation of losing HP Heaters in the Process	199
Table 6–6:	Evaluation of early failure warning detection capability	200
Table 6–7:	Evaluation of Test Efficiency according to expected plant behaviour	201
Table 6–8:	Preventing Load Losses with improved Operator Training	205
Table 7–1:	Typical Cost of Scenarios (2008)	213
Table 7–2:	Adjusted Typical Cost of Scenarios (2015/6 Cost Reflectiveness)	213
Table 7–3:	Average Production Costs (Historical and 5–Year Projection) [Eskom, 2013/4]	213
Table 7–4:	Probability Factor Definition	214
Table 7–5:	Overall Full Value Proposition – All Drivers linked to IPI BIM Model Elements	216
Table 7–6:	Typical Cost of Incidents in the Power Utility	217
Table 7–7:	Typical Engineering Productivity and Risk Savings	217
Table 7–8:	Typical Operating Savings	219
Table 7–9:	Typical Maintenance Practices Savings	219
Table 7–10:	Typical Reliability/Availability Savings	220
Table 7–11:	Typical Construction/Project Execution Savings	220
Table 7–12:	Typical IT Infrastructure Savings	221
Table 8–1:	Status of IPI–BIM Model Elements Implemented at the Research Study Plants	226
Table 8–2:	Actual IPI–BIM Value Propositions Identified and Documented	230
Table 8–3:	External Validation – The use of the IPI–BIM Framework	232
Table 9–1:	Cost Savings achieved by implementing an IPI System Platform using the new research Implementation Methodology	236
Table 9–2:	System Implementation Timeline Impact	237
Table 9–3:	Actual Productivity Time Saving by introducing Automated Data– Mining	238
Table 9–4:	Decrease in Design Base Volumes by defining the CORE Design Base	239
Table 9–5:	Optimal Information Delivery – Actual Savings	241
Table 9–6:	Typical Actual Savings having Advanced Analytics Capability	244
Table 9–7:	IPI System Implementation Methodology Benefits [Swanepoel, 2008]	245
Table 9–8:	IPI System Implementation Methodology Benefits	249

LIST OF FIGURES

Figure 0–1:	The Integrated Plant Information Business Improvement Model (IPI–BIM)	xiii
Figuur 0–2:	Die Geïntegreerde Aanleg Inligting Besigheids Verbeterings Model (IPI–BIM)	xv
Figure 1–1:	Business Impacts challenging existing Utility Business Models [Jones, 2015]	2
Figure 1–2:	Business Impacts of Data is not the Only Issue [Wegener et al., 2013]	7
Figure 1–3:	Volume and Velocity of Plant Process vs ERP/CRM System Data [Rozados et al., 2014]	9
Figure 1–4:	Advanced Plant Analytics Building Blocks for Asset Management Optimisation [Hales, 2013]	10
Figure 1–5:	KPMG Survey – Causes for Cost Overruns on Mega–Projects [Hogarth, 2009]	12
Figure 1–6:	KPMG Survey – Causes for Mega–Projects Time Delays [Hogarth, 2009]	12
Figure 1–7:	Structured Research Approach to Build the IPI–BIM	16
Figure 1–8:	Phased Advanced Analytics Capability Creation Stack proposed [Swanepoel, 2014b]	18
Figure 1–9:	Systems Engineering V–Model [Federal Highway Administration, 2005]	21
Figure 2–1:	Eskom Operating Expenses (Year on Year) [Eskom, 2014]	29
Figure 2–2:	PWC Survey: Triggers that will initiate business model changes [Price–Waterhouse–Coopers, 2013]	30
Figure 2–3:	Smart Technology Maturity Map [Hales, 2013]	31
Figure 2–4:	Power Utility comparison to Global Utilities (EAF comparison) [Ngubane, 2014]	32
Figure 2–5:	Age Profile: Power Generation Capacity [Department of Minerals and Energy, 2010]	34
Figure 2–6:	Integrated Resource Planning – Changes to Energy Mix and Supply [Department of Minerals and Energy, 2011]	34
Figure 2–7:	Key elements of the Baldrige Business Model Review Framework [NIST, 2015]	38
Figure 2–8:	EFQM Excellence Model Review Framework™ [Van Rompuy, 2012]	39
Figure 2–9:	Information Management Models – Focus Area [Socha et al., 2016]	40

Figure 2–10:	Information Management Capability Model [Bell, 2015; Data Management Association International (DAMA), www.dama.org , DAMA, 2013].....	41
Figure 2–11:	EPC vs. O&M Perspective on Plant Information Management [Feldman et al., 2001]	45
Figure 2–12:	Plant Slot, Asset and Asset Type Relationship [Venketiah, 2011]	46
Figure 2–13:	Complexity of Asset Placement within Plant Slots [Venketiah, 2011]	47
Figure 2–14:	Designing an integrated engineering workflow and process eco-system for lifecycle Design Base Change Management [Swanepoel, 2012b].....	49
Figure 2–15:	Benefits of Better Information Management over the Plant Asset Lifecycle [Coopers et al., 2007].....	50
Figure 2–16:	Plant Information management system implementation approaches	51
Figure 2–17:	Technology Adoption Strategies [Hogan, 2016]	52
Figure 2–18:	SDLC Lifecycle for system development and optimisation [James, 2013].....	53
Figure 2–19:	Requirements V&V Process within the SDLC Lifecycle [James, 2013].....	54
Figure 2–20:	Rapid vs. Traditional Application Development Methodology Summary [Koredla, 2014].....	55
Figure 2–21:	Intergraph SPO™ – Deployment Strategy of Capability Enablement [Intergraph, 2014].....	57
Figure 2–22:	Process Focus in O&M Asset Lifecycle [Swanepoel, 2010a].....	58
Figure 2–23:	Design Base Creation in the EPC Asset Lifecycle [Swanepoel, 2012d].....	59
Figure 2–24:	Process Focus in EPC Asset Lifecycle [Swanepoel, 2012d].....	60
Figure 2–25:	Process Focus in O&M Asset Lifecycle [Swanepoel, 2006].....	61
Figure 2–26:	Advanced Analytics Capability Building Blocks [Swanepoel, 2014b]	63
Figure 2–27:	Typical key Design Base deliverable timeframes in a project timeline [Intergraph, 2007]	66
Figure 2–28:	Information Volumes and Quality over Project Timelines [Botterill, 2007].....	67
Figure 2–29:	Evolution to smart capability – Document to Data-centric applications [Botterill, 2007]	68
Figure 2–30:	GEDI Project – Proposed Typical Design Base Content [Swanepoel, 2012b].....	68

Figure 2–31:	Business Drivers for integrated and improved information delivery [PennEnergy et al., 2012]	70
Figure 2–32:	3D Visualisation investment prioritisation [Rozados et al., 2014]	70
Figure 2–33:	Emerging 3D and new Technology maturing over 4 years – Increased use and faster deployment [Rivera et al., 2013]	71
Figure 2–34:	Sample of Complex Visual Information System Architecture [Swanepoel, 2014c]	73
Figure 2–35:	EEMUA findings of Alarm Rates and Alarm Statistics in Typical Process plant [Mayssat, 2009]	77
Figure 2–36:	Response times to data captured at different Information Layers [Marszal, 2002]	79
Figure 2–37:	Classification of Diagnostic Algorithms [Venkatasubramanian et al., 2002]	80
Figure 2–38:	Failure Curve in Predictive Maintenance Management Environment [Rohling, 2014]	80
Figure 2–39:	Pushing the boundaries using Advanced Analytics [Parlour, 2007]	82
Figure 2–40:	Gartner Emerging Technologies Hype Cycle for 2013 [Rivera et al., 2013]	82
Figure 2–41:	Emerging Technology maturing over 4 years – Increased use and faster deployment [Katzenelson, 2015]	83
Figure 2–42:	Brownfields Plant System Group Control Dependencies	85
Figure 2–43:	Boiler Trip System Dependencies to return to Full Load [Swanepoel, 2014b]	85
Figure 2–44:	Typical RMD C structure deployed for on–line monitoring of power plants [Siemens, 2006]	89
Figure 2–45:	Top 10 Problem Plant Areas, 2006/7 (10 Year Historical Window) [Swanepoel, 2008]	90
Figure 2–46:	Plant State during Trips (10–Year History) [Swanepoel, 2008]	90
Figure 3–1:	IPI System Platform Elements	97
Figure 3–2:	Rapid Application Development (RAD) vs. Traditional (SDLC) IT System Implementation Approach [Koredla, 2014]	98
Figure 3–3:	6–Step Idealised IPI System Engineering Process Implementation Approach [Swanepoel, 2012b]	101
Figure 3–4:	Standard Template for Process Workflow Design	102
Figure 3–5:	Standard User Interface Template	103
Figure 3–6:	Business Rule Application Example	103
Figure 3–7:	System User Interface Design	104

Figure 3–8:	Business Process Metadata Definition.....	105
Figure 3–9:	IPI Engineering Business Process Integration [Swanepoel, 2012d].....	106
Figure 3–10:	Improved Estimation of Business Process implementation timelines.....	109
Figure 3–11:	Creating separate environments for EPC and O&M business environments [de Kock et al., 2015]	110
Figure 4–1:	Core Design Base Content needed for C&I Upgrades	120
Figure 4–2:	Data Mining Rule–set Validation: 1st Iteration vs. Manual Assignment [Tullis, 2014]	124
Figure 4–3:	Top 10 IEC Assignments using Automated Rule–set: Brownfields Plant 2 [Tullis 2015].....	125
Figure 4–4:	Top 10 IEC Assignments using Automated Rule–set: Research Study Brownfields Plant [Tullis, 2013].....	126
Figure 4–5:	Using incoming documentation and data to build the Design Base: Greenfields Project [Swanepoel, 2012d]	127
Figure 4–6:	Design Base Content creation process for Greenfields [Swanepoel, 2012d].....	128
Figure 4–7:	Reverse Engineering Design Base using Plant Operating Simulator...	134
Figure 4–8:	Brownfields Rankine Cycle Critical Data Enablement in Engineering Simulator for Analytics	137
Figure 4–9:	Plant Ideal State Rankine Cycle developed in Engineering Simulator .	138
Figure 4–10:	Boiler Operating Parameter Performance monitoring (Design Base vs Actual)	139
Figure 4–11:	Turbine Operating Parameter Performance monitoring (Design Base vs Actual)	140
Figure 4–12:	Unit Start–up Curve in Operating Simulator showing key operating curve hold–points	141
Figure 5–1:	Methodology to establish 3D Visualisation Capability in a Brownfields Plant [Swanepoel, 2012c]	156
Figure 5–2:	Conceptual Utility SmartPortal Design.....	157
Figure 5–3:	Implemented Taxonomy of key business data and information	158
Figure 5–4:	SmartPortal Concept PoC enabled in SharePoint System Platform.....	159
Figure 5–5:	Sample of Real–time Information	Figure 5–6: Sample of static information..... 159
Figure 5–7:	Real–time information availability in Prototype portal.....	
Figure 5–8:	Information from multiple data sources enabled in one single user interface.....	160

Figure 5–9:	Outcome of plant process visualisation on real–time data with alarming and state indication	161
Figure 5–10:	Air System near real–time plant process monitoring (Brownfields Plant)	162
Figure 5–11:	Visualisation of Design Base Content in 3D interactive plant model ...	163
Figure 5–12:	Interactive 3D Visualisation in Simulator Technology using Point Cloud Data.....	164
Figure 5–13:	FGD Advanced Analytical Model enabled in the 3D Plant Simulator....	165
Figure 5–14:	Plant Process Engineering Simulation Model in Flownex™	167
Figure 5–15:	Simplified Process Model only reflecting controllable parameters and process values.....	168
Figure 5–16:	SmartPortal Concept PoC enabled in SharePoint System Platform.....	169
Figure 5–17:	Brownfields Plant Combustion Process Animation.....	171
Figure 5–18:	Nerve Centre vs Portal Capabilities Comparison.....	172
Figure 5–19:	Typical Operating Savings.....	174
Figure 6–1:	Technology Building Blocks Enabling Advanced Analytics and AI [Swanepoel, 2014b].....	176
Figure 6–2:	Advanced Plant Analytics Information Building Blocks for Asset Management Optimisation [Hales, 2013].....	177
Figure 6–3:	Advanced Analytics Categories [Phillips, 2014]	178
Figure 6–4:	Occurrence Analysis to identify Problem Plant Areas [Swanepoel, 2008]	179
Figure 6–5:	IBI Analysis of Barrier Failures resulting in Occurrences [Swanepoel, 2008]	180
Figure 6–6:	FMECA/Root Cause Failure Analysis Results [Swanepoel, 2008]	181
Figure 6–7:	Trip Analysis Findings [Swanepoel, 2008]	182
Figure 6–8:	EPRI Model for Plant Maintenance (Reliability Base) Optimisation [Abbott, 2004].....	183
Figure 6–9:	Brownfields Plant Maintenance Criticality Distribution [Swanepoel, 2016].....	183
Figure 6–10:	Basic structure and elements of an advanced analytics system [Angeli, 2004].....	184
Figure 6–11:	620 MW Power Generation Unit Ideal Design Process Efficiency Model.....	189
Figure 6–12:	620 MW Power Generating Unit PFD Level Controllable Parameter Visualisation Model.....	190

Figure 6–13:	Boiler Actual Operating Control vs Expected Operating Design	
	Base Control Value	191
Figure 6–14:	Layout and high–level visual process model of Wet FGD Plant.....	192
Figure 6–15:	Controllable parameters enabled on the FGD Plant Process	
	Simulation Model in Flownex.....	193
Figure 6–16:	Boiler Feedwater Temperature Control	194
Figure 6–17:	Boiler Feedwater Flow Rate Control.....	195
Figure 6–18:	Unit Loading 40–100%MCR Curve – Parameters and criteria	
	monitored	195
Figure 6–19:	Problematic Oxygen Control vs Desired HP Condenser Pressure	
	Control.....	196
Figure 6–20:	Problematic Oxygen Control vs Desired HP Condenser Pressure	
	Control.....	197
Figure 6–21:	Loading Curve to Restore Unit to full load after BFPT Trip	198
Figure 6–22:	620 MW Unit De–loading curve.....	200
Figure 6–23:	Turbine Over–speed Test ideal plant behaviour curve	201
Figure 8–1:	Revolutionary vs. Evolutionary Capability Implementation	
	[Swanepoel, 2006]	225
Figure 8–2:	Brownfields Power Station IPI–BIM Framework Implementation	229
Figure 8–3:	Greenfields Project IPI–BIM Framework Implementation	230
Figure 9–1:	Analytics Techniques used in development of the IPI–BIM	
	Framework.....	243
Figure 9–2:	Boiler Stability Control (Comparison to other sites).....	244
Figure 9–3:	Brownfields Power Station IPI–BIM Framework Implementation	247
Figure 9–4:	Greenfields Project IPI–BIM Framework Implementation	247
Figure 10–1:	Existing Silo Approaches to Business Improvement	251
Figure 10–2:	A New Integrated Approach to Business Improvement.....	252
Figure 10–3:	Potential future integrated Business Information Hub	255
Figure 10–4:	Using 3D point cloud data to create solid 3D Models	259

Ernst & Young reports from their 2013 survey the major (Top 10) Global Business strategic, operations, financial and compliance risks and challenges [Watson, 2010 and Ernst and Young, 2013]. Their findings indicate issues like access to credit, cost cutting, pricing pressures, talent management and increased regulatory compliance requirements as risks to existing business models that are forcing all businesses to take a hard look at the way they manage their operations and what business improvement opportunities can be identified and realised.

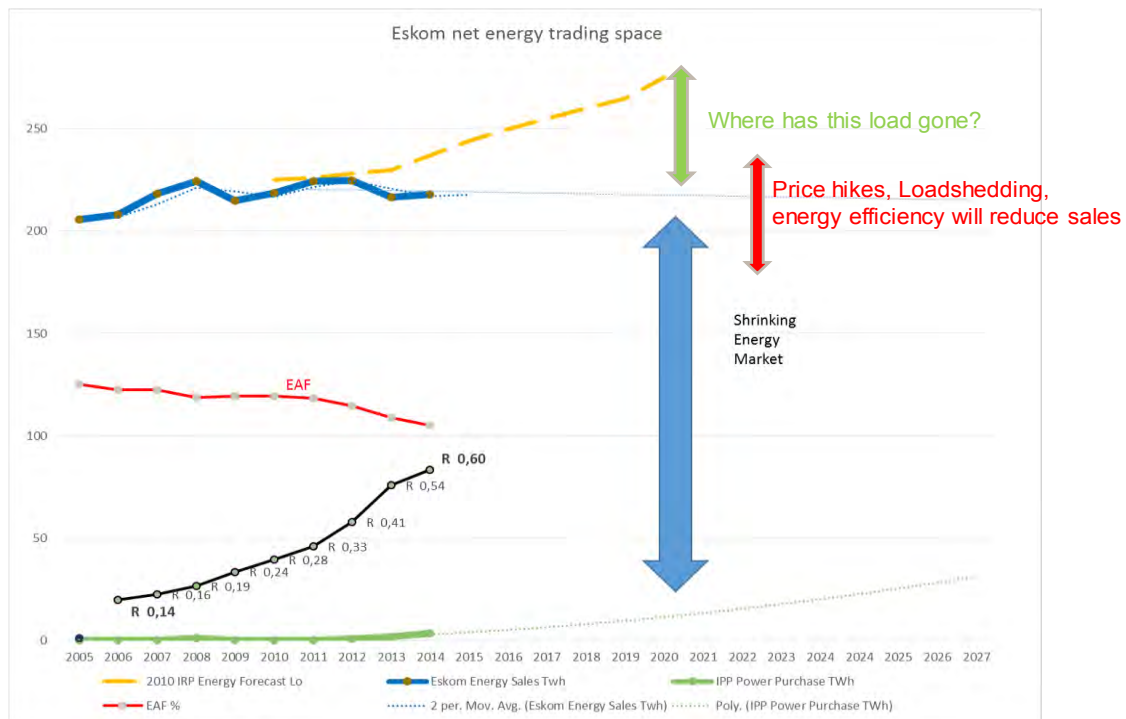
In addition to these generic business challenges, the World Energy Council points out that there are numerous new issues in the Global and African energy arena that are adding to the pressure to operate existing plants better and more efficiently [Frei, 2014; Jain, 2007; Wyman, 2010]. The most notable impacts being the advent of smart grids, changing climate management frameworks, increased commodity prices and an under-investment in infrastructure.

The South African Power Utility is under enormous pressure to better manage plant performance following a continuous declining trend in key performance indicator measures over the past few years [Eskom Holdings, 2011/2014; Oosthuizen et al., 2014]. The current performance is no longer on par with average to top quartile global power utility performers, while in the period 1990–2000 the Power Utility consistently performed in the top quartile of power producers.

The South African Integrated Energy Resource Plan [Department of Minerals and Energy, 2003/2011] define the government strategy of how the sources of energy supply and energy mix (and thus business models in this space) will change in the next 15–20 years. This introduces a significant impact on the current Power Utility business model that previously centred its asset lifecycle planning and replacement strategies on a predominant energy mix of coal.

Internal Power Utility research has confirmed that the current Power Utility business model is no longer sustainable [Jones, 2015]. Operating challenges, rising operating costs and deteriorating plant availability are creating a perfect storm that demands radical changes in the way the Utility is managing its business operations and how it addresses the challenges (Figure 1–1).

Figure 1–1: Business Impacts challenging existing Utility Business Models [Jones, 2015]



The South African environment and challenges are not unique, as is shown by the PWC Survey on Energy Sector business models, which covered 53 utilities in 35 countries confirming similar business environment triggers that will initiate business model changes [Price–Waterhouse–Coopers, 2013].

Pressures for business improvement are therefore present globally, in the Energy/Power Utility industry and in a South African context.

The World Energy Council in their 2011 studies [Wyman, 2010] defines the core “3 A’s” of **future sustainability** that are forcing utilities to evaluate their operations in the context of Cost, Efficiency, and Safety sustainability measures as:

- Accessibility to Energy/Electricity.
- Availability of Electricity/Energy.
- Acceptability of Energy Options offered.

The World Energy Council summarises their evaluation of the changing energy environment with the comment: “**Power Generators will need a PACKAGE OF MEASURES to deal with this scenario – single measures will no longer have the desired effect.**“ [Wyman, 2010]

At the heart of this package of measures is the ability to access the correct and most relevant business and plant process information to make the right decisions at the right time to improve business operations and efficiency.

The current world of work revolves around information generated in business operations and analysing this information to make business decisions that will drive business efficiency and maximise profits and plant outputs. The ABB Grid Automation Product Research Group documents the challenges with a converging Information Technology–Operational Technology (IT–OT) infrastructure. Their paper highlights the findings of a study they performed with 221 utility executives in collaboration with MicroSoft and Zpryme [ABB, 2016]. More than 25% of respondents indicated serious concerns about effective IT–OT integration and its impact on improved asset management.

Unfortunately, the biggest downfall with the mass of data and information being produced on a continuous basis is that very few, if any individuals can effectively deal with the avalanche of information without the help of intelligent information systems. This becomes an even bigger issue in process plant control and information systems due to the frequency and volumes of process information collected to effectively control the plant operations.

A further challenge is that most of the existing power generation plants were built prior to the information technology era, with the result that the bulk of plant technical Design Base information is in paper format with a high risk of poor change management of this documentation over the lifecycle of plant operations to date. There are therefore currently many concerns on access to Engineering information that can be seen as Accurate, Reliable, and Relevant (the CARAT principle).

An IDC Study [Feldman et al., 2001] highlights the costs (obvious and hidden) of not being able to find or access the right information at the right time, i.e.:

- Poor decisions (based on incorrect or missing information)
- Duplicated efforts
- Reduced output
- Lost productivity

Most business productivity improvement initiatives currently under way in the Power Utility requires access to better and more effective information analytics in all business areas as a critical element to support and drive improved business operations [Ngubane, 2015]. This is echoed in the ABB research study where 52% of utilities indicate the critical importance of better asset management, while 65% indicates that it is crucial to their long–term capital planning efforts for asset management [ABB, 2016].

A notable finding from this study is the fact that Real–Time control system data, asset management, and outage management systems are now deemed of much higher importance for asset management than traditional ERP and supply chain management systems.

The ***Integrated Plant Information Business Improvement Model*** (IPI-BIM)[©] and implementation approach developed by this research study introduces a new integrated Business Improvement Model (BIM) that has at its heart an integrated plant information (IPI) system framework centred around management of the plant Design Base. Introducing a business improvement model that is plant data-centric (both from a Design Base as well as the operating control data perspective) will, therefore, be of high value as it leverages content from the typical systems seen as critical applications and systems to use for asset management [ABB, 2016].

Coupling this information framework with advanced analytics capability provides a powerful mechanism to optimise the asset life, reliability and efficiency in a standardised, cost-efficient and structured manner and to introduce structured and measurable business improvement initiatives in process plants. The outcome of this research study and the IPI-BIM Framework and approach proposed is in direct support of the SmartUtility Strategy developed to enhance Power Utility operations [Hales, 2013].

This is echoed by the ABB research findings of what data is rated the most valuable to drive from an information integration perspective [ABB, 2016]. Real-time data system (plant process, engineering, and business) information feed into the Asset Management system are deemed the most valuable by the respondents – yet **only 31% of respondents** in the research study **considered their applications and data exchange to be well integrated**.

Verification of the viability of the IPI-BIM Framework and implementation approach were proven with operational research, prototyping, and hypothesis testing over the period 2007 to 2016, and its value proposition could be quantified with measurable benefits. It is therefore deemed an operationally ready and viable business improvement model.

Validation of the new IPI-BIM Framework and implementation approaches was done by documenting its value proposition at the two research study power stations (where the Framework was implemented) and comparing its implementation successes against power stations and build projects of the same design and complexity where conventional or alternative Frameworks and implementation approaches was allowed.

The researcher had no control over the choice of framework or implementation approaches used at these power stations (as it was assigned independently), allowing for a fair external validation exercise. All the power stations had the same level of access to the required resources and system technologies.

Although the prototyping and proof of concept were primarily done in a Power Utility environment, the proposed IPI–BIM and implementation approaches are generic enough in nature to be applicable to most process plant environments and thus have industry application in any process orientated business endeavour.

1.1 Problem Statement

1.1.1 Current Business Improvement Models (BIM's)

Literature surveys show that Business Improvement initiatives, models, and approaches are generally focused on the improvement of business processes (core or underlying processes). The most notable and widely used improvement framework being the ISO 9001 quality management system, supported by frameworks like Baldrige [Tanner, 2014; NIST, 2015] or the EFQM Framework [Van Rompuy, 2012; DAMA website, www.dama.org].

Because of their generic nature, these models offer very little information and specifics on what methodology could be followed to improve business operations using plant information and data. Very few of these models, if any, evaluate the impact of not using critical plant design and control data effectively. Limited focus is 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 as it lacks the plant and process data that can be used to demonstrate and prove the value proposition.

A further drawback identified from research is the subjective manner in which the business process efficiency evaluation is done – although a questionnaire can be very effective in prompting the organisation to look at the right business model elements, proper quantification of what is deemed “good practice/role model” process maturity is required.

In both the Baldrige and EFQM cases, the business improvement models and frameworks make use of very generic questionnaires to “rate” and quantify the business maturity levels [NIST, 2015, Van Rompuy, 2012]. As an example, at what percentage of repeatable process execution is an organisation considered “mature”, and when is it considered a “role model”?

Similarly, Information Management business improvement models (BIM's) focus on the implementation of the required systems and governance to manage the information infrastructure. [Bell, 2014; DAMA website, www.dama.org; Socha et al., 2016] The web discussion on this topic confirms the researcher's view that the most commonly used IT business improvement frameworks (TOGAF and COBIT) again focus on IT business processes, resulting in a focus on documenting processes rather than prescribing how to identify and deal with (and make decisions on) the actual data generated [Ledergerber, 2012].

None of the frameworks, models or approaches deals with the complexity of data management or gives operational and practical guidance on how to use plant information management data to improve business efficiency. Many organisations have implemented ISO 9001 systems but are still plagued by business inefficiencies and unreliable/inefficient operations.

The Business Improvement Model proposed by this research study differs from these well-known business improvement framework models in that it does not focus on process, core values, and/or concepts as its foundation, but rather uses an integrated plant information management framework as the foundation for business improvement initiatives.

The enhanced IAEA PAS 55 framework states that “**good decisions should be balanced between deterministic and probabilistic analysis to provide the required insights, perspective, comprehension and balance**” [IAEA, 2011]. The framework also states the importance of well-managed Design Base information datasets to assist in decision making – something the IPI-BIM model and approach sets out to deliver.

1.1.2 Integration of Advanced Analytics into Business Improvement Models

An IDC Study highlights the costs (obvious and hidden) of not being able to find or access the right information at the right time [Feldman et al., 2001]. Very few technical (plant process industries) plants have access to a **workable operational model** that will assist them to bring about business improvements using their plant information.

Popular Business Improvement Models primarily focus on business processes and not plant production processes – research literature surveys confirmed that very limited information is available when it comes to defining the data sets needed to model and improve plant operations. Even less guidance is available on plant data analytics required for business improvement and it is left to the plant owner to figure out what makes up the dataset required.

Gartner predicts that about 70% of the world's most profitable companies in 2015 will be using predictive analytics software extensively by 2020 [Gartner, 2015]. But switching over to such technologies poses a major challenge because big data infrastructure differs fundamentally from conventional IT infrastructure in terms of system stability and network structures.

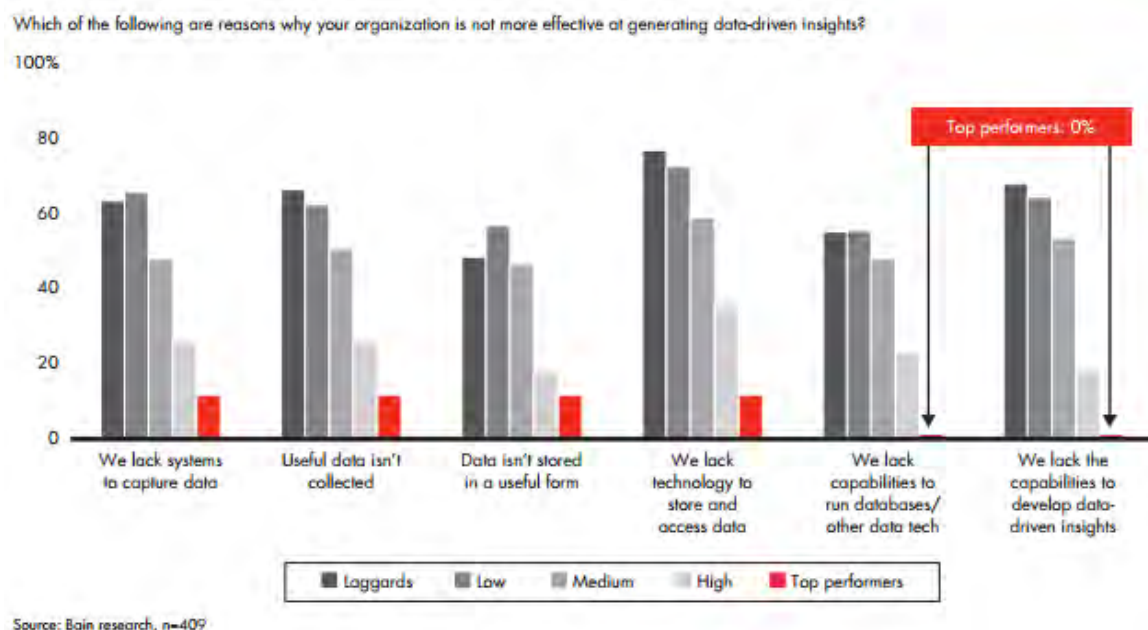
Data scientists believe that as little as 5% of the “big data” gathered results in 95% of the value contribution of the data. [Biehn, 2013] And herein lies one of the biggest challenges of data analytics – **identifying, modelling and analysing the 5% critical data effectively to improve business operations**.

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” have a significant impact on situational analysis, response and decision times.

Wegener and Sinha aptly show that Top Business performers have developed the required analytical models and know **exactly what data and information are important** [Wegener et al., 2013]. Their industry survey of 409 companies shows that **only 4%** of the participants had the right people, tools, data and intent to drawing meaningful insights and take action from it.

Analysing the top performing companies showed an ability by these companies to execute data-driven decisions fast for very positive outcomes. The researchers also point out that top performers have the required analytical models and decision-making algorithms developed to enhance their business decision making. (Figure 1–2)

Figure 1–2: Business Impacts of Data is not the Only Issue [Wegener et al., 2013]



This confirms a significant shortcoming in the industry to have a business improvement model that can be used as a **practical guide** to implementing the required infrastructure and analytics framework that will stimulate and improve business operations and efficiency (the other 96% of companies in the survey).

Lustig's research states that a combination of analytical methods would be required to provide a holistic plant improvement framework [Lustig et al., 2010]. The level of detail provided in his research findings does, however, not adequately demonstrate how it is used to achieve plant performance improvements.

1.1.3 Access to Information

In research numerous issues in business operations with access to information are described [Bravo et al., 2013; Feldman et al., 2001], especially in cases where information is many times seen as mission critical to business operations, but cannot be timely or effectively sourced.

An IDC study highlights a further key constraint in access to information – the fact that many "information access/availability" issues are not technical in nature, but rather reside in the human realm of business processes, corporate culture and individual knowledge and skill that is not something that is as easily transferred as some may believe [Feldman et al., 2001]. This study highlights the costs (obvious and hidden) of not being able to find or access the right information at the right time. i.e.:

- Poor decisions (based on incorrect or missing information)
- Duplicated efforts
- Reduced output
- Lost productivity

And this usually becomes the greatest challenge for any Knowledge Management practitioner and data scientist – the integration of the highest value data and information within a dynamic business environment to create a knowledge worker platform where there is high-value "on demand" information available – accurate, reliable and

Research has shown that improved information management of the operating Design Base; integration of this information asset with plant process control data and using it for daily operations have significant savings from a productivity and economic benefit point of view [Emerson, 2003]. The challenge is to create an integrated information system framework where this information asset management benefits can be realised.

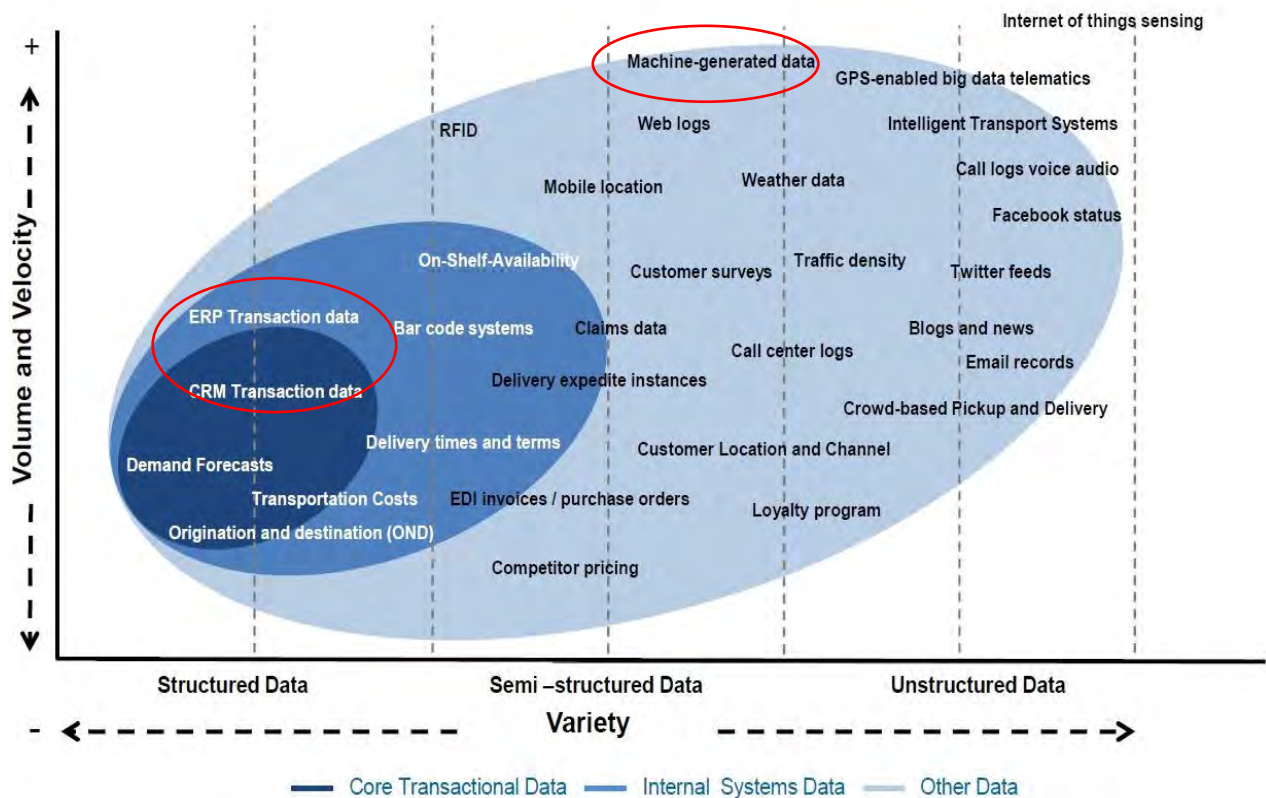
1.1.4 Complexity of a Process Plant Environment

The research literature survey and prototype evaluations that were done as part of the research confirmed that developing and establishing an integrated and holistic plant information (IPI) system to support business improvement initiatives is a complex and time-consuming process.

Rozados and Tjahjono show with their research how ERP transaction data is low volume, velocity, and variety when compared to Machine Generated Data (stemming from C&I systems – Figure 1–3) [Rozados et al., 2014].

Analytics of ERP transactional data is therefore much easier than data stemming from the plant control environment where volume, variety, and size of the data become a major challenge to meaningfully analyse and interpret the dataset.

Figure 1–3: Volume and Velocity of Plant Process vs ERP/CRM System Data [Rozados et al., 2014]



Bravo's research also confirms some of the biggest challenges posed by volumes of information and availability of information – large computation and simulation time, large data volumes and data management and integration issues [Bravo et al., 2013].

Most vendors of Plant Information Management Systems sell their software on the primary value proposition that it will bring visibility of plant information from disparate sources and allow/enable improved business decision making.

But it is generally left to the business owner to figure out **what** plant data in this information system is important and should be used for decision making. Interaction, integration and an explanation of the dependency of plant and business information are seldom defined or put in the correct context.

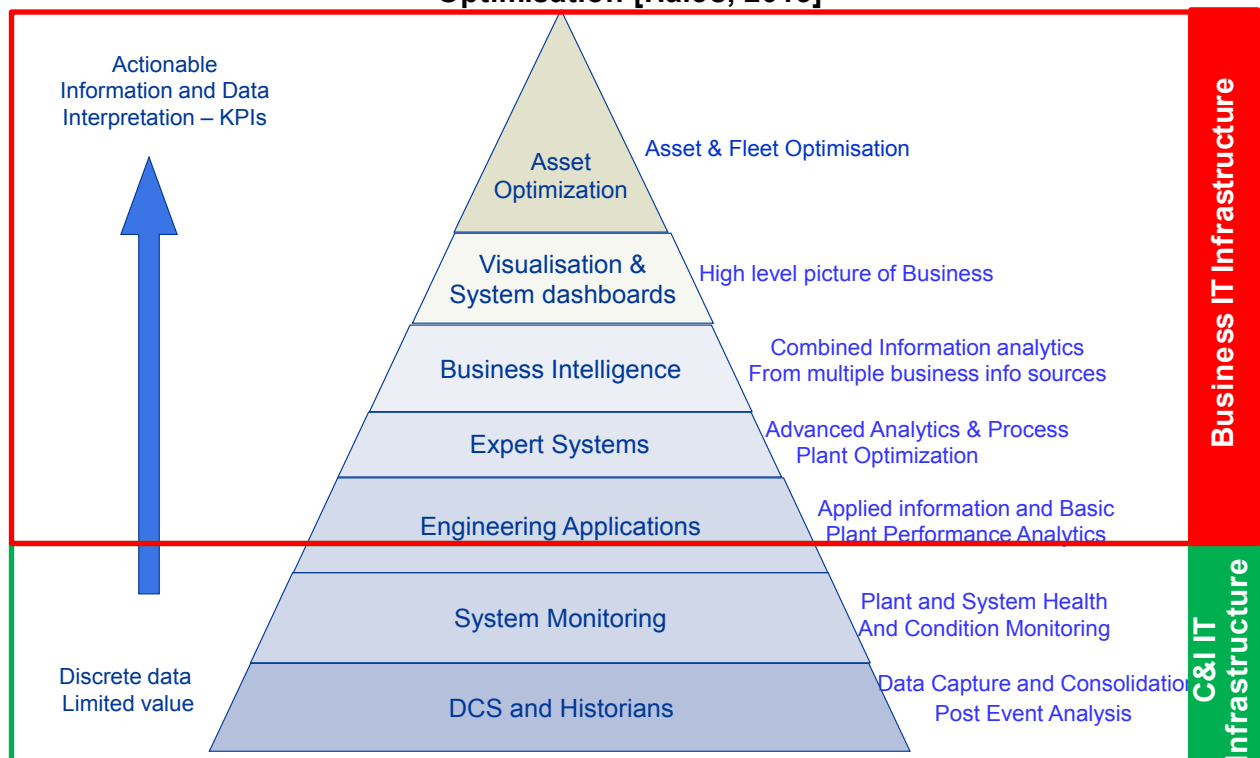
Integration of business and plant process is more complicated in that business and plant control information systems are generally managed in separate IT/IM infrastructures with a difference in focus on the elements and content that makes up such an infrastructure.

ABB confirms the typical challenges with information integration between IT–OT infrastructures in their research study [ABB, 2016]. Despite the challenges, 80% of the ABB research study respondents indicated that there is significant value in integrating IT–OT information for better decision making, asset planning and asset management of the plant lifecycle.

Respondents in this research study further indicated a 55% increase in the importance business placed on better asset management practices over the past year, while 65% of respondents indicated that it is also crucial for longer term capital planning in the asset management space. ABB predicts that this planning will also move beyond the conventional new project/capital investment planning portfolio into maintenance management as well [ABB, 2016].

Figure 1–4 depicts how advanced analytics technology building blocks are distributed over the Business and C&I IT Infrastructure. This adds to the complexity of managing the overall process plant Design Base, and specifically the operating technical specifications portion of the Design Base where reverse engineering process analytics are often required to verify intended Design Base against actual plant control and process settings.

Figure 1–4: Advanced Plant Analytics Building Blocks for Asset Management Optimisation [Hales, 2013]



The challenge is therefore to create information integration, data visualisation, and information delivery infrastructure that seamlessly integrates all the required building blocks across the two IT Infrastructures (as shown in Figure 1–4) – converting discrete data into actionable information and business knowledge.

A further challenge is the implementation of such an integrated solution without introducing unnecessary information security risks to plant process control and business operations.

Another challenge is the availability of the critical baseline data required for predictive analytics – it demands a solid, well-defined and documented plant Design Base and data of the highest quality and integrity to be of value.

Most of the existing Power Utility generation plants were built prior to the information technology era, with the result that the bulk of plant technical Design Base information is in paper format with a high risk of poor change management of this documentation over the lifecycle of plant operations to date.

And where this information is available electronically, it is usually captured in systems on the Business IT infrastructure. To be of optimal value, this data must be correctly and aptly integrated with plant process control data and seamlessly made available to the Control and Instrumentation (C&I) infrastructure and systems to use as the V&V baseline for plant process control settings.

1.1.5 Impact of Inadequate Design Base Management and Change Control

There are currently many concerns in the Power Utility regarding plant and technical information that can be seen as Accurate, Reliable, and Relevant (according to CARAT Principles). Business realisation of the impact that access to Engineering information has on the organisation, its decision-making processes, and business efficiency has also become very evident.

Inadequate Design Base management and change control also significantly impacts plant process improvement initiatives. Changes to process settings to improve process efficiency and reliability also comes at much greater risk if the change impact cannot be properly defined against the intended plant Design Base or changes to plant control settings were not properly documented.

KPMG conducted a survey of large project owners, and reported that inadequate engineering Design Base management (Design Base scope creep/poorly defined engineering scope) and poor Design Base change control has a major impact on cost control and the ability to timely and efficiently complete projects. A summary of their survey results is shown in Figures 1–5 and 1–6 [Hogarth, 2009].

Figure 1–5: KPMG Survey – Causes for Cost Overruns on Mega–Projects [Hogarth, 2009]

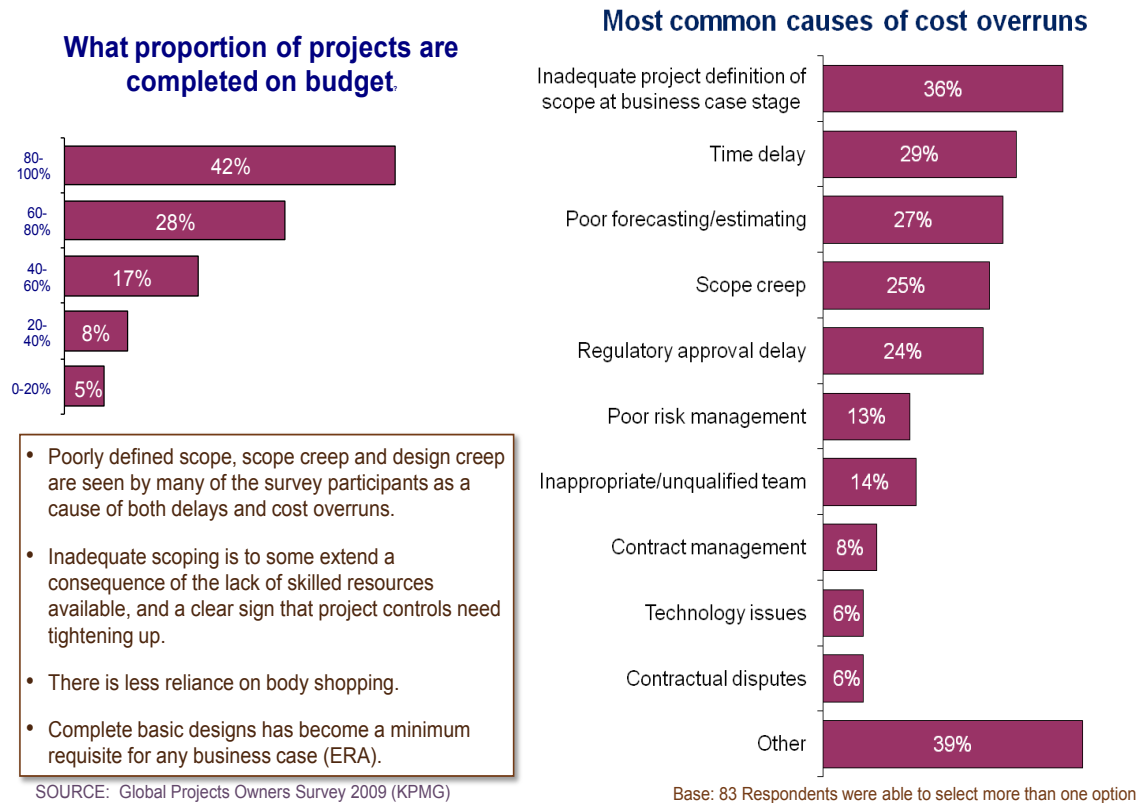
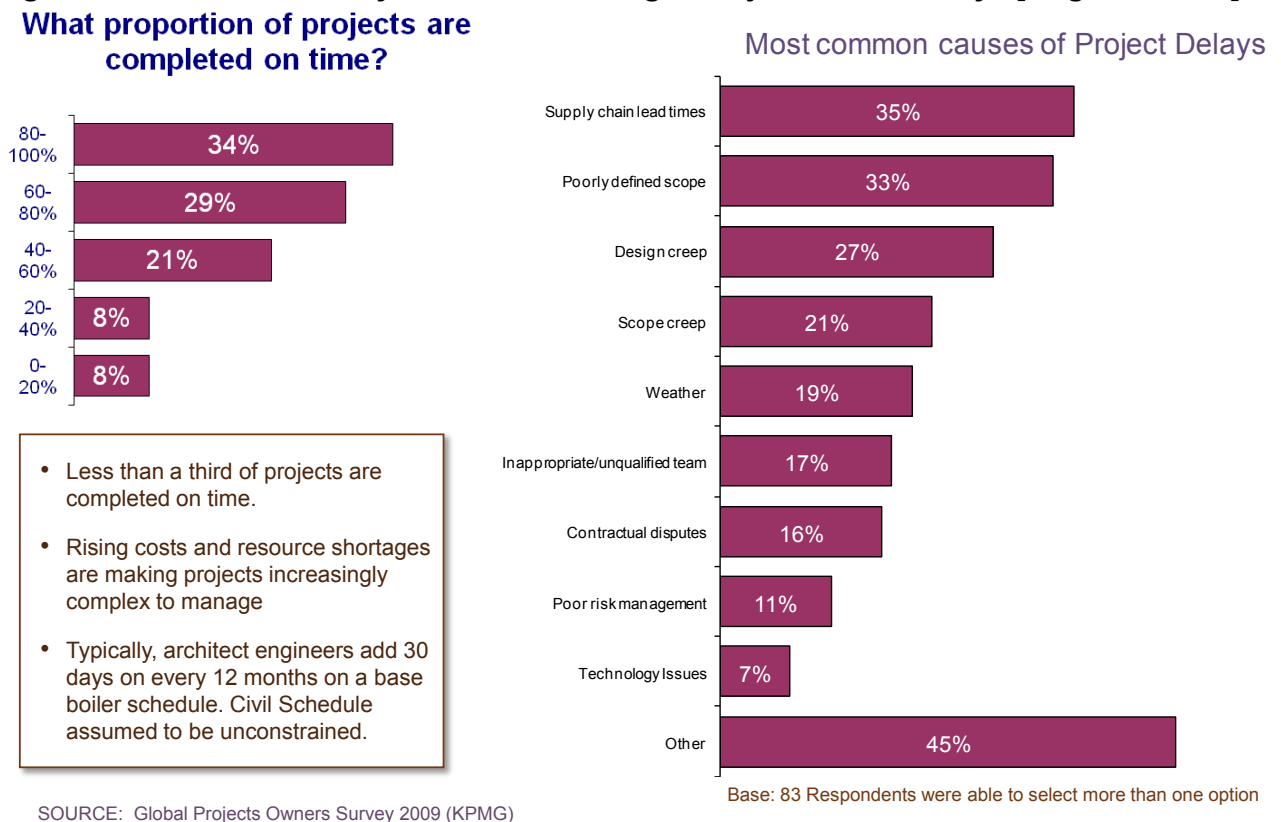


Figure 1–6: KPMG Survey – Causes for Mega–Projects Time Delays [Hogarth, 2009]



With the current electricity supply constraints, there is a concerted effort by the South African Power Utility to improve its operations through **two core output areas** – improvement in business productivity/product output; and cost management.

Underpinning this business improvement effort is an **increased focus on the use and better understanding of business–, plant and engineering/technical plant information/data and leveraging this to make better, more integrated and informed decisions on the plant.**

There will be little value to use Design Base information for decision making if it does not conform to CARAT principles. It thus becomes mission critical to ensure a plant Design Base that is of the highest quality data content, properly verified and validated and exposed to business/engineering users in the most efficient and productive manner. This entails the provision of an information delivery capability that seamlessly integrates required information from disparate business and process plant infrastructures in an “on demand” fashion.

1.2 Research Hypothesis

The following hypotheses apply to the research study:

Hypothesis 1: A sequential approach to developing the business improvement model and implementation approach will yield the most efficient framework.

Hypothesis 2: The methodology and approach taken to implement an integrated plant information management system will have a direct impact on Design Base management, system implementation, and engineering efficiency.

Hypothesis 3: A minimum plant Design Base content is required to enable advanced analytics. This Design Base needs to be managed in a well–designed system and engineering process environment.

Hypothesis 4: The age of the process plant where the IPI–BIM is implemented may necessitate the need to perform reverse engineering to establish core Design Base content.

Hypothesis 5: A good and efficient information delivery capability needs to be enabled to make information available in the most efficient, productive and clear manner to support decision making.

Hypothesis 6: A combination of analytical methods would be required to provide a holistic plant improvement framework.

Hypothesis 7: The IPI–BIM implementation methodology will yield a measurable value proposition.

Hypothesis 8: If the individual elements of the IPI–BIM can be proven successfully, it will be possible to successfully implement the Framework as a whole.

Hypothesis 9: The IPI–BIM framework will provide a significant enough value proposition to be a viable implementation, either in portions or as a holistic framework.

Hypothesis 10: The IPI–BIM model developed in this thesis can be implemented successfully in a Power Utility environment, and is generic enough to be applicable to most process plants.

1.3 Research Aims, Objectives, Approach and Deliverables

1.3.1 Research Aims

Key aims of the research are to:

- Develop an IPI–BIM that fulfils the need for a Business Improvement Model (BIM) that focuses on the plant data of the Process Plant/Utility, and which can be used to assist the process plant in evaluating its operational efficiency in the context of the World Energy council future sustainability measures [Jain, 2007; World Energy Council, 2010].
- Determine the most cost effective and efficient methodologies, processes and implementation strategies to implement the IPI–BIM. The **operational research target area is power utility process plants**, but the relevance of research outcome and the IPI–BIM Framework to other process plant industries will be evaluated and considered.
- Given that the bulk of business improvement models and methods focus on business processes, determine what engineering processes need to be enabled to support the traditional business process improvement capability in the engineering domain. In doing so, enhance the holistic approach and workability of the IPI–BIM Framework as it will then also consider efficiency and completeness of engineering business processes to support management of the plant Design Base.
- Identify and define the “**critical** Design Base” content of a process plant that will support improved business and analytic decision making. Propose an approach to building the core plant Design Base into an integrated plant information system (IPIS) platform (hub) at the least cost (considering current financial and organisational constraints).
- Draw a comparison between brownfields available Design Base content and that of a new plant asset under construction, and determine whether the required Design Base content can be successfully sourced on plant that is more than 40 years old (and what

additional reverse engineering may be required to re-establish Design Base content that may not be available).

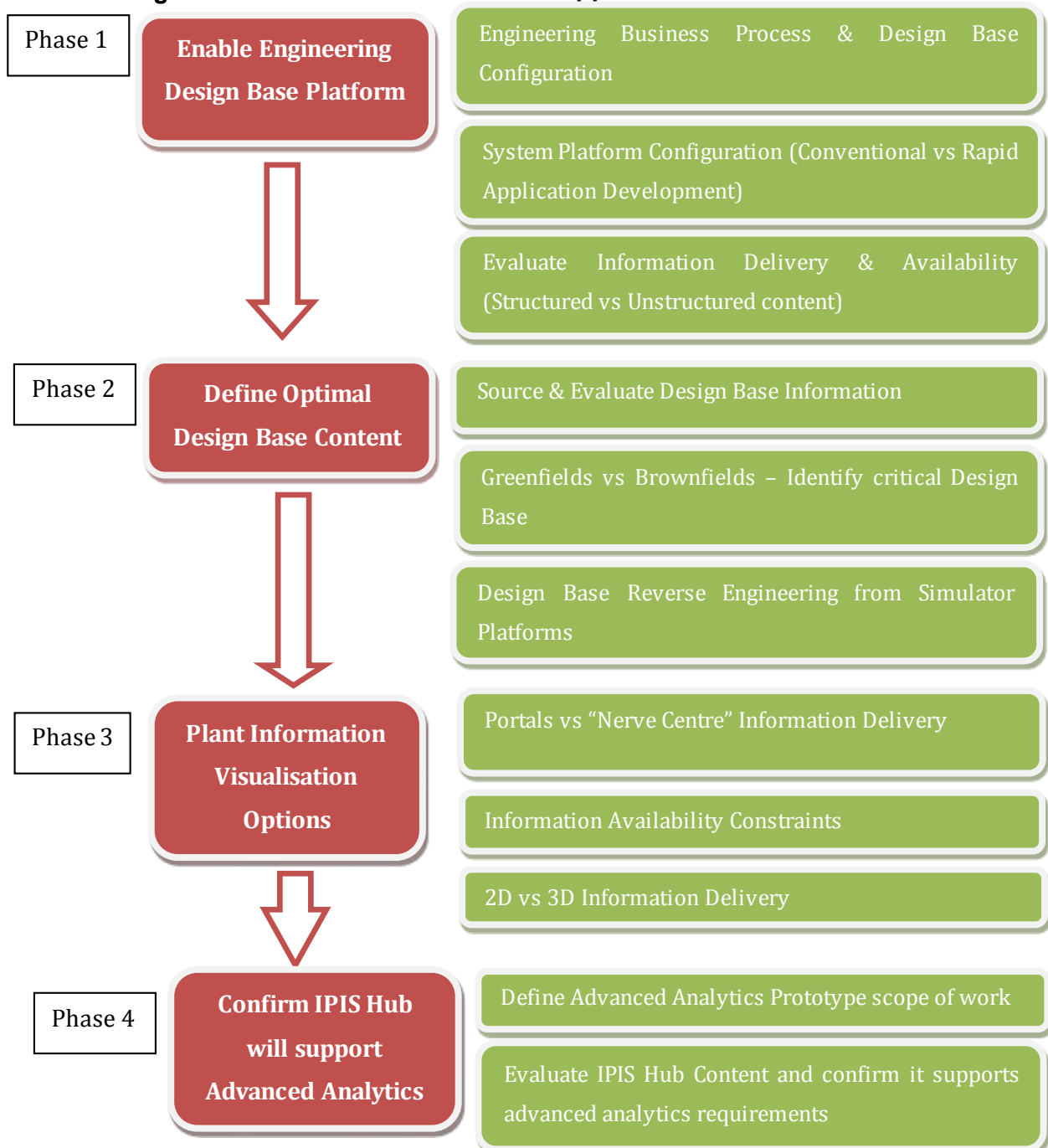
- Prove with prototyping that the core elements identified define the Plant Information System hub is extensive enough in nature to allow for efficient asset management and predictive diagnostics. Use prototypes to show that the proposed plant information model (IPIS Hub) and the analytical models developed, can be used to:
 - Measure efficiency of current operating practices against operating Design Base.
 - Demonstrate that improved early warning failure detection is possible using big data analytics and methodology to analyse plant operating and control data.
 - Measure efficiency of operations during upset and test conditions of the process plant.
- Evaluate information delivery options and technology in order to define the most cost efficient and effective/productive way to make the information available. Investigate the pros and cons of a “nerve center” approach vs. an information portal approach for the dissemination of information. Evaluate whether there are any constraints from a technology point of view that will impede implementation of the proposed information delivery capability of the IPI-BIM.
- Evaluate readiness of the proposed IPI-BIM framework and approach to be used operationally. Prototype and test the framework, approaches and operational research done to date under this research project scope of work (covering the period 2007–2016) to determine whether it is sufficient to lay the plant information foundation framework for enhanced predictive plant condition analysis and simulation (and future artificial intelligence algorithms and simulations).
- Define the value proposition of the IPI-BIM Framework (with quantifiable results). Evaluate whether there is a sufficiently good value proposition to implement the research outcomes more extensively into a process plant industry or organisation. Show that it effectively supports typical key business operational activities like:
 - Operator Plant Training
 - Operator Inspections
 - Hazardous Location Training
 - Safety Training
 - Maintenance Job Safety Analysis (Improved pre-work safety briefings)
 - Outages – Determining and scoping scaffolding requirements
 - Emergency Preparation training
 - Emergency Scenario Planning
 - Improved incident analysis capability

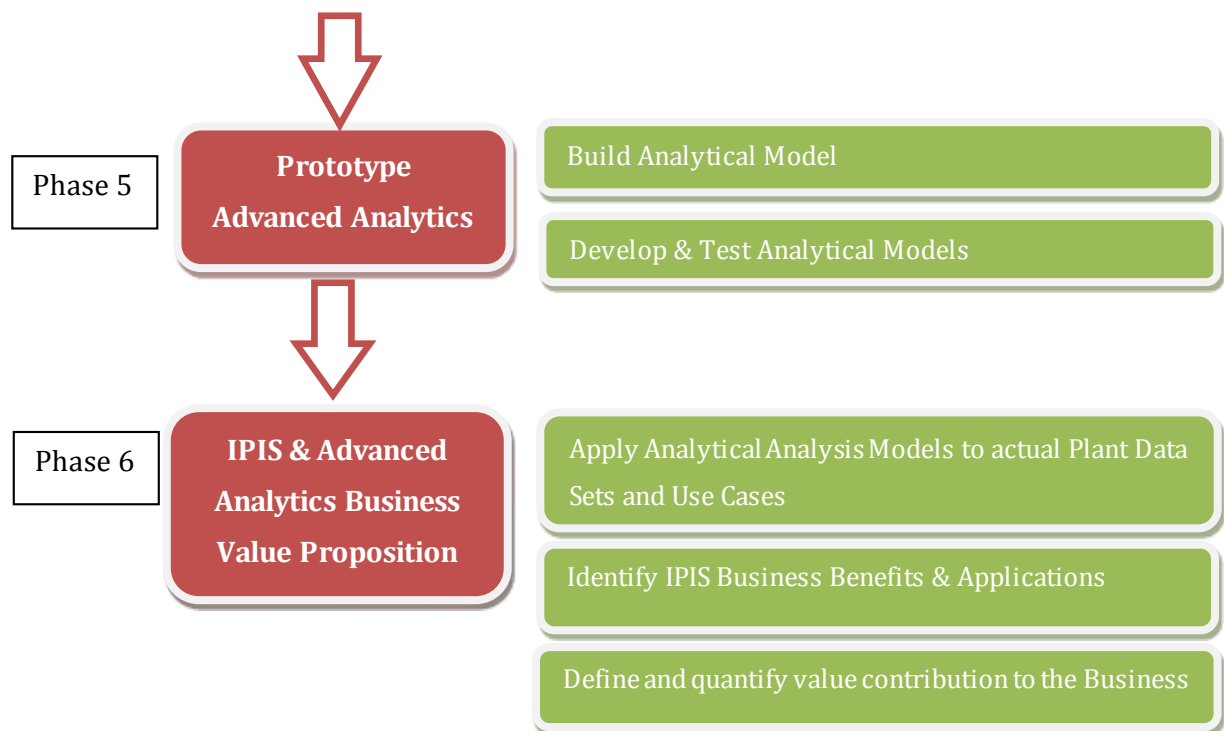
- Commissioning Activities on Plant
- Constructability analysis
- Maintainability/Operability analysis

1.3.2 Research Approach

Due to the scope and complexity of the IPI-BIM Framework, a phased, sequential and structured approach will be taken in the research study to develop and prove the IPI-BIM Framework (Figure 1–7), its core elements and the implementation approaches required to establish each element of the proposed Framework successfully.

Figure 1–7: Structured Research Approach to Build the IPI-BIM



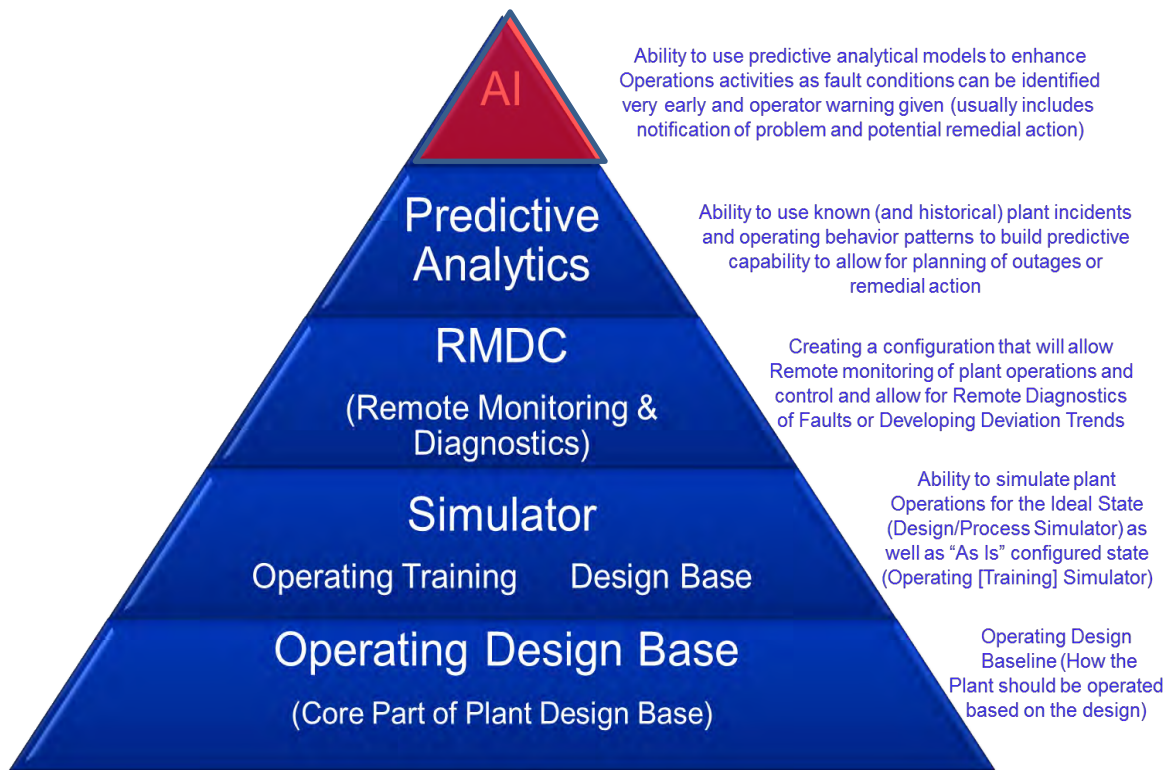


1.3.3 Research Objectives

The research aims to achieve the following objectives:

- Create and define a Business Improvement Model (BIM) Framework and prove it with operational prototyping and testing. Prove that a structured approach to creating and establishing the elements of the framework is a cost effective and viable approach to enable advanced data analysis and algorithm development in a complex process plant (and that it can support efforts to improve operating efficiency).
- Provide a set of business improvement model **implementation approaches** that is well-defined, repeatable and enables the fastest, most cost-efficient method of implementing the IPI-BIM Framework.
- Define the scope, effort, establishment methodology and extent of Design Base information required for a brownfields plant in order to deploy and use more advanced predictive plant information analysis capability to enhance and improve business efficiency.
- Investigate and confirm that the **core** operational and technical/Design Base data sets and plant control information proposed is sufficient to support advanced analytics and business improvement initiatives. Delivery of the research output will include evaluation of the advanced analytics capabilities shown in Fig. 1–8, **excluding the AI capability (highlighted in red)**.

Figure 1–8: Phased Advanced Analytics Capability Creation Stack proposed [Swanepoel, 2014b]



- Define the most appropriate information delivery mechanisms to make critical business information available in the Integrated Plant Information system (IPI) platform.
- Define the Analytics Techniques required to develop and implement the IPI–BIM Framework and confirmed this with prototype test cases.
- Confirm that the proposed integration and data interaction capability in advanced analytics prototypes are sufficient to support predictive analysis of plant behaviour in order to increase the reliability of the plant.
- Practically demonstrate (through operational research) how improved and increased usage of plant information management technology results in and supports business improvement initiatives.
- Define and quantify the value proposition of implementing the IPI–BIM Framework by means of actual use cases, cost saving benefit and plant history.

1.3.4 Research Deliverables

The final deliverable of this thesis is a fully defined IPI–BIM Framework and implementation approach, capable of being implemented not only in the Power Utility environment but potentially any process plant/industry. This Framework will be supplemented by a Value Proposition Model that can be used to justify implementation and return–on–investment of the IPI–BIM Framework.

1.4 Delimitations of the Study

The following aspects of business operations were excluded from scope of the research study:

- The organisational culture, management style or approaches to plant management.
- The impact of different maintenance strategies on plant asset life. The study covered aspects of the Maintenance Design Base – thus only aspects of identifying the maintenance strategy and associated maintenance scope of work to maintain the plant assets within the boundaries of the Design Base.
- Socio–economic factors that will affect changes in business models.
- Human performance aspects that affect operating efficiency.
- Non–technical business processes.
- Development of Artificial Intelligence (AI) algorithms – this was deemed a research field of study in its own right.
- Plant control system upgrade initiatives – definition of any user requirements or enhancements needed to the future upgrade of the plant control system. Although the Design Base back–fit work undertaken at the Brownfields Power plant (as part of this research study) was seen as a contributing input to future control system design and requirements, it was not deemed part of the scope.
- Full fault analytics, scenario or simulation models for the entire plant. Conceptual Proof of Concept studies will be conducted but the full set of fault analytics to be developed will not form part of this research. (It is foreseen that it will most likely form the basis of future research studies).
- New system configurations or alternative information systems to what is installed at the Power Utility. Given the current organisational financial constraints, the research brief was to utilise existing resources, software, and infrastructure. Research into alternative systems and capabilities was therefore not part of the research scope, and if reference is made to other configurations or systems at all in this research study, it was done to provide clarity on different industry views on the topic in question.
- Testing the IPI-BIM Framework and its implementation approaches in other process plant industries.

1.5 Assumptions

- The required plant historical and cost analytical data will be available to support the research study.
- The required timeline and infrastructure will be provided to do the required prototyping and hypothesis/functionality testing.
- Existing Power Utility IT/IM Infrastructure options will be sufficient to do the intended prototyping and proof of concept work required by the research study.

1.6 Importance of the Study

Most business productivity improvement initiatives currently underway in the Power Utility requires access to better and more effective information analytics in all business areas as a critical element to support and drive improved business operations.

As such there is an increased focus on the use and better understanding of business—, plant and engineering/technical plant information/data and leveraging this data to make better, more integrated and informed decisions on the plant. The outcome of this research study is therefore in direct support of such business improvement initiatives as captured in the Power Utility's SmartUtility Strategy [Hales, 2013].

Implementing a successful Smart Strategy calls for an in-depth understanding and characterisation of what makes up an Integrated Plant and Business Information Hub for a power utility and finding the most appropriate methodologies and approaches to implement this.

The research provides an operational framework and the required phased implementation approaches that can be considered as an implementation methodology for the proposed SmartUtility Strategy [Hales, 2013].

The research study (and this research paper) contributes to the Engineering Management body of knowledge by introducing a new and alternative integrated Business Improvement Model (BIM) that has at its heart an integrated plant information (IPI) framework based on the plant Design Base.

The ***Integrated Plant Information Business Improvement Model*** (IPI-BIM)[®] developed by the research study was proven to be a viable and operationally ready business improvement model Framework by means of operational research, prototyping and hypothesis testing over a number of years.

1.6.1 Importance to Industrial/Process Plants

Although the prototyping and proof of concept operational research were executed in a Power Utility environment, the proposed IPI–BIM Framework and implementation approaches should be generic enough in nature to be applicable to any process plant environment.

The IPI–BIM Framework provides a systematic and integrated approach to configuring and building an Integrated Plant Information (IPI) infrastructure and architecture using the System V–model approach (Fig. 1–9) and using it to drive more informed decision making and improving business operations.

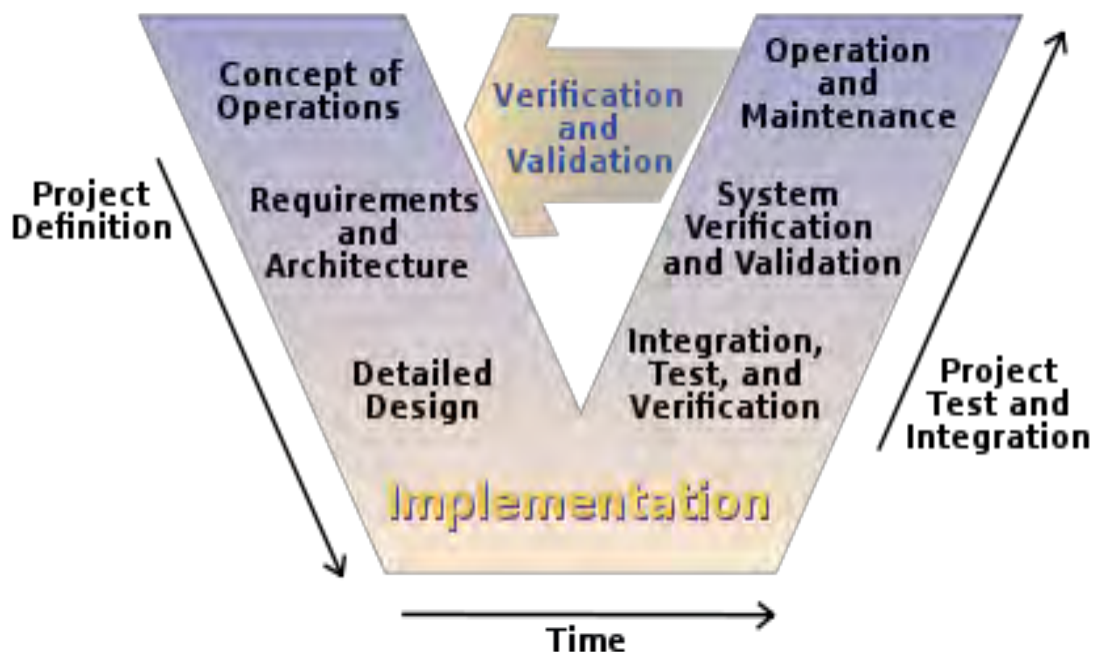
1.6.2 Academic Importance

The research adds to the Engineering Management academic environment by introducing an alternative business improvement model and approach to the conventional Business Improvement Models currently on offer.

1.7 Explanation for using the V–Systems approach for the Research Study

The research study primarily used the V–Model (Figure 1–9) of Systems Engineering to evaluate the IPI–BIM Framework and implementation approaches proposed [Federal Highway Administration, 2005]. The reason for taking this approach is that it provided a means of proving each element of the IPI–BIM Framework in its own right.

Figure 1–9: Systems Engineering V–Model [Federal Highway Administration, 2005]



Chapters 3 to 7 of this research thesis detail how the IPI–BIM Framework elements were built up in a sequential and structured way to create an integrated business improvement framework using integrated plant information and data analytics.

Researching and proving each element of the IPI–BIM model thus covered the following:

- A Conceptual model/hypothesis for the various IPI–BIM elements/approaches was defined.
- The required IT/IM architecture and system configuration requirements were defined (if needed).
- A Proof of Concept Design of the IPI–BIM Framework element was undertaken (or a more detailed design if this was required to prove/disprove hypothesis).
- Validation and Verification was undertaken where required (to confirm integration, configuration, and operability of the IPI–BIM Element/hypothesis posed).
- Where possible, the developed Framework element would be conceptually implemented and proven in an operational environment (on either the Greenfields Project or Brownfields Plant that formed part of the research study).
- Optimise/rationalise the IPI–BIM element as/where needed, or as a minimum indicate areas for improvement (as potential future research).

By successfully proving each individual element of the IPI–BIM Framework, **the overall IPI–BIM Framework verification strategy was the successful implementation of all the proven elements on the research study Power Utility plants to measure and confirm its completeness in delivering a compelling business value proposition.**

Validation of the IPI–BIM Framework and implementation approach was a comparative study between the research study power stations (where the IPI–BIM was implemented) and other power stations of similar size, construction and process complexity (where it was not implemented and other implementation approaches used).

The comparative study was also used to document actual benefits realised by the use of the new IPI–BIM Framework. This would support the Value Model proposed by the research study and also assist in quantifying the value proposition for process/power plants who would consider using the IPI–BIM Framework as a business improvement implementation methodology.

1.8 Structure of the Thesis

As indicated, the IPI–BIM model was developed in a phased and structured approach. To guide the reader, the IPI–BIM model element under discussion will be highlighted and non–relevant items greyed out on the visual IPI–BIM model as shown below:



To prove the IPI–BIM Framework, the study will set out to define the **critical set of requirements for a Plant Information System platform** that can enable advanced data analytics on what will be considered a "big data analytics" application scenario. It evaluated different methodologies for integrated plant information system implementation. **This is covered in Chapter 3.**



Chapter 3 will also cover **identification of the engineering business processes required to manage the plant Design Base efficiently**, as well as ensuring that the required Design Base classification structure is implemented to support Design Base management.



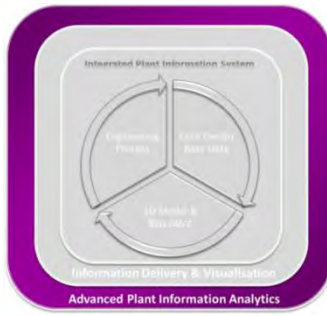
The research will then define the Design Base requirements in **Chapter 4, specifically focusing on the core elements of the Design Base needed for advanced analytics** research (which will be covered in Chapter 6). The core Design Base elements will be evaluated in a Brownfields plant scenario, and if needs be, reverse engineering work will be conducted to establish any additional Design Base content required for advanced analytics.



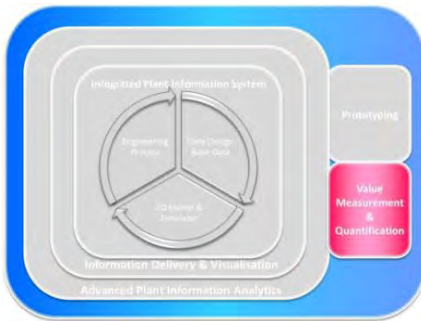
Chapter 4 also covers **evaluating the use of simulator technology in the process of reverse engineering missing Design Base content**. It discusses the impact of Design Base quality on the Design Base integration efforts; and the use of this information for advanced analytics.



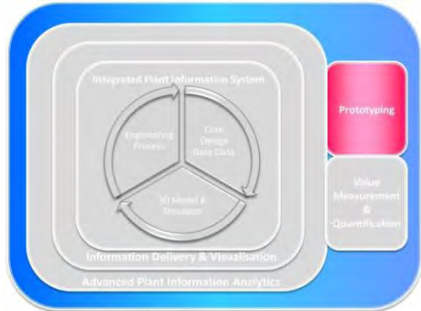
Chapter 5 covers the **evaluation of available information delivery options** and proposes an optimal arrangement that will support the overall IPI–BIM framework. It evaluated potential technology constraints for visualisation of Design Base information on Brownfields plants.



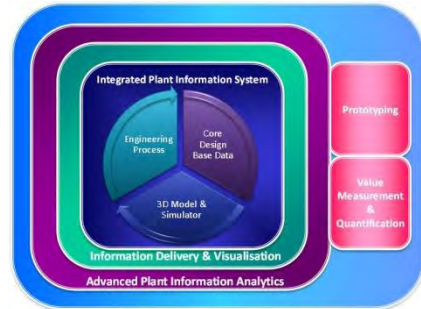
Chapter 6 evaluates the outcomes of advanced analytics prototyping using the deliverables of the IPI-BIM Framework Design Base definition (covered in Chapter 4). It aims to support the research objective of proving that the defined **core Design Base** is sufficient in scope to enabling advanced analytics of problematic plant health issues in order to improve plant reliability and business operations.



Chapter 7 will set out defining the high-level value proposition for implementing the IPI-BIM Framework by measuring it against typical business drivers and focus areas.



Where appropriate or required, research **prototyping** and case studies will be conducted to support theories and hypothesis. Such undertakings will be indicated with this colour key image in the body of the research study.



Chapter 8 will cover the results of the operationalisation work done in implementing the FULL IPI-BIM Framework proposed. Full implementation scope was executed on the research study Greenfields Project and Brownfields Power Station plants.

These colour code keys will be used throughout the remainder of this research study to guide the reader and provide an indication what element of the IPI-BIM is under discussion within the chapters that follow this introduction.

1.9 Summary

This research study has evaluated existing business improvement models and found that most of them are focused on **business process** improvement initiatives and methodologies. The measures of determining such improvement efficiencies were also found to be very subjective in nature without extensive reference or use of data and information analytics to prove the claimed value proposition (“improvement gains”).

Many companies embrace at least one of the most common business improvement models. These business improvement models are usually supported by further “implementation approaches” to execute the model, but the focus of these approaches remains on *business processes and workflows*. Data and information analytics are at best seen as measures to determine “efficiency” of the business improvement model and are not incorporated as a core or integral part of the actual business improvement model.

This research study adds to the body of knowledge in engineering management, specifically the realm of business improvement models. It introduces a new and practical business improvement model and approach that is measurable in real business (and monetary) value.

Although each element of the proposed business improvement model in this research study was proven individually, all the elements of the IPI–BIM Framework were implemented on the Brownfields Plant and Greenfields Project used in the research study to confirm that the proposed business improvement model can be practically executed and that a holistic approach will yield the most business benefit. The outcome of this is covered in Chapter 8.

The study demonstrated how Descriptive, Predictive, and Prescriptive analytics methods were very effectively used throughout the IPI–BIM development to achieve the final result. The study further demonstrated how a business improvement model using plant data as its baseline to support smarter ways of work is a very efficient catalyst to bring about:

- Improved plant reliability and availability.
- Real–time effective decision making based on trustworthy plant and business information.
- Timely and informed decision making off a common information platform.
- Knowledge Management (KM), improved training and Best Practice information sharing.
- Critical and Scarce Skills leverage.
- Enhanced Operational and Technical Support.
- Improved Asset Management planning and management.
- Pro–active fault prediction/identification and incident prevention.

Although the prototyping and proof of concept were done in a Power Utility environment, the proposed IPI-BIM and implementation approaches are generic enough in nature to be applicable to most process plant environments with minor adjustments to the core Design Base content and implementation approaches recommended.

The relevance and importance of this study, therefore, lies in the fact that it proposes an operational, working Business Improvement Model (and associated implementation methodology approaches) that can be used to improve business operations using plant information management systems and data analytics.

This chapter covers the literature surveys conducted in the course of the research study and is focused on the core elements of the IPI–BIM Framework. The most pertinent issues around each element were researched and discussed.

2.1 Business Environment Changes challenging existing Business Models

This portion of the literature survey evaluated significant impacts and changes to the global business and power utility environment and how it is challenging existing business models.

2.1.1 Global Business Sustainability

The World Energy Council in their 2011 studies [Jain, 2007; World Energy Council, 2010] defines the core “3 A’s” of future sustainability:

- Accessibility to Energy/Electricity
- Availability of Electricity/Energy
- Acceptability of Energy Options offered

This requires of the utility to evaluate its operations in the context of these sustainability measures – using the core business driver areas of Cost, Efficiency and Safety (Table 2–1).

Table 2–1: World Energy Council 3A’s vs Key Business Drivers [Jain, 2007]

Criteria	Accessibility	Availability	Acceptability
Safety			X
Regulation	X	X	X
Climate Change			X
Air Pollution			X
Energy Security		X	
Energy Quality		X	
Reliability		X	
Infrastructure	X	X	X
Technology	X	X	X
Affordability	X	X	X
Conservation	X	X	X
Public Attitude		X	X

SOURCE: World Energy Council : *Deciding the Future - Energy Policy Scenarios to 2050*

In addition to these sustainability pressures, global power utilities also face additional constraints as well as changes in their operating models and business environment – creating increased complexity in managing ageing plant at optimal production and cost levels (Table 2–2 below).

This table indicates the typical pressures energy and electricity utilities are facing since 2008. Notable should be the commonality in industry of the key issues identified by the World Energy Council and how this plays out in practical and real cost terms for the power utility industry.

Table 2–2: Business and Operational Challenges for Power Utilities (2008/9) [Swanepoel, 2011a]

Primary Energy Resources Scarcity & Cost	• Global Demand (Highest Bidder) • Oil at > \$120/barrel • Water Cost increased by 20% p.a.	• Coal Cost increased by 50% in 2007/8 • Availability of Coal • Coal Transport Costs
Environmental Pressures	• Green Energy Demands • Water Scarcity • Lower Emission limits allowed	• Reducing Carbon Footprint • Building a sustainable energy mix • Increased Environmental Legislation
Economic Pressures, Recovery & Growth	• Cost of Capital for Expansion Projects • Timeframes to Build new Capacity • Adding 106,000+ customers/year	• Consumption Pattern changes • Changes in Consumer Profiles • Demands for competitive markets
Legal Compliance, Good Governance and Increased Focus on Safety of Plant	• Increased Health & Safety Requirements • Increased governance reporting • Financial Acts	• Increased Business Operations auditing • Stakeholder influence on power supply options
Increased Business Efficiency Demands	• Increase Productivity • Optimised Business Processes • Maintain/Improve technical performance	• Lower \$/MWh to generate electricity • Less funds to spend on projects (ROI/ROA) • Standardise, consolidate & Integrate
Improved Asset & Fleet Management	• Larger SoW, Less Plant Downtime • Old Technology deployed in “old” plant • Fleet Management approach to assets	• Major “Mid-Life” Refurbishments • Maintaining Long Term Plant Health • Limited operating margins (supply/demand)
Improved Leverage of Scarce Technical/Engineering Resources	• Engineering Staff Turnover > 20% p.a • Ageing Workforce • Engineering Skills Levels, Complex plant	• Knowledge & Experience of new Staff • Access to specialists & contractors on major plant refurbishments/technology changes

**Note: Although the price of crude oil has dropped significantly since 2008, the sourcing and supply of this commodity still come at high cost and impacts supply chain management infrastructure (supply of spares and materials to the power station facilities).*

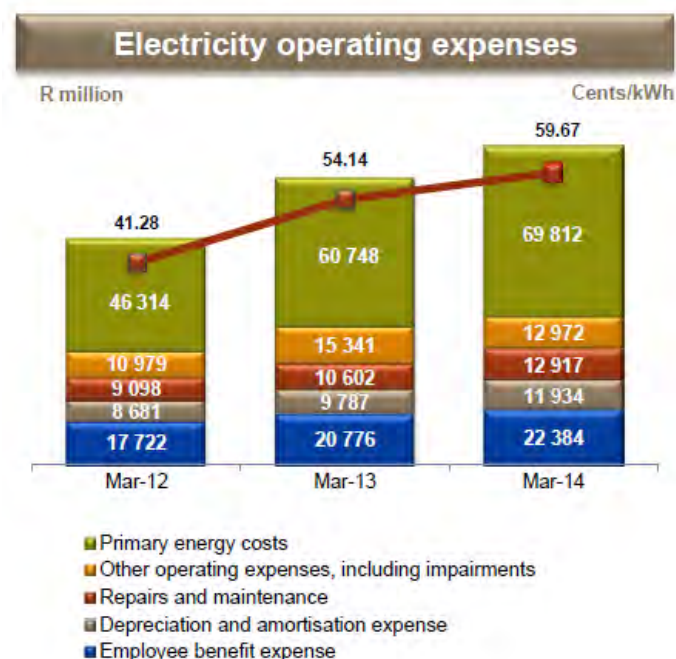
2.1.2 African and South African Business Pressures

When reviewing the World Energy Council analysis of African energy utility issues, the similarity with challenges faced by the South African Utility is clear: the cost of commodities, resource and funding availability and pricing structures are listed as critical uncertainties that require immediate/short term action [Frei, 2014].

It also underpins the reality that the South African Utility is not unique in the problems it is experiencing – these are global issues of concern to all energy utilities.

As a case in point, Figure 2–1 shows the significant increase in operating expenses the power utility has experienced over the past few years [Eskom, 2014]. The sharp increase in Primary Energy Costs (Coal, Fuel Oil, and Water) has a significant impact on the cost of producing electricity and the resultant impact on financial sustainability and viability.

Figure 2–1: Eskom Operating Expenses (Year on Year) [Eskom, 2014]



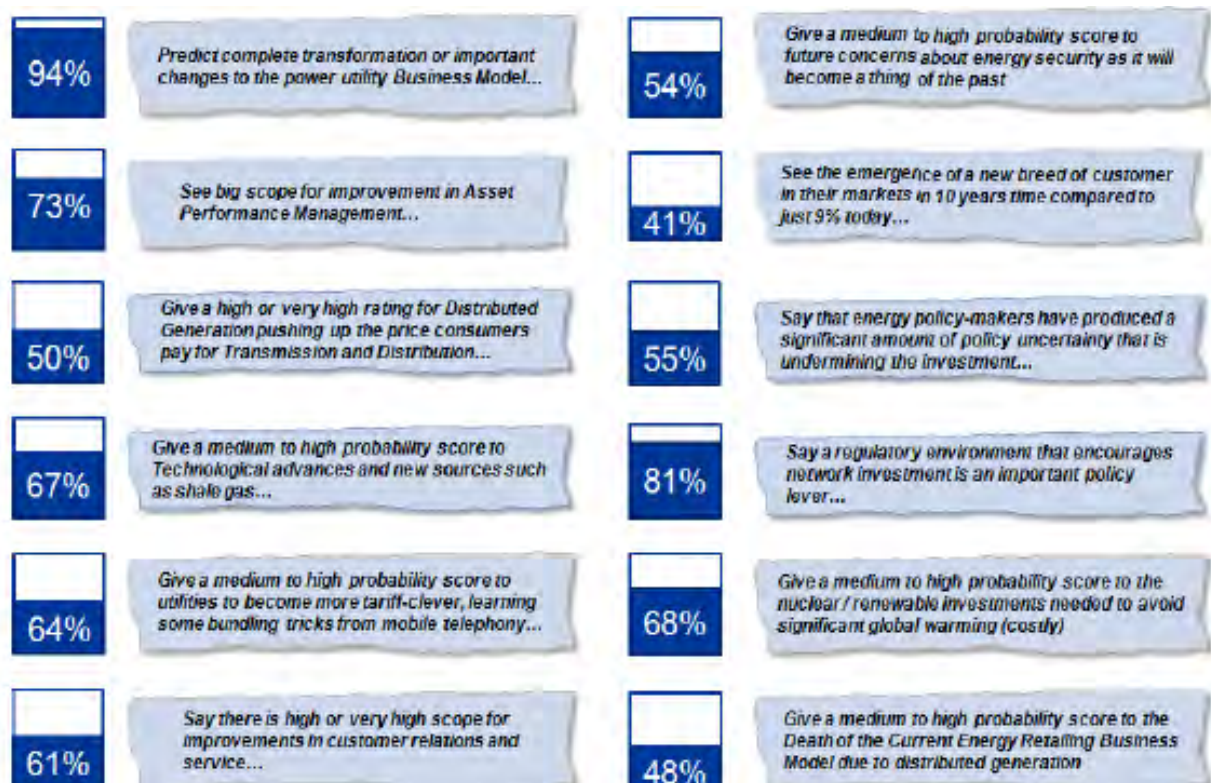
Internal research has also shown that the current business model adopted by the Power Utility is no longer sustainable. It is believed that operating challenges, rising operating costs and deteriorating plant availability are creating a perfect storm that demands radical changes into the way the business is operating and how it addresses the challenges [Jones, 2015].

This view is also shared by the Ernst & Young Energy Utility survey which points out that most energy utilities are now considering a review and most likely radical changes to business models to remain competitive in the changing environment [Ernst & Young, 2013].

Jones believes that there are significant changes happening in the South African energy market sector and energy utilisation practices/patterns, causing a shrinking future potential customer market. This impacts the utility's sustainability very directly and significantly, demanding a re-look at existing business models and future business strategies [Jones, 2015].

The South African environment, is however not unique, as is shown by the PWC Survey on Energy Sector business models (Figure 2–2), which covered 53 utilities in 35 countries [Price–Waterhouse–Coopers, 2013].

Figure 2–2: PWC Survey: Triggers that will initiate business model changes [Price–Waterhouse–Coopers, 2013]



This need for a change in business model and strategy is also echoed by the World Energy Council in their evaluation of the changing energy environment, their comment being ***“Power Generators will need a PACKAGE OF MEASURES to deal with this scenario – single measures will no longer have the desired effect.”*** [Wyman, 2010]

2.1.3 Advent of the Smart Grid and Smart Utility

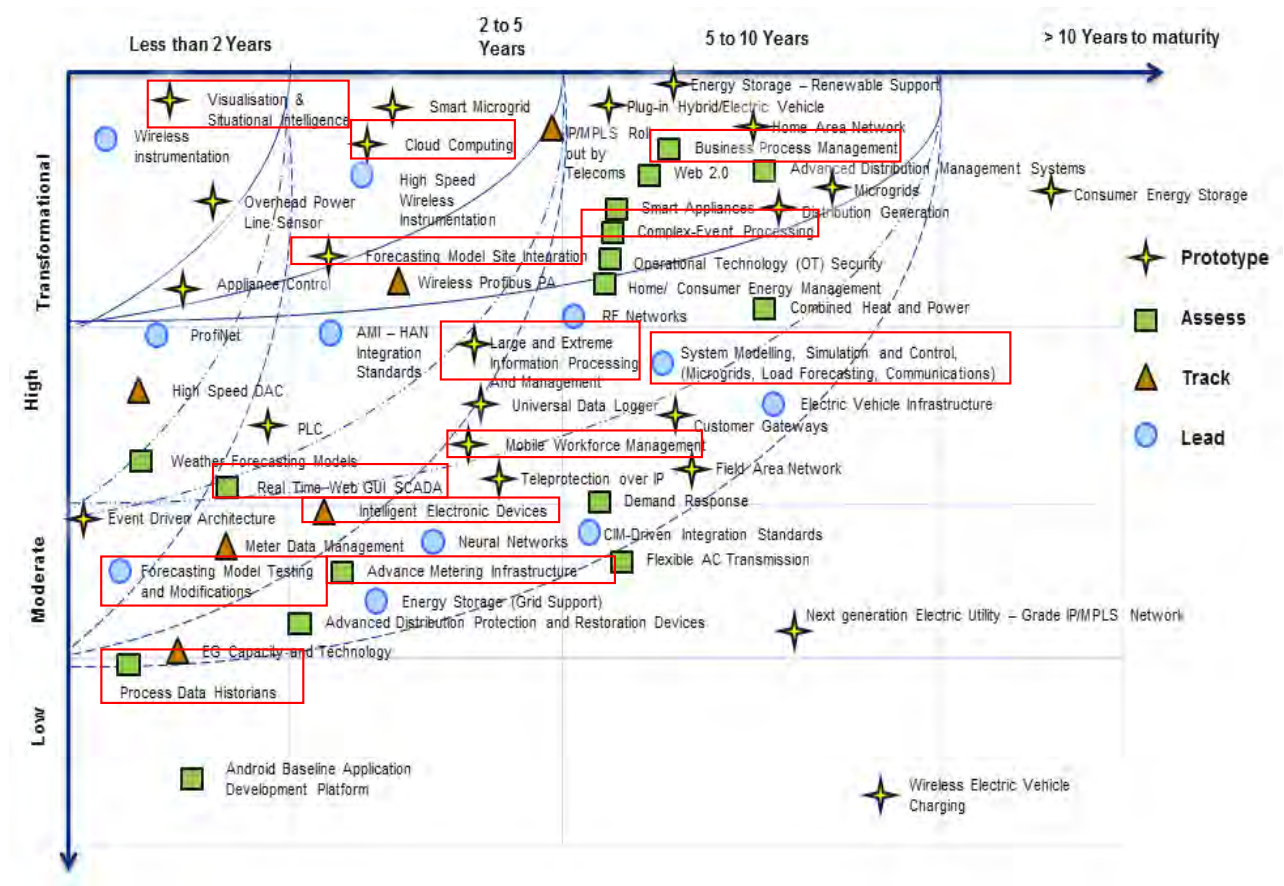
Advances in information technology have led to the rapid adoption of “smart meters” and “smart” information management infrastructure technology.

Research into this area indicates that the SmartGrid concept generally targets only the Distribution and sometimes Transmission aspects of power utilities. Very limited focus is placed on the generation aspects. Due to the interconnected nature of the power generation business and its operations, many utilities that operate in all three these areas now realise the importance of creating an “all-inclusive smart approach” to optimise their business operations.

It was for this reason that the Power Utility chose to rather develop a “Smart Utility” strategy to ensure that all lines of business are adequately covered and supported by a “smarter approach” to business operations.

As part of the Smart Strategy development for the utility, a detailed literature survey and technology scanning exercise was performed [Hales, 2013]. A summary of the technology scanning, maturity mapping and time impact on the power utility is depicted in Figure 2–3.

Figure 2–3: Smart Technology Maturity Map [Hales, 2013]



Items outlined in red in Figure 2–3 show that smart technology on plant data management, visualisation, cloud computing, analytics forecasting and big data management are maturing at a rate that warrants fast and targeted adoption in the utility.

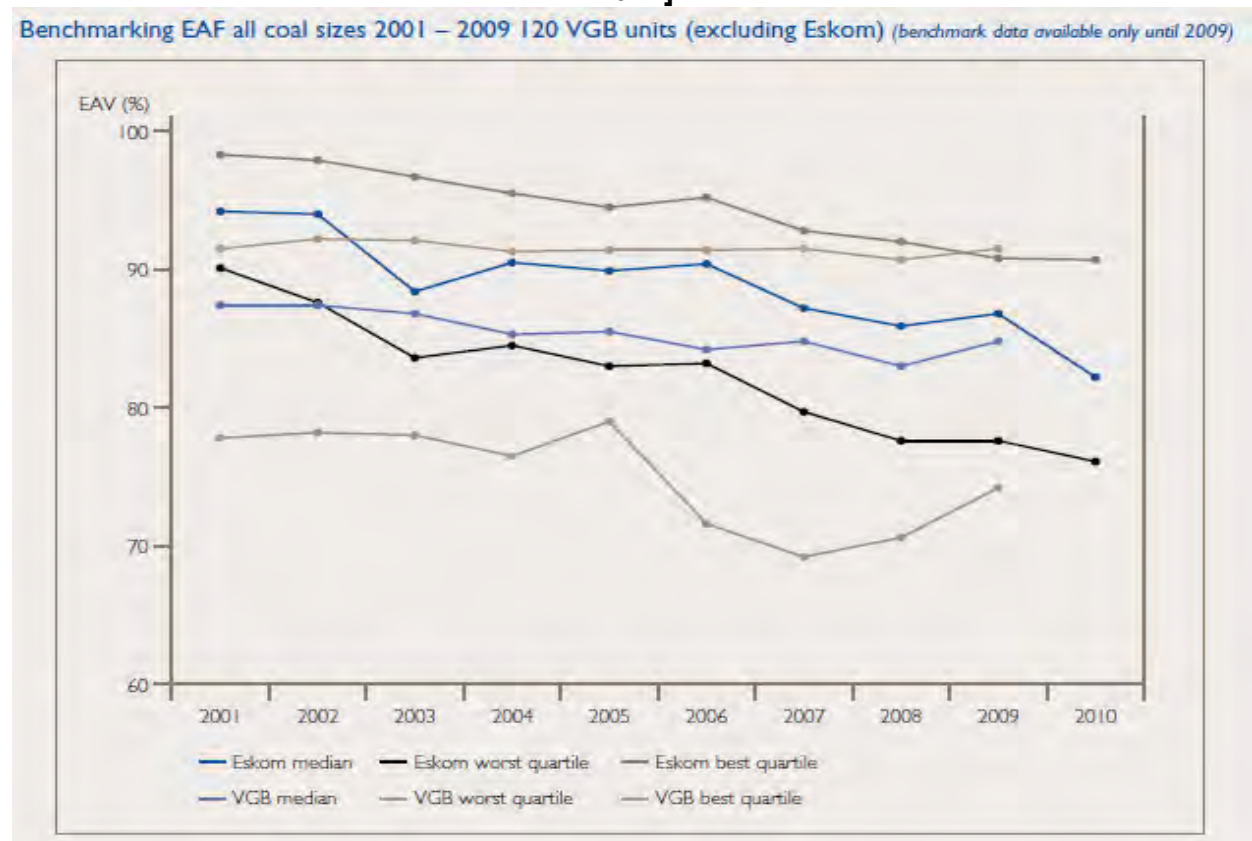
This technology scan confirms that a focus on visualisation and situational intelligence capability would be an appropriate strategy and that it can have a major impact on transforming business operations in the next 2 to 5 years. The technologies outlined in red above are also typical technology areas covered to varying degrees by this research study.

2.1.4 Ageing Plant and Performance Deterioration

Eskom is regularly benchmarked against other global electricity utilities to evaluate plant performance. A review of Eskom technical performance against other power producers in the world (Figure 2–4) shows the decline in technical performance compared to other utilities [Ngubane, 2014].

This figure indicates a key performance indicator used in Power generation, i.e. the Energy Availability Factor (EAF), comparing the Power Utility against other utilities. Of concern is the fact that **worst quartile** VGB performers have managed to **improve** EAF performance over the past few years, whilst that of the Power Utility continually declined.

Figure 2–4: Power Utility comparison to Global Utilities (EAF comparison) [Ngubane, 2014]



Best quartile performers also managed to **maintain** their EAF performance over the same comparative period despite the deteriorating economic conditions and challenges listed in Table 2–2 [Boston Consulting Group, 2014].

This continued decline is of particular concern to the Power Utility as it was always in the past seen as one of the top quartile performers.

Analysis of the reasons for the declining performance is provided in the Eskom Corporate Plan [Ngubane, 2014]. Performance is typically impacted by aspects like:

- Funding models for electricity tariffs.
- Financial sustainability and viability.
- Operations and maintenance strategies that support plant reliability and availability (and an understanding of factors and triggers that affect these plant performance indicators).
- Primary energy costs (well-defined and cost controlled supply contracts).
- New capacity funding models and asset creation models.
- Compliance to regulatory and environmental requirements.
- Government policy.
- Customer debt (Cost recovery in sales/revenue environment).
- Shortage of skilled technical/engineering staff.

Similar causes for performance issues are also echoed by the Power Utility 2013/4 Stakeholder Report [Eskom Holdings, 2014] and Eberhard in his research and subsequent presentation on the topic. [Eberhard, 2012] The VGB Research regarding the performance of utilities indicates that best quartile utility performers have the above impact factors under control [Emerson, 2003].

It should be noted that some international power utilities do have the benefit of more lenient government policies around environmental management. Issues like cost subsidisation, and very flexible electricity costing and funding models also have a significant impact on how effectively an energy/power utility can maintain and manage its asset base and performance levels.

The state and ageing of the plant in the Power Utility's Generation, Transmission and Distribution Business areas will also impact the ability to operate and maintain these assets as close as possible to the original Design Base.

Figure 2–5 shows the current age profile of the Power Utility Generation Fleet, with the red arrow indicating the year 2015. This graph depicts the age of current Power Utility Generating Plant assets, which makes up more than 95% of the existing asset base.

It shows how the Power Utility faces a significant decline in generating capability in the next 10–15 years due to ageing plant, starting from the year 2025 onwards.

Figure 2–5: Age Profile: Power Generation Capacity [Department of Minerals and Energy, 2010]

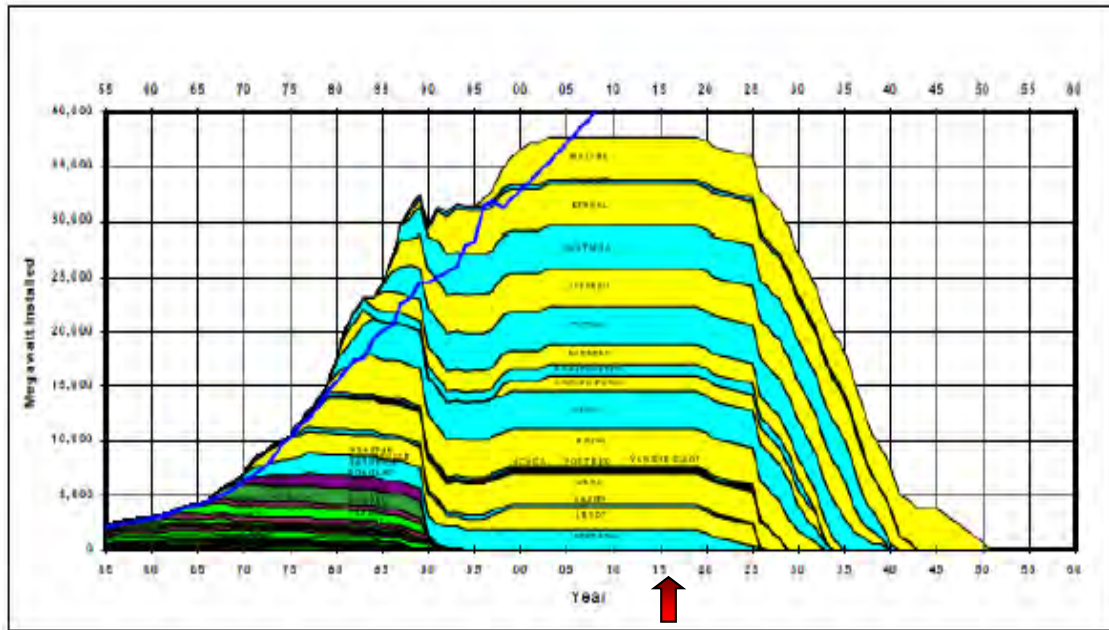
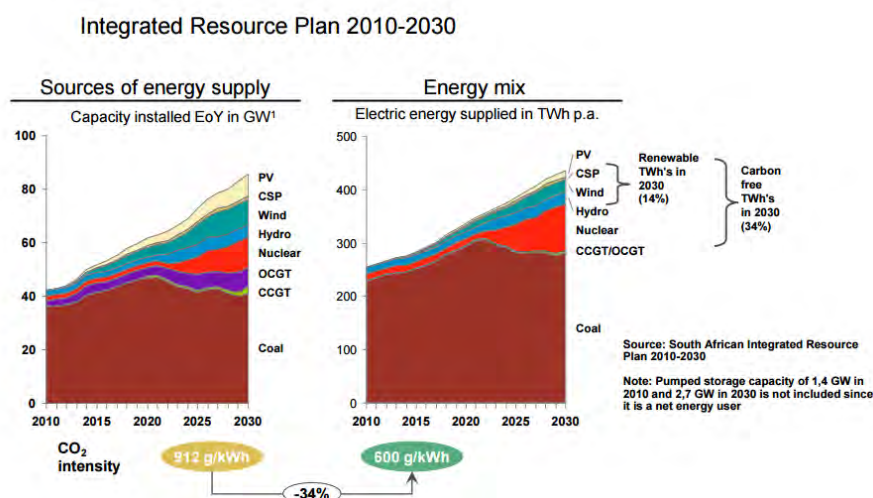


Figure 2–6 shows an extract from the South African Integrated Energy Resource Plan [Department of Minerals and Energy, 2003 and 2011] depicting how the sources of energy supply and energy mix (and thus business models in this space) need to change in the next 15–20 years [Eberhard, 2012]. This energy mix change demands the significant addition of renewable energy sources over this time period.

Figure 2–6: Integrated Resource Planning – Changes to Energy Mix and Supply [Department of Minerals and Energy, 2011]



Of particular concern is that the Energy Mix picture of 2030 clearly does not consider the loss of existing Power Utility Generating capacity as depicted in Figure 2–5. A review of current capacity additions to the electricity grid indicates that it will not be nearly enough to cover the shortfall in 15–20 years' time (Figure 2–5), let alone increase the available capacity as indicated/required by the SA Integrated Energy resource Plan (Figure 2–6).

This future scenario and situation make it even more crucial for the Power Utility to improve reliability and extend the useful operating life of existing plant generating assets. Similarly, prediction of plant performance risks and mitigating them fast enough and effectively is becoming a key business imperative.

Consideration of the age–profile of plant assets, remaining design life and the plant’s ability to continue operating close to the Design Base operating limits may significantly influence reliability simulation parameters and analytical predictions. An understanding of the Design Base and plant operating behaviour will be crucial in advanced analytics to ensure operations within the acceptable design life boundaries.

This portion of the literature survey confirms that there are significant challenges in the Power Utility and Global environment that necessitate a need to re-look existing business models and introduce radical business improvement initiatives that can ensure future sustainability.

The survey confirms that South Africa is not unique in the challenges it experiences and that globally power utility and energy market players need to seriously revisit their business models and approaches to plant asset management in order to remain relevant.

2.2 Business Improvement Models (BIM's)

This portion of the literature survey evaluated current Business Improvement Models in use in business and industries, focusing on those most commonly used in business/industry, and reviewed the challenges experienced with these models. It evaluated the most common general business process improvement frameworks and implementation approaches, as well as improvement frameworks in the Information Management/Technology space.

2.2.1 The Most Common BIM Frameworks

A literature review indicates that there are a plethora of business improvement models offered to business [Tanner, 2014; National Institute of Standards and Technology (NIST), www.nist.gov]. The most notable and widely used business improvement framework is the ISO 9001 quality management system, which in turn is supported by frameworks like Baldrige [Tanner, 2014; NIST, 2015] or the EFQM Framework [Van Rompuy, 2012]. The Power Utility has implemented the ISO 9001 Framework.

A key (and common) driver in developing these business improvement models is the aim to deliver a framework generic enough to be of use to any organisation, regardless of size, industry sector or maturity of the business.

Because of their generic nature, they offer very little information and specifics to process plants on how to ***practically and operationally*** improve business efficiency using deterministic and probabilistic analysis.

Research indicates that Business Improvement initiatives, models, and approaches are generally focused on the **improvement of business processes** (either core or underlying processes).

Tanner very aptly points out that there is a difference between business improvement ***models*** and improvement ***approaches***. [Tanner et al., 2014] The business models are generally more holistic and coverage is deemed organisation wide, while the associated implementation approaches would focus on specific tasks or areas of improvement in the organisation.

The generic nature of the fundamental Baldrige and EFQM business improvement models have led to the development of numerous business improvement ***approaches*** to enhance the implementation effort. Most business leaders will admit that at least one (but generally many) of these additional approaches and “initiatives” have been sold to them to improve their business operations and ultimately their “bottom line” (with quite varying degrees of success and ***real*** business improvement).

Examples of commonly implemented business improvement model “Approaches” found in industry are:

- Balanced Scorecard
- Benchmarking
- Business Process Re–Engineering
- Carbon Foot–printing
- Customer Service Excellence
- Six Sigma and “Lean” Six Sigma
- FMECA/FMEA
- High–Performance Culture
- Integrated Business Improvement
- ISO 14001
- Kaizen – Continuous Improvement
- Theory of Constraints (ToC)
- Total Productive Maintenance (TPM)
- Total Quality Management
- Value Stream Management

Similarly, Information Management and specifically plant information management work focuses on the implementation of systems and the governance around the management of information. [Socha et al., 2016; Bell, 2015; DAMA website, www.dama.org] A discussion on the EDM website, confirms the researcher’s view that even the information management technology business improvement frameworks focus on business processes, (documenting data management processes) rather than how to deal with (and make decisions on) the actual data generated. TOGAF and COBIT are typical “information management/technology” business improvement models in this space [Ledergerber, 2012].

In addition to the ISO 9001 Framework, the Power Utility has also started implementing the ISO 55001 Asset Management framework (successor to the PAS 55 framework) [ISO website, www.iso.org] to enhance asset management practices and improve business operations. Most Utilities are adopting this framework as they believe that ISO 55001 will provide them with improved asset management practices.

The International Atomic Energy Agency (IAEA) has developed an additional framework (to PAS 55) where decisions regarding assets are also subjected to an integrated risk–informed process [IAEA, 2011].

The enhanced PAS 55 framework states: “**good decisions should be balanced between deterministic and probabilistic analysis to provide the required insights, perspective, comprehension and balance**”. [IAEA, 2007] The IAEA, therefore, confirms the researcher’s view that conventional business improvement frameworks and process improvement initiatives are not enough when it comes to process plants and power utilities.

The IAEA further states the importance of well–managed Design Base information datasets to assist in decision making – something the proposed research IPI–BIM Framework and approach sets out to deliver. Coupling the Design Base to well–established and proven failure prediction models and analytical analysis of operational data can create a very potent combination to bring about a step–change in plant asset performance and reliability.

It can also become be a key enabler and source of evidence to measure the success of the asset management program.

2.2.2 The Baldrige Model

The Baldrige Model is heavily influenced by U.S. trade and practices but are still used worldwide [National Institute of Standards and Technology (NIST), 2015]. In this model, business improvement initiatives and success are evaluated against the 6 main elements shown in Figure 2–7 (Leadership, Strategy, Customers, Workforce, Operations and Results).

Figure 2–7: Key elements of the Baldrige Business Model Review Framework [NIST, 2015]



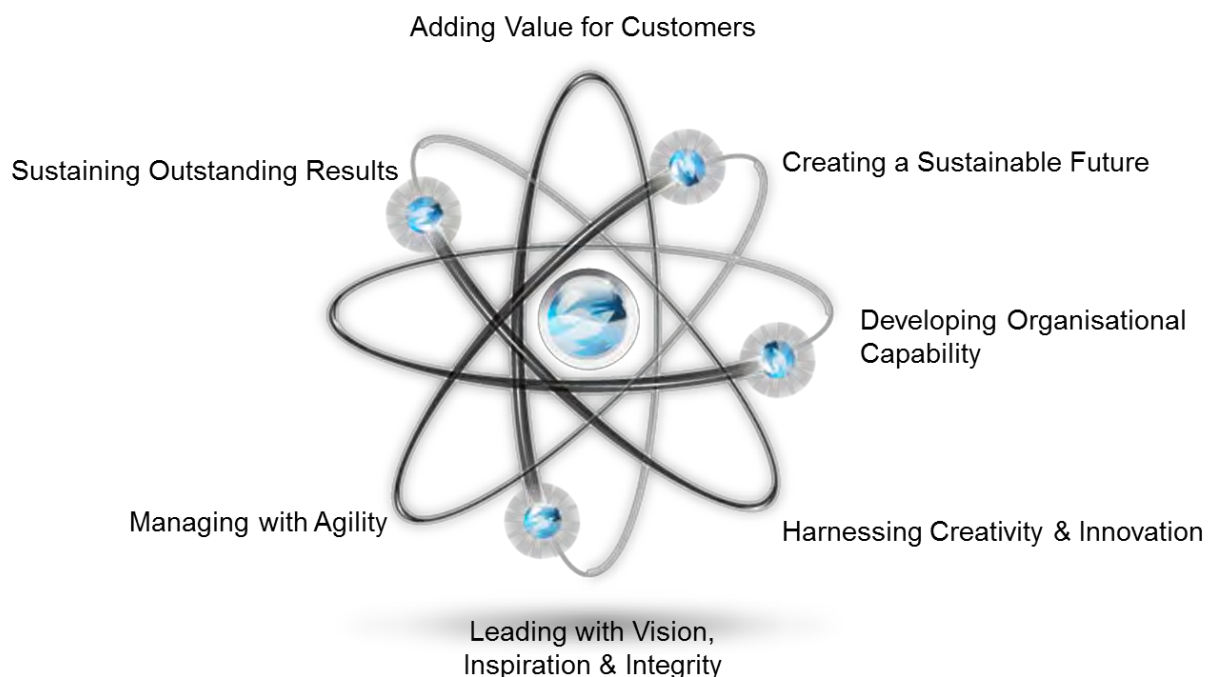
Although questions are asked about business data in this framework, the efficiency measurements or criteria to rate the response are not clearly identified. (e.g. *Comparative Data: What key sources of comparative and competitive data are available from within your industry? What key sources of comparative data are available from outside your industry? What limitations, if any, affect your ability to obtain or use these data?*)

This in the researcher's opinion makes it a very subjective business efficiency review model.

2.2.3 The European Foundation for Quality Management (EFQM) Excellence Model™

The European Foundation for Quality Management (EFQM) Excellence Model™ is wider in use across European countries. The model strives to evaluate the understanding of the business of cause-and-effect relationships in the business processes and people's understanding of this (Figure 2–8).

Figure 2–8: EFQM Excellence Model Review Framework™ [Van Rompuy, 2012]



Evaluation of business efficiency measurement initiatives recently undertaken by the Power Utility shows a preference towards business improvement models that has this efficiency measurement model as its underlying framework (confirmed by the drive of the Power Utility over the past few years to achieve ISO 9001 certification).

Evaluation of implementation approaches also confirms that the Utility lean towards models that align to this fundamental BIM Framework to improve business operations. A case in point is the project management framework implemented in the Power Utility [Du Plooy, 2013].

2.2.4 Information Management Models

Information Management is generally focused on the management of data and information and providing the required information management governance from a legal, risk efficiency, ownership and business control point of view [Socha et al., 2016]. As with business improvement models, the aim is again the generation of generic enough business improvement frameworks and models that can be implemented in any industry.

Figure 2–9: Information Management Models – Focus Areas [Socha et al., 2016]



Bell refers to the Data Management Book of Knowledge (DMBoK) and an Enterprise Information Management capability model [Bell, 2015]. Figure 2–10 shows how this model reflects a strong focus on the various **data management** aspects, but will not go into the specific requirements of exactly what data is needed for effective information and knowledge management or how it can/should be used for business improvement.

The focus in this framework (supported by further IT frameworks and approaches like COBIT and TOGAF) is on the appropriate management of the information architecture (and elements that make up an information architecture and infrastructure). The “what data?” that should be managed is not answered at all by these frameworks.

Figure 2–10: Information Management Capability Model [Bell, 2015; Data Management Association International (DAMA), www.dama.org, DAMA, 2013]



Again, the management of these items would be handled as “processes” to be optimised. Actual data use, analytics, and interpretation of information system data content would not be covered by these models as an integral area of business improvement.

2.2.5 Challenges with the Common BIM Frameworks

Most of these frameworks focus on the implementation of a “Business Improvement System” or “Business Process Manual” depicting the business operations and high–level statements of the continuous improvement requirements, but rarely go to the level of detail to define specifically what would be required to realise the improvements. This is generally left up to the business to define/figure out how to ***practically*** achieve business improvement using the newly developed system/business process manual.

A detailed analysis and review of these business improvement models indicate that when it comes to evaluation of success rate of the BIM implementation, it always boils down back to the efficiency of “business processes”. (See Tables 2–3 and 2–4 below for the two most common model evaluation frameworks).

A further drawback identified from the research is the subjective manner in which the evaluation is done – although a questionnaire can be very efficient in prompting the organisation to look at the right business model elements, proper quantification of what is deemed “good practice/role model” quality feedback vs. “major improvement/reactive” feedback responses. In both cases, these business improvement models and frameworks make use of very generic questionnaires to “rate” the business maturity.

Table 2–3: Baldrige Evaluation Outcome – Showing a “Process Centric” improvement mode [NIST, 2015]

DESCRIPTOR	PROCESS	RESULTS
Reactive 	Operations are characterized by activities rather than by processes, and they are largely responsive to immediate needs or problems. Goals are poorly defined.	Results that are important to the organization's ongoing success are missing, not used, or randomly reported.
Early 	The organization is beginning to carry out operations with repeatable processes, evaluation, and improvement, and there is some early coordination among organizational units. Strategy and quantitative goals are being defined.	Results that are important to the organization's ongoing success are reported, tracked over time, and improving.
Mature 	Operations are characterized by repeatable processes that are regularly evaluated for improvement. Learnings are shared, and there is coordination among organizational units. Processes address key strategies and goals.	Results that are important to the organization's ongoing success are trending in the right direction and doing well relative to competitors or other relevant organizations.
Role Model 	Operations are characterized by repeatable processes that are regularly evaluated for change and improvement in collaboration with other affected units. The organization seeks and achieves efficiencies across units through analysis, innovation, and the sharing of information and knowledge. Processes and measures track progress on key strategic and operational goals.	The full array of results that are important to the organization's ongoing success are reported and trended over time, indicating top performance relative to other organizations.

Like Baldrige, the EFQM Model requires a subjective definition of what would be deemed “good results” in the four areas defined; and the success is highly dependent on the correct Cause–Effect definition and identification. Many organisations have e.g. implemented ISO 9001 systems but are still plagued by business inefficiencies and unreliable/inefficient operations.

Table 2–4: EFQM Radar Model Outcome Evaluation [Van Rompuy, 2012]



This portion of the literature survey confirms the view that the most commonly used existing business improvement models focus on **business processes** to introduce business improvement. This holds true for business as well as information management environments.

Introduction of an alternative business improvement model that uses integrated plant information management and plant Design Base and control data as its underlying basis would therefore be a departure from the conventional way business improvement initiatives are undertaken (i.e. focusing on business processes to bring about business improvement).

It will significantly add to the Engineering Management and Business Improvement Model body of knowledge by introducing an alternative business improvement model for process plants and the Power Utility environment.

2.3 Integrated Plant Information Management Systems

This portion of the literature survey evaluated a number of aspects and challenges around the design, configuration and implementation of integrated plant information management systems.

2.3.1 The Need for Integrated Plant Information Management

The International Atomic Energy Agency (IAEA) has developed a framework in addition to PAS-55 [ISO, 2014]. The framework stresses the importance of a well-managed Design Base information and data set to assist in decision making.

A nuclear industry study on advanced AI on control systems points out the critical importance of a well-managed, integrated plant database where all critical plant Design Base information is contained [IAEA, 1997]. This research study also supports the researcher's view that it is crucial to apply rule sets in the management of information and even when dealing with the ordering of large data sets for analytical analysis.

2.3.2 The Challenges of Integrated Plant Information Management

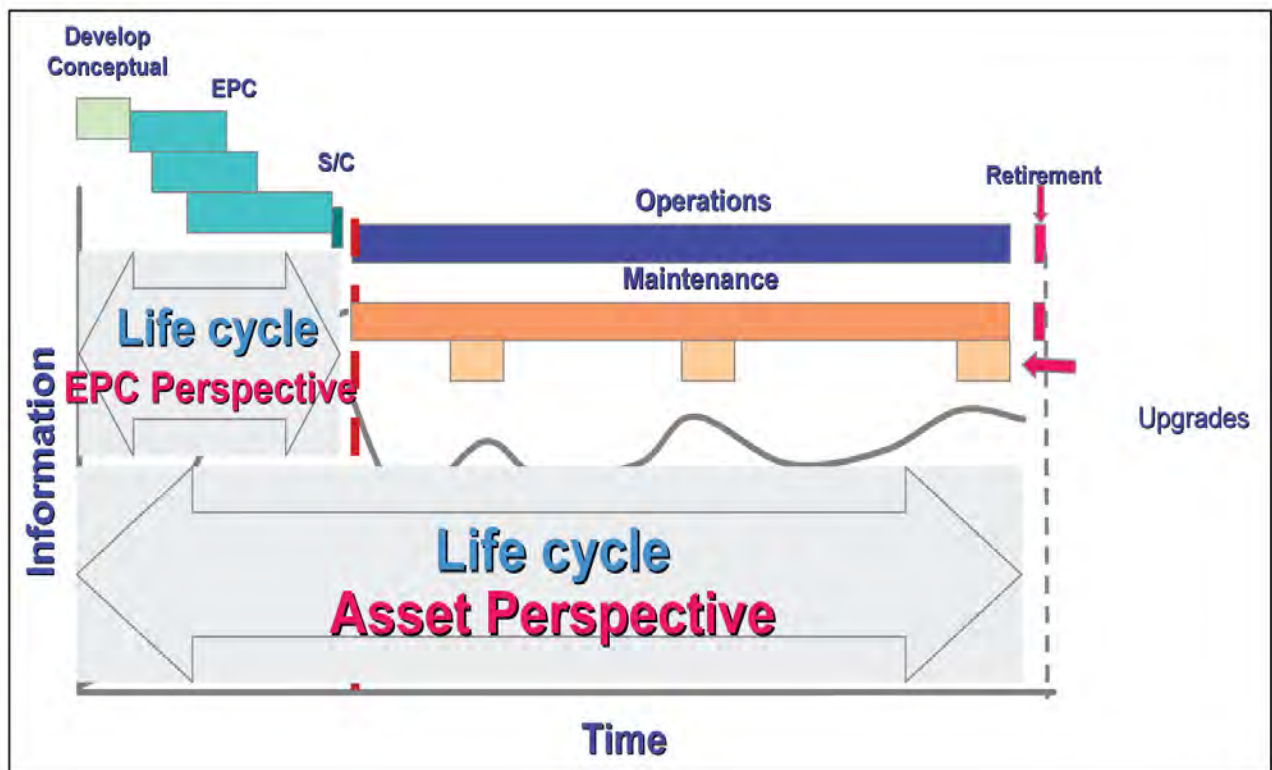
Engineering information management systems are a much more complex undertaking than conventional ERP systems.

Many vendors propose a very integrated approach in dealing with all the required engineering management objects and processes, but very few (if any) has managed to successfully implement a fully functional set of inter-related engineering business processes in an integrated Plant Information Management system platform.

A potential reason for this may be the very different information delivery and usage timeframes as well as business drivers involved in the lifecycle phases (EPC vs O&M phase of a plant asset).

During the EPC cycle, (Figure 2-11) constructors are mostly concerned with the building of the plant and the focus is not always on sourcing and/or handing over all the Design Base information crucial to the operations and maintenance cycle of the asset. Focus would rather be on asset delivery and project cost containment, so the need and importance of some Design Base information and data may not be evident or even important for the role players in this lifecycle phase.

Figure 2–11: EPC vs. O&M Perspective on Plant Information Management [Feldman et al., 2001]



The sheer volumes of project and engineering information generated during the EPC phase also creates data quality management issues in that Design Base information shortcomings are not always identified in time or corrected while there is still contractual leverage to rectify the situation.

Without a proper Engineering Design Base Information hand-over specification to mitigate this very real EPC risk, the Owner-Operator may find himself in a very challenging position of not having the information needed to make well-informed plant and process decisions during the O&M cycle. (The information handover should be supported by appropriate business data hand-over and QC processes and associated project governance mechanisms).

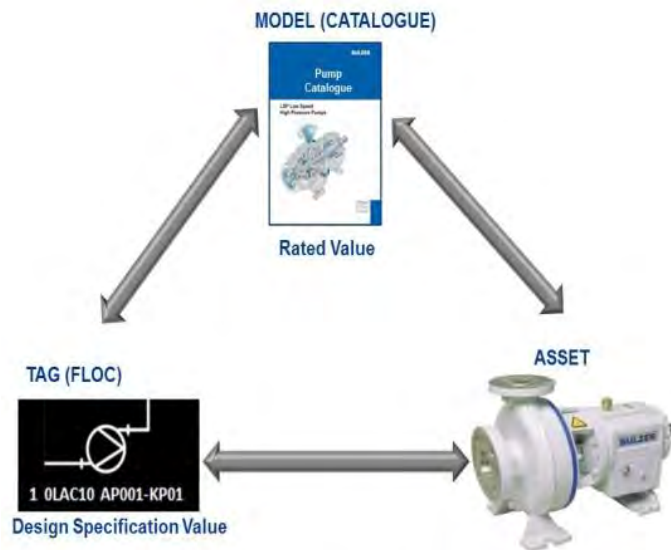
The challenge of incomplete Design Base information and data content usually manifests itself most profoundly at times when a major plant refurbishment or replacement needs to be planned and the information needed to compile an appropriate user requirement specification cannot be sourced from available Design Base content.

And the impact of the incomplete solution stretches over a much longer timeframe (the 10 year EPC versus the 40+ year O&M lifecycle of a typical power utility generation asset).

2.3.3 Plant Information Relationship Complexity

Technical plant information is also highly complex to manage due to the very integrated relationships that exist between Asset, Asset Type and Plant Design Position (Plant Slot). Figure 2–12 shows the information configuration relationship of plant assets.

Figure 2–12: Plant Slot, Asset and Asset Type Relationship [Venketiah, 2011]



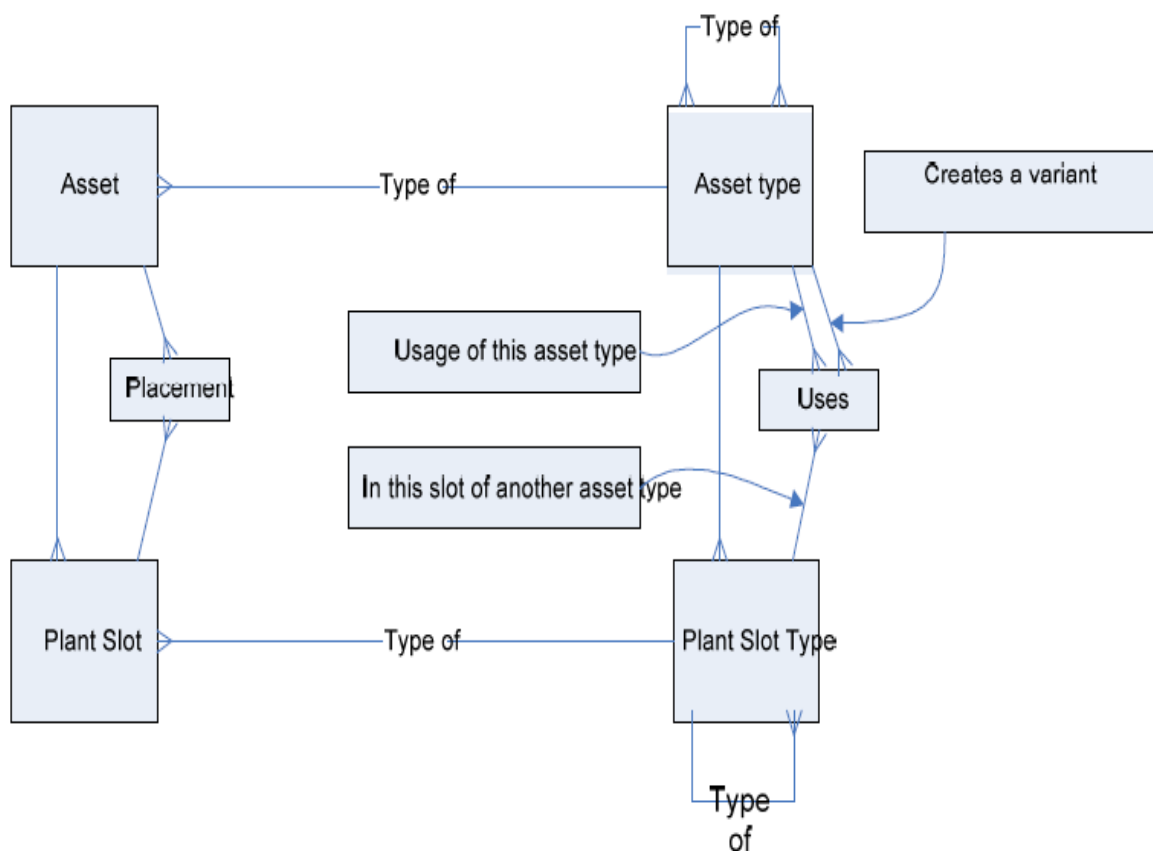
The **Functional Location (FLOC)** is the Design Base position of a plant asset in the plant process based on very specific design and performance requirements put forward by the plant owner (e.g. an electrical drive with a power output requirement of 75 kW is required for the plant to function as per design intent).

The **Model** (Catalogue) is the equipment type and designed equipment type model that can fulfil the function that was intended by the design (e.g. a 75 kW motor manufactured by General Electric or Siemens can fulfil this function. Should the Siemens model be chosen, their motor Model “500DL” can fulfil the function).

The **Asset** would be the physical instance of the equipment type installed in the plant (thus if a Siemens model 500DL motor was selected for installation, it will have a unique manufacturing serial number of 45–55423 that uniquely identifies this very specific motor).

This complex and inter-dependent relationship makes trending of historical information and evaluation of plant condition more complex as equipment is many times inter-changeable and can move from one plant position to another. In many cases, the asset type can be constant, but different variant types of the asset can fit into the same plant slot. The new Power Utility Data Model (Figure 2–13) pointed out the complexity of dealing with these core engineering relationships in the plant operational environment [Venketiah, 2011].

Figure 2–13: Complexity of Asset Placement within Plant Slots [Venketiah, 2011]



This information model and historical data relationships due to movable assets will become a major consideration when evaluating performance and failure modes/patterns in algorithmic modelling or simulations – misinterpretation of plant historical operational information when used within the wrong context can introduce the risk of reporting inaccurate results or making wrong deductions from analytical analysis outcomes.

2.3.4 Plant Information Volumes and Structure

A further challenge to effective Design Base management is establishing a well-structured and ordered management of Design Base content within the complex multi-tier relationship model shown in Figures 2–12 and 2–13. This challenge includes the appropriate alignment of Design Base attributes to asset base attributes within the same functional design location of the plant.

Table 2–5 indicates typical discipline based Design Base artefacts for a large 3,600 MW power station after 9 months of Design Base content definition and back-fit data sourcing under this research study. Currently, such information is stored and managed in an unstructured manner over a multitude of information technology system solutions at most of the Brownfields power stations, which makes it very difficult to identify and source core Design Base content, and creates concerns about data quality and integrity in identifying the “one version of the truth”.

Similarly, on the Greenfields Project, the EPC contractors were allowed to implement their own document classification methods resulting in a plethora of different standards and document classes for the same type of document.

Table 2–5: Typical Technical Design Base Content Volume Profile: 3,600 MW Power Station

Level 1	Discipline	Quantity
A	General/Administrative	679
B	Technology Specific	2,618
C	Civil	8,740
D	Electrical	39,041
E	C&I	66,237
M	Mechanical	7,851
P	Process	5,915
X	Unallocated	669
TOTAL		131,750

Once the information is sourced and migrated into a central repository, accuracy of current drawings and engineering Design Base content and artefacts would require verification and validation (V&V) and any changes required must be subjected to formal change control processes. This is not an easy exercise in a cost–constrained environment.

Given the fact that the utility runs a fleet of 27 “brownfields” power stations, it becomes even more important to define a set of Design Base content that will reflect an acceptable plant asset Design Base (especially in cases where all Design Base information cannot be sourced or found and have to be reverse engineered and subjected to V&V before it can be used).

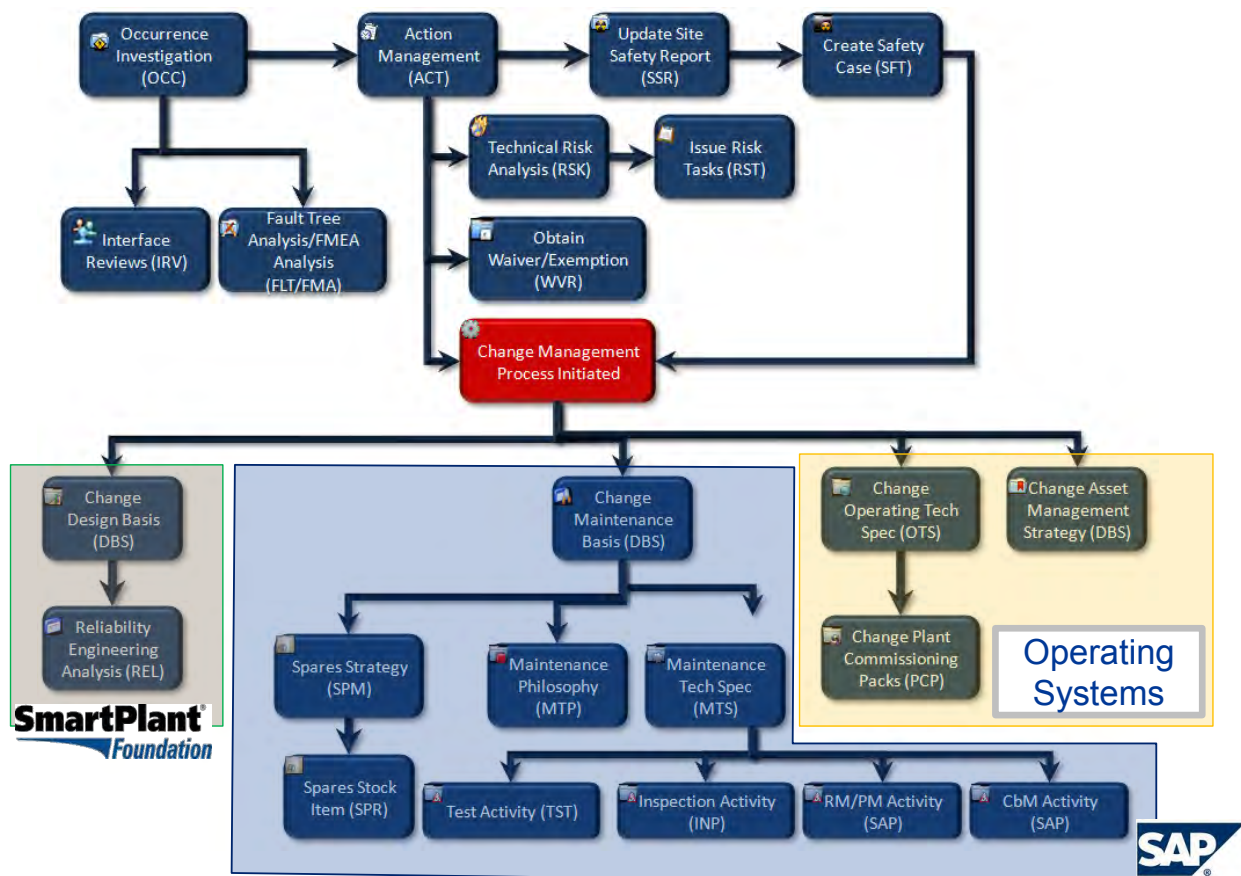
Increased Regulatory Compliance on refurbishments and plant upgrades also require a much higher data quality control on and management of the plant Design Base, which can prove very problematic on plants more than 60 years old. As the Brownfields Power Plant is due for a C&I refurbishment upgrade, the research proved invaluable to determine to what extent the core Design Base content could be sourced in support of compiling the C&I upgrade design requirements (URS).

It was for this reason that research was required to define the **core** Design Base elements and artefacts that would be crucial for asset management and advanced analytics and decision making over the entire asset lifecycle.

2.3.5 The Integrated Nature of Engineering Business Processes

Figure 2–14 shows a typical business scenario where changes can be triggered by numerous business events, e.g. occurrences or plant incidents, changes to legislation (that would result in changes to the plant safety case for Nuclear power plants), etc.

Figure 2–14: Designing an integrated engineering workflow and process eco–system for lifecycle Design Base Change Management [Swanepoel, 2012b]



In the case of an occurrence, the outcome would generally be certain actions to be taken to prevent a recurrence, which can include significant Design Base changes.

Figure 2–14 depicts how change management requirements flow into a controlled evaluation and Management of Change (MoC) process. It further shows the subsequent change that may be required to various elements of the Design Base (Maintenance, Operating and Reliability Base) depending on the nature and complexity of change required.

The design of an IPI System platform needs to consider this inter–related nature of engineering business processes, and the design should include capturing of meta–data related to the business process. It should also consider the potential requirement for meta–data that would support *other downstream business processes and not just the primary process under consideration at the time*.

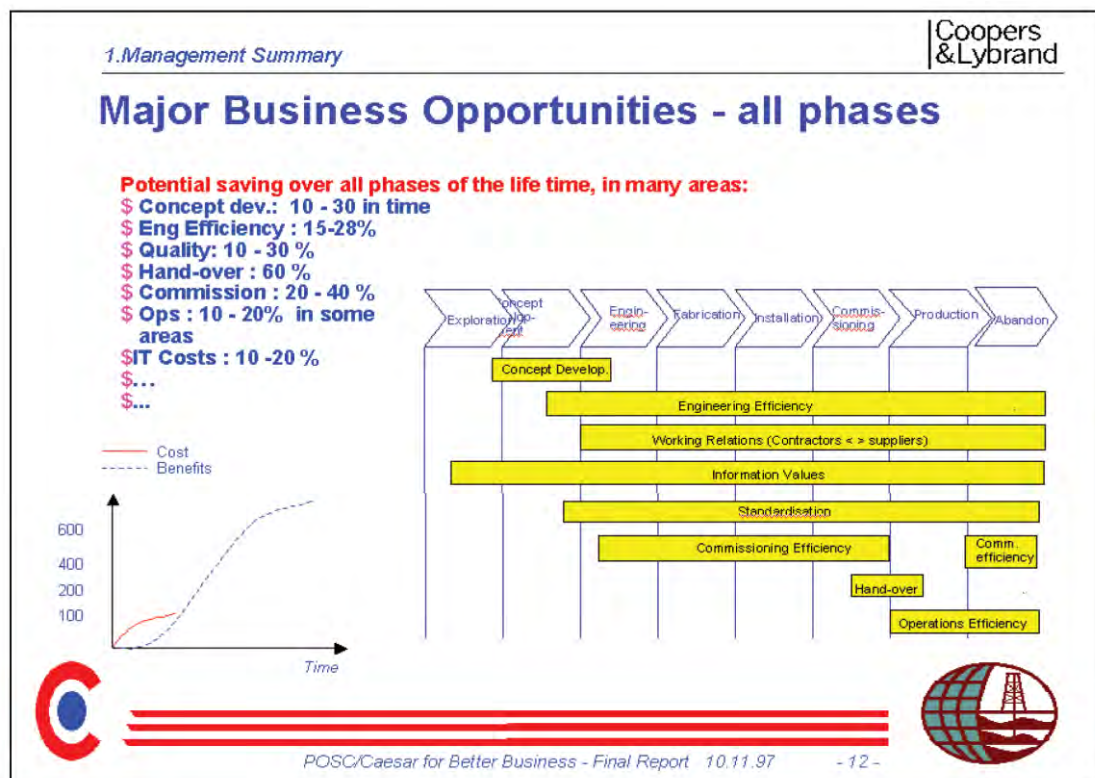
The configuration of additional process meta-data may be seen as unnecessary time added to system configuration timelines, but the benefit of this needs to be weighed up against the risk of having to data-mine documentation in an unstructured and non-standardised way, trying to extract analytical data needed to make informed business decisions.

2.3.6 The Value and Benefits of Integrated Plant Information Management

Levitt demonstrated the benefit of merging the CAD (visual) depiction of a design with actual Design Base information, processes and content as early as 1990 [Levitt, 1990]. At the time, the software and programming complexity became the inhibitor for Levitt to prove the concept beyond theory, hypothesis, and basic prototyping concepts. But he managed at this early technology stage to demonstrate the productivity savings that can be achieved working in an integrated engineering environment where the relevant information is readily available for decision-making purposes.

Coopers and Lybrand consulting performed an independent study on the benefits of an integrated Engineering lifecycle information management system (managed environment) in 1997 (summarised in Fig. 2–12) [Coopers et al., 2007].

Figure 2–15: Benefits of Better Information Management over the Plant Asset Lifecycle
[Coopers et al., 2007]

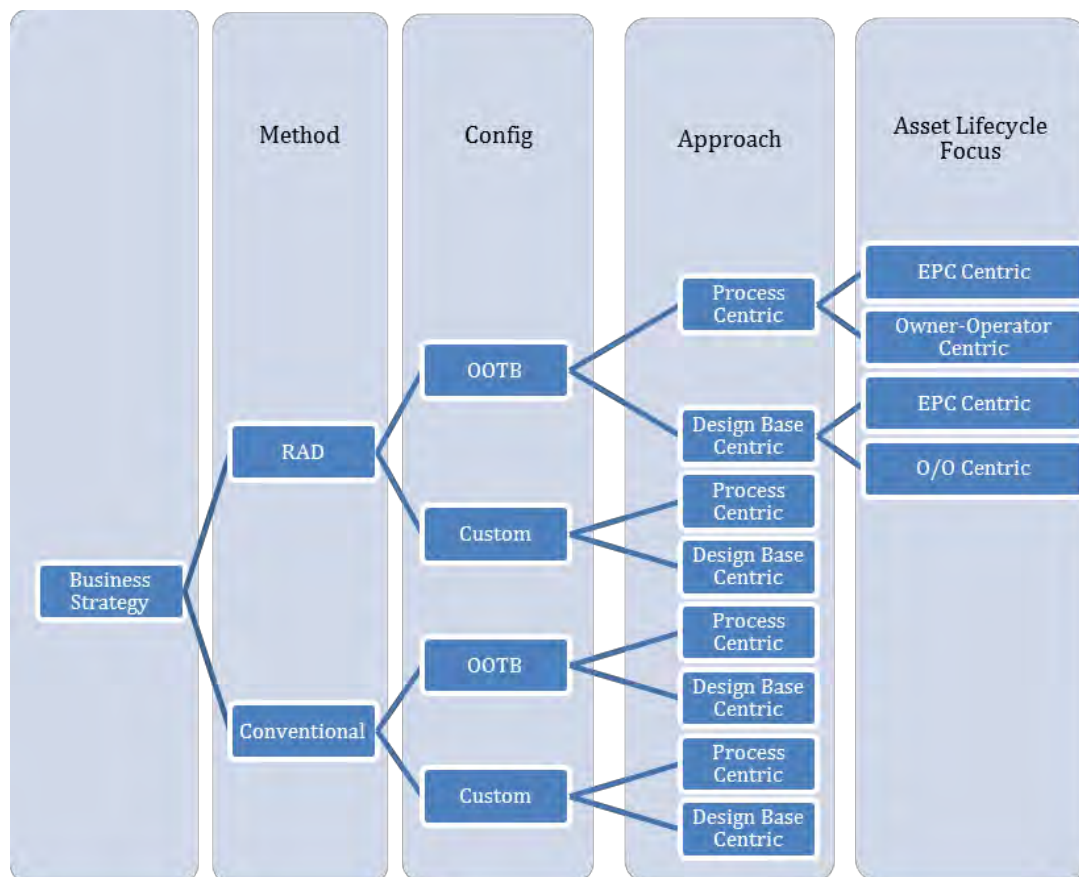


The study identifies potential savings across all phases of the plant and project lifecycle, covering aspects like improved design practices, more engineering efficiency and productivity and reduced commissioning and hand-over time frames (and thus faster return-on-investment).

2.3.7 Integrated Plant Information Management System Approaches

A number of implementation approaches are evident from research and literature surveys – the following implementation tree (generated by the research study), is a summary of these approaches (Figure 2–16). A detailed explanation of the impact that the elements of Business Strategy, Configuration method, System Configuration, Business Process Implementation approach and Asset Lifecycle Focus have on system implementation follows Figure 2–16.

Figure 2–16: Plant Information management system implementation approaches

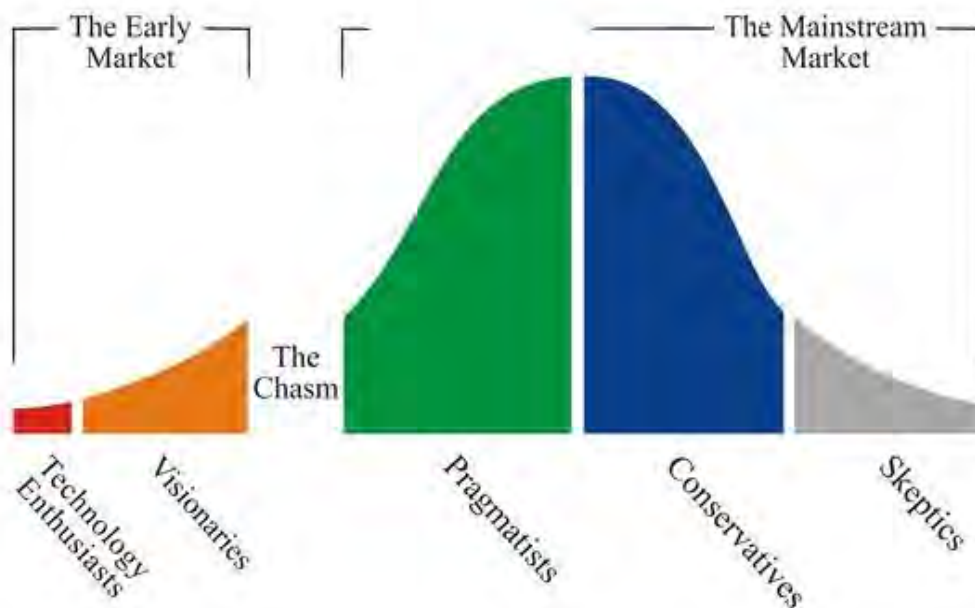


2.3.7.1 Business Strategy

Research indicated that the business strategy, specifically concerning technology adoption will dictate the implementation method. Figure 2–17 shows that Technology Adoption strategy follows the typical Bell curve distribution. As such “Normative”/“Follower” companies make up the mainstream market [Hogan, 2016].

Although Hobson covers a different process plant production segment (meat processing), his findings regarding adoption of new technology shows the general trend that early market adopters are as low as 16% of the total business profile generally considered. Normative strategy adoption is around 65–70% while technology followers usually are around 16% of the Bell-profile distribution [Hobson, 2010].

Figure 2–17: Technology Adoption Strategies [Hogan, 2016]



An interesting observation from Hobson’s research is that he reported that technology solution providers will generally have minimal/low engagement with late adopters (the “Followers”). Conversely, the solution providers would very actively engage “Early Technology Adopters” to help them mature new technology and drive more innovation. This observation was confirmed within the engineering integrated information system space where “early adopters” are actively engaged and involved in solution development and enhancement.

It is also notable that a company that embraces a “Bleeding or Leading Edge” technology adoption strategy will be more comfortable adopting a RAD system implementation approach than a company with a “Normative or Follower” technology adoption strategy.

2.3.7.2 Development Methods

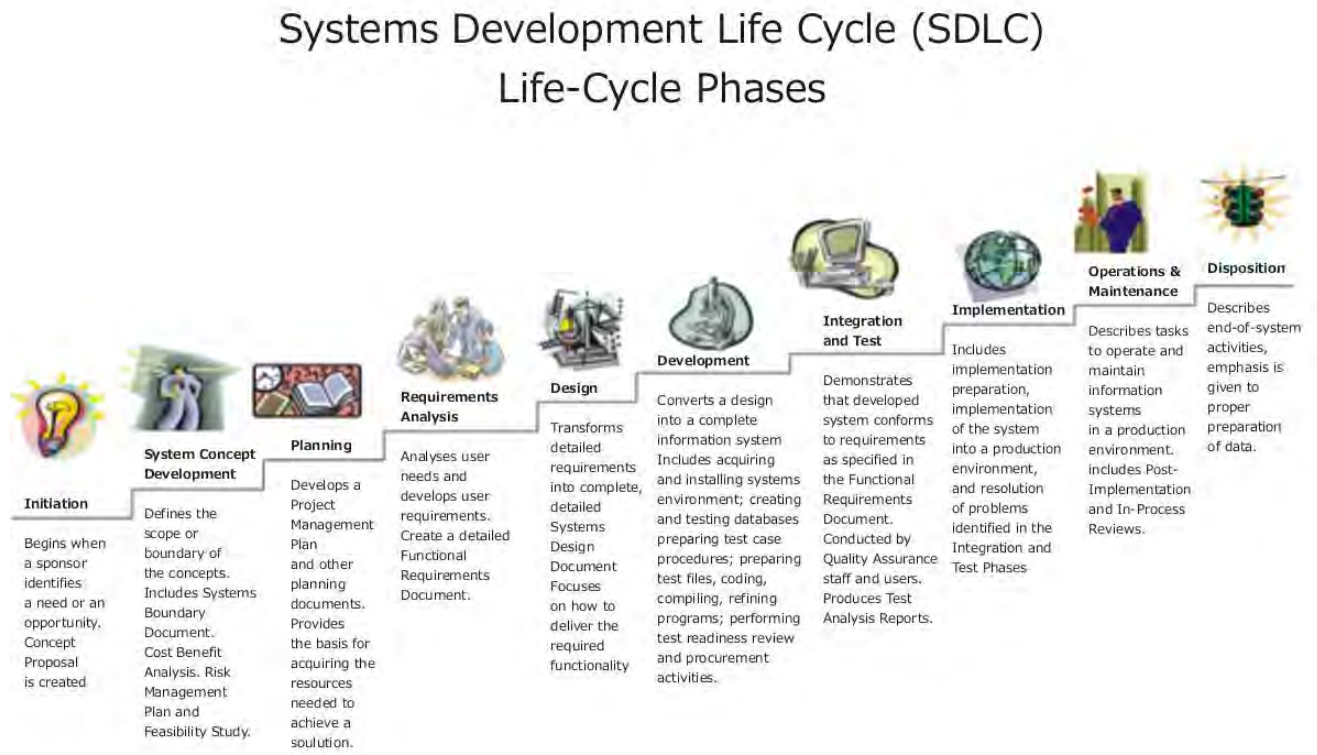
Generally, one of two implementation methods is followed. A hybrid approach is obviously also possible, but needs careful consideration and requires detailed and extensive documentation of what is conventional implementation system implementation scope, and what portions of the configuration are under “RAD” implementation scope.

Method 1: Conventional System Development (SDLC Methodology)

This involves extensive URS development, system functional design specifications, interactive user design sessions, actual system design, implementation and extensive UAT/FAT cycles.

In general, the conventional approach is favoured by most large corporations as it is seen as lower risk and due to the extensive validation and user interaction base is also seen as a “safer” method of capturing all the user requirements and defining system functionality.

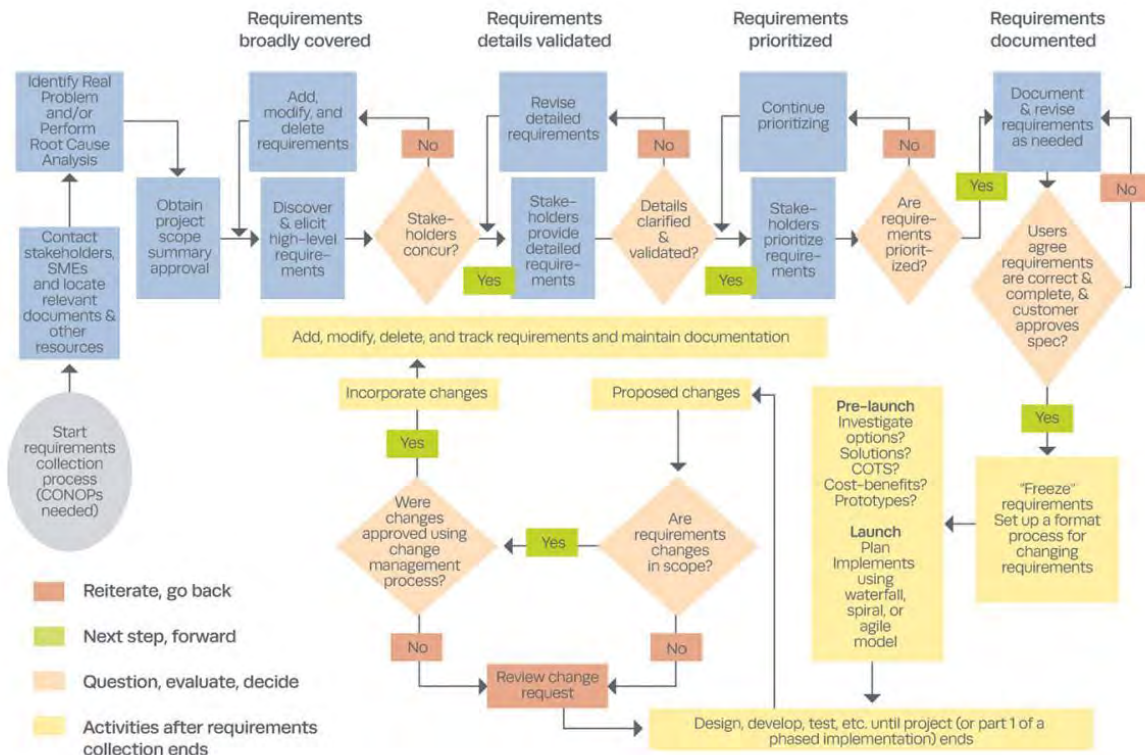
Figure 2–18: SDLC Lifecycle for system development and optimisation [James, 2013]



Unfortunately, the “requirements definition phase” and agreement of all documented requirements can become a very lengthy and time consuming process as the typical requirements validation portion of the process in Figure 2–19 below shows.

A further drawback is that requirements documented on paper is not always what can be achieved in software, and without being able to test or see what the defined requirement would eventually look like in the software system designed solution, it is very difficult for users to confirm that the requirement stated was adequately and correctly defined.

Figure 2–19: Requirements V&V Process within the SDLC Lifecycle [James, 2013]



Method 2: Rapid Application Development (RAD) Methodology

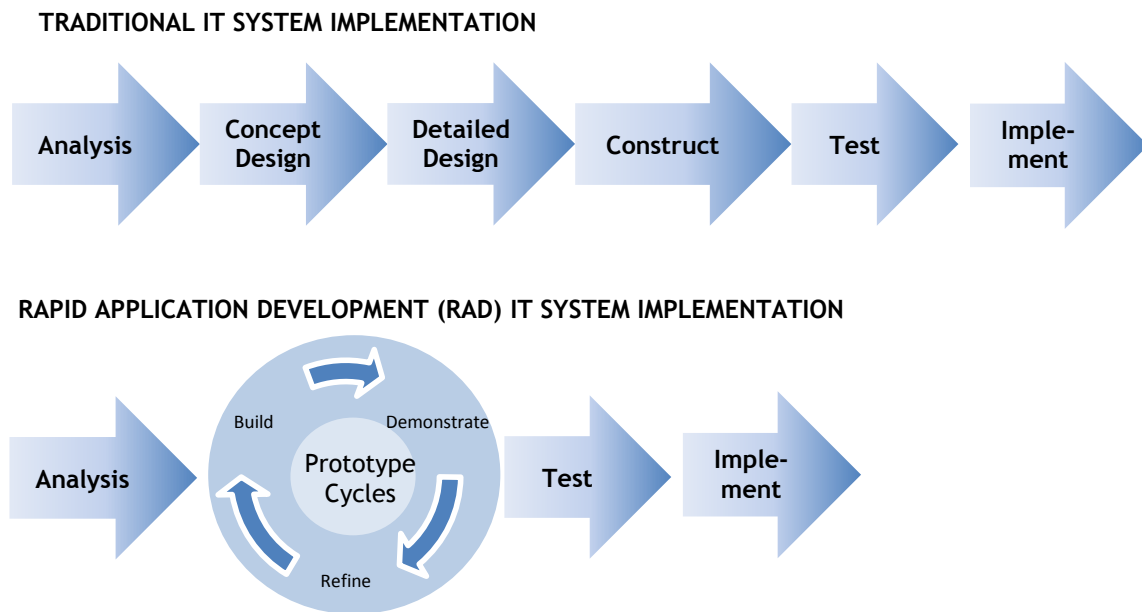
In this approach, an engineering framework is developed and implemented into an information management system platform in a rapid fashion with a very small team of highly skilled individuals from the required disciplines and process/systems engineering background. The comparison of RAD against traditional methods is shown in Figure 2–20 below.

By demonstrating prototype system functionality early on in the implementation cycle of the RAD methodology, it is possible to confirm and refine requirements faster and speed up the building of a solution that meets end-user requirements.

Design assumptions and user expectations can be tested very early on and changes can be effected with more ease. Documentation of changes and the final configuration is, however, mission critical in the RAD process to ensure repeatability and consistency, especially if the final system design is to be deployed widely in a large organisation.

The use of RAD methodology generally yields a much shorter system development timeline.

Figure 2–20: Rapid vs. Traditional Application Development Methodology Summary [Koredla, 2014]



2.3.7.3 System Configuration Approach

The risk tolerance strategy of the business will also dictate whether the business would rather opt for an “out-of-the-box” (OOTB) system configuration approach or a customised software configuration. Very few companies opt for (and can justify) a fully customised solution due to the long term support and maintenance risk of a solution that is developed in-house and not used by anyone else in the industry.

Most companies prefer the more risk-neutral approach of an OOTB solution with minimal configuration to align it to internal business terms and practices/work methods.

Most Engineering Information System vendors will offer an “Out of the Box (OOTB)” baseline solution to facilitate configuration and speed up the implementation process. This would be done by configuring core and basic engineering principles within the solution. But, in trying to serve the widest possible potential customer market, most of these OOTB pre-configured solutions are found to be very generic and the work processes are generally defined to a level that makes outright execution of the basic engineering process configured very difficult within a specific business context.

The result of this system solution delivery approach is that most customers end up doing some level of customised configuration to ensure that the purchased product can work within their defined processes and work environment. In interaction and information sharing discussions with other process industries, the researcher observed that many companies made more than one attempt at system configuration or ended up introducing additional

“enhancement/continuous improvement” initiatives (associated with the initial configuration effort) to achieve the desired specification and requirements. Their feedback regarding the amount of customization required was at least 15–20% from the OOTB configuration, but generally it approached levels of between 40–75% depending on the business process maturity and complexity of their engineering processes involved.

The alternative approach to this OOTB approach is to utilise the baseline functionality and building blocks that the software solution has on offer and to use these to configure the solution to very specific business requirements using a very well-defined URS.

Although there may be a perception that this approach may be more time consuming during the implementation phase, results to the contrary has been found in this research study when comparing outcomes of the different system development and implementation methods on Power Utility efforts that formed part of the operational research scope and evaluation.

In addition to findings that the RAD methodology and a hybrid OOTB/customisation system configuration approach are more time efficient, it was also found to have a higher end-user uptake as familiar terms and business processes are used, configured and implemented (as was evidenced by the research results shown later on in this study).

2.3.7.4 System Design Approach

As indicated in literature survey on business improvement models, adoption of a specific business improvement framework and implementation approach (e.g. ISO 9001) can dictate the system configuration approach. Where the business operations are very engineering-centric, a Design Base centric configuration of the system would be preferred, while more generic business operations would prefer a more process-centric implementation.

Many engineering companies and process plants function within a larger enterprise, and it is not uncommon to see hybrids of the process and design-centric approach implemented to provide the “best of both worlds”.

Figure 2–21 shows the Intergraph™ approach, where the focus is on specific business *capabilities*, e.g. “Project Execution Capability” (thus reflecting a process-centric implementation strategy). Taking this approach, their software will provide the Owner/Operator with the required baseline business/engineering processes to manage the execution of certain grouped engineering capabilities within their organisation [Intergraph, 2014].

This approach allows the business to decide on which capability they want to focus on and gives the flexibility of ***implementing the software solution in phases based on capability*** (with the obvious benefits of faster deployment, lower cost, and deployment of only what is needed at a specific point in time).

Implementation of a module like “SPO Project Execution” will as an example enable the business to implement key project execution processes like the management of interfaces, project change management, non-conformity management, managing technical and site queries from contractors, etc.

Figure 2–21: Intergraph SPO™ – Deployment Strategy of Capability Enablement [Intergraph, 2014]



Alternatively, Figure 2–22 shows the approach undertaken in a system implementation project [Swanepoel, 2010a]. In this case, the key Design Base elements were defined; and engineering processes, workflows, and management meta-data sets were developed that would support the management of these Design Base elements.

Figure 2–22: Process Focus in O&M Asset Lifecycle [Swanepoel, 2010a]



2.3.7.5 Asset Lifecycle Impact

The asset lifecycle focus would also dictate the extent and scope of system configuration. For companies operating predominantly in the EPC space, a Design Base centric solution based on EPC processes like Front End Engineering Design, Plant Design, Design Review, Construction, Commissioning and Handover processes and data will dominate the system configuration requirements.

In an EPC environment, the focus of an engineering system would, therefore, be the creation, capturing and maturing of the plant Design Base in a continuous ongoing process (Figure 2–23) until “design freeze” can be achieved. This is depicted in the typical Design Information and data flow that would happen in an engineering information management solution like the Intergraph SmartPlant™ software.

Figure 2–23: Design Base Creation in the EPC Asset Lifecycle [Swanepoel, 2012d]

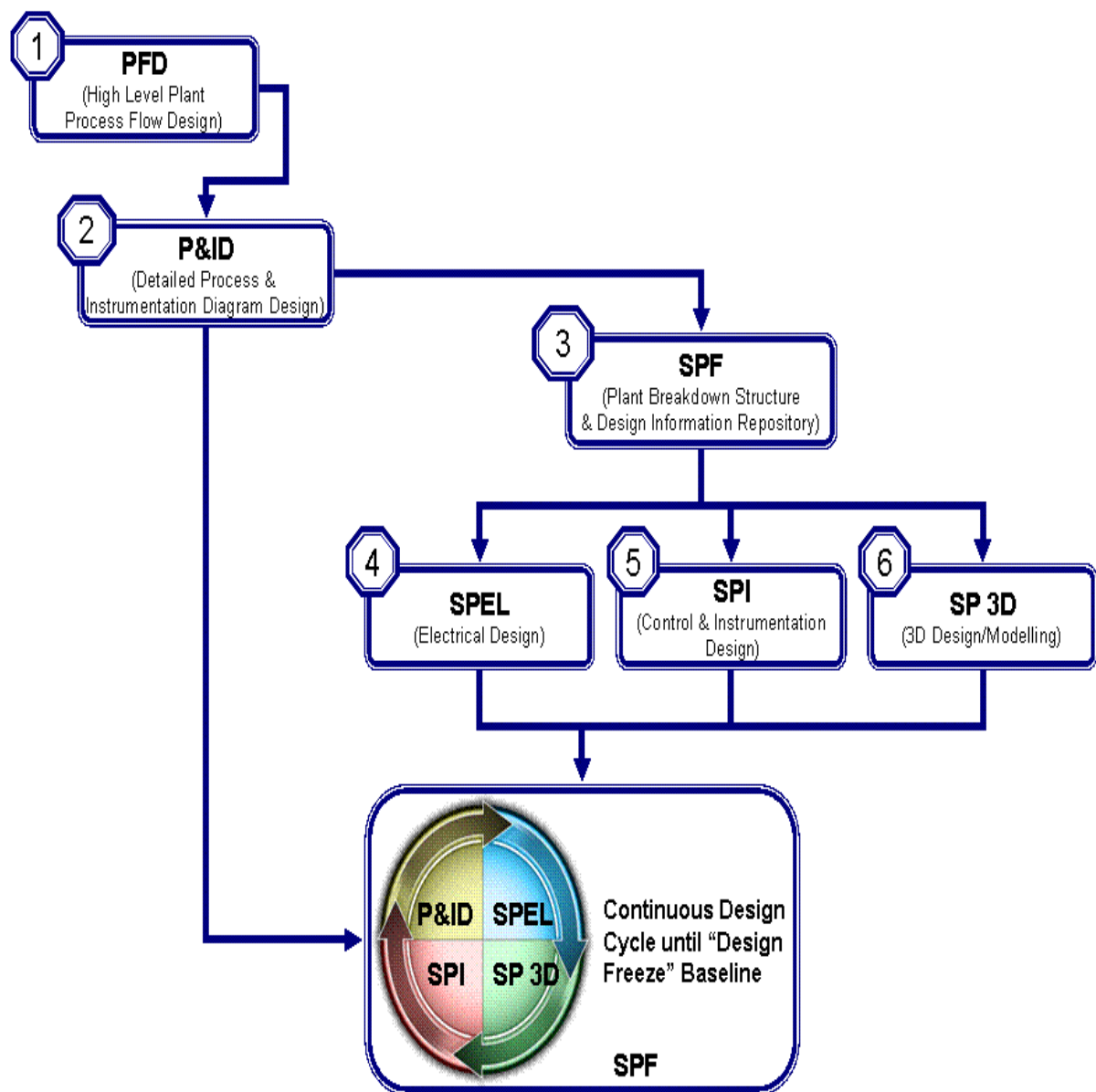
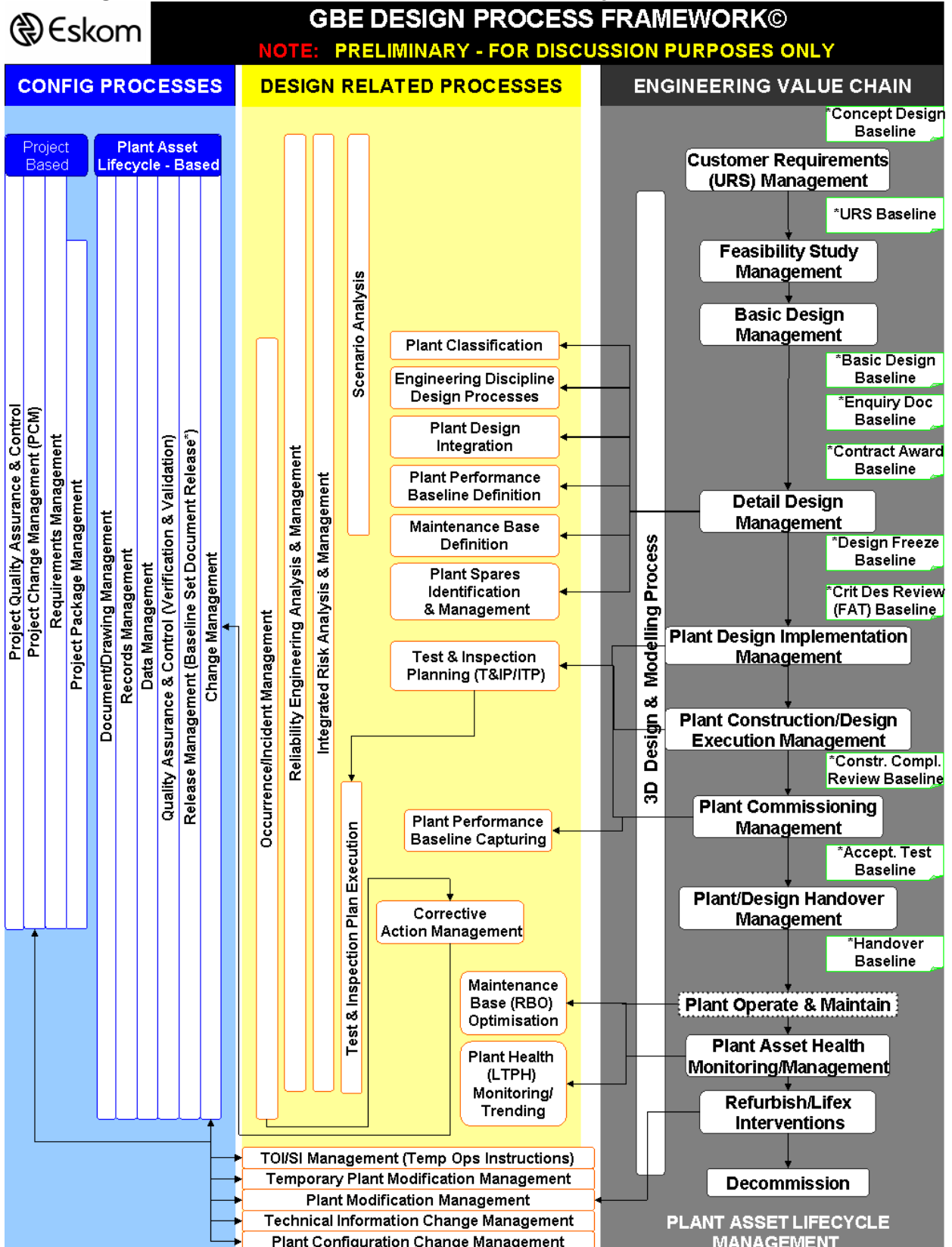


Figure 2–24 indicates the set of EPC engineering processes required to create, manage and maintain this set of Design Base information in the EPC stages of the asset lifecycle. This process landscape, however, covers an engineering work environment where there is limited need for engineering O&M processes as there would be little/no “in production” operational or maintenance influences that need to be considered for the management of Design Base changes.

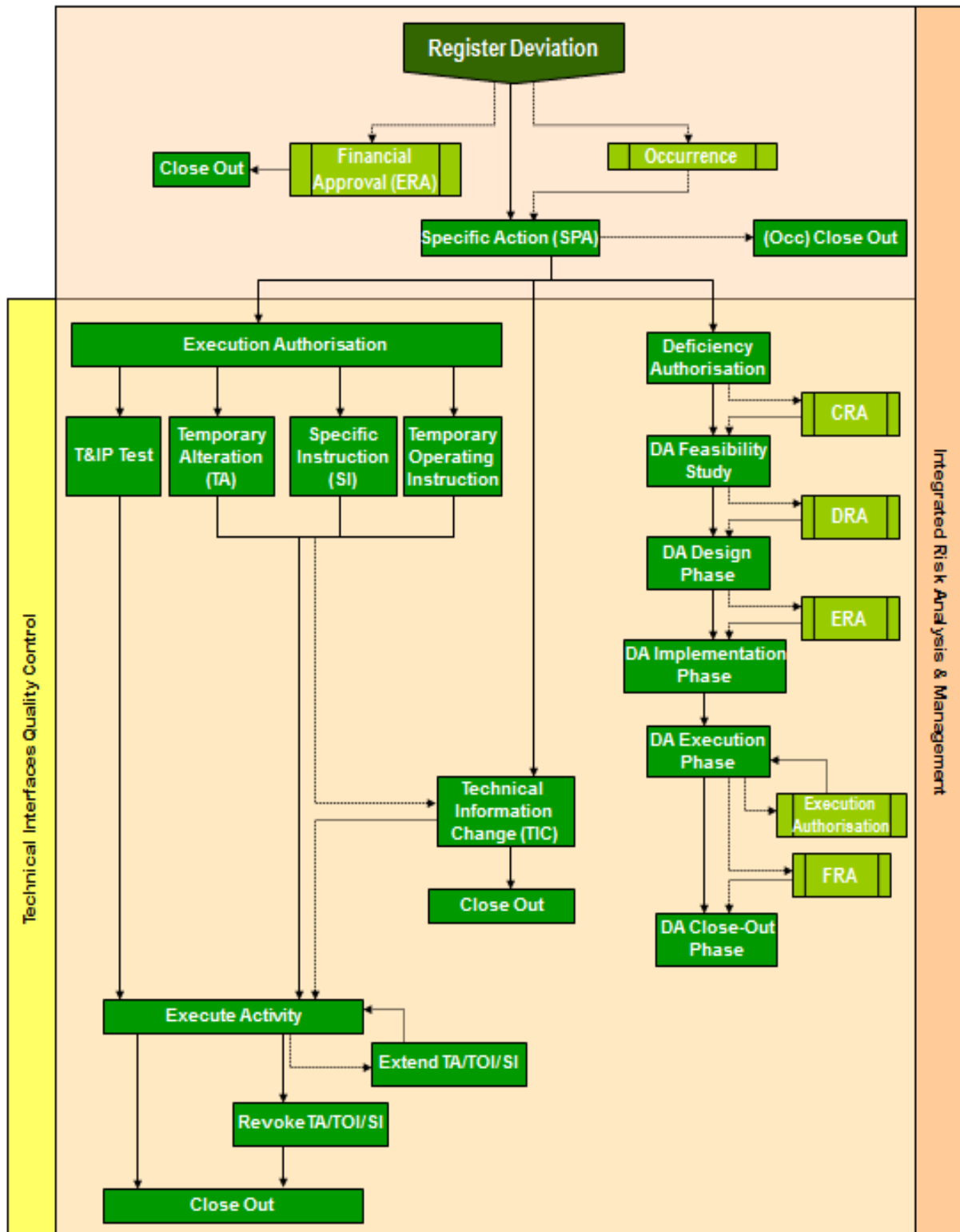
Figure 2–24: Process Focus in EPC Asset Lifecycle [Swanepoel, 2012d]



Consideration of production operation and maintenance issues would be aspects crucial for Design Base management and optimisation in the O&M environment (Figure 2–25). For an engineering company that only operates and maintains a plant asset, the focus would be on

O&M processes and data management depicted in Figure 2–25, but for those building as well as owning/operating plant (like the Power Utility secenario), both these engineering business process landscapes would have to be considered.

Figure 2–25: Process Focus in O&M Asset Lifecycle [Swanepoel, 2006]



Regardless of the approach and configuration option deployed, the ideal solution would have to be one that can deal with the complete engineering lifecycle for a typical process plant asset. This would ensure a “cradle to grave” management approach for the plant asset and accompanying Design Base information.

Given that most power utilities would operate in both the EPC and O&M asset lifecycle phases, a hybrid approach that covers both these lifecycle aspects and requirements is again not an uncommon approach. An obvious challenge with such a hybrid system is the increased complexity in system configuration, user management, and user interface design.

This portion of the literature survey discussed the typical complexities encountered with the implementation of integrated plant information management systems.

It highlights the integrated nature of the engineering business, establishes the requirements to implement an integrated plant information management system that covers Design Base content adequately and reflects the typical engineering processes required to manage such content. Aspects around information management delivery for business decision making as/when needed was also briefly discussed.

It covered potential system development and implementation approaches that can be taken; and highlighted potential challenges that can be experienced when selecting a specific approach. Challenges with technology adoption, system implementation strategies, software development, design and configuration approaches were discussed.

The different business needs regarding system configuration in different plant asset lifecycle phases were also discussed.

The literature survey confirmed that integrated engineering information system implementation requirements and considerations are much more complex; and that challenges experienced differs significantly from those experienced with Enterprise Resource Management System implementations.

2.4 Design Base Definition

This portion of the literature survey reviewed aspects around Plant Design Base definition and management.

2.4.1 The Importance of the Plant Design Base

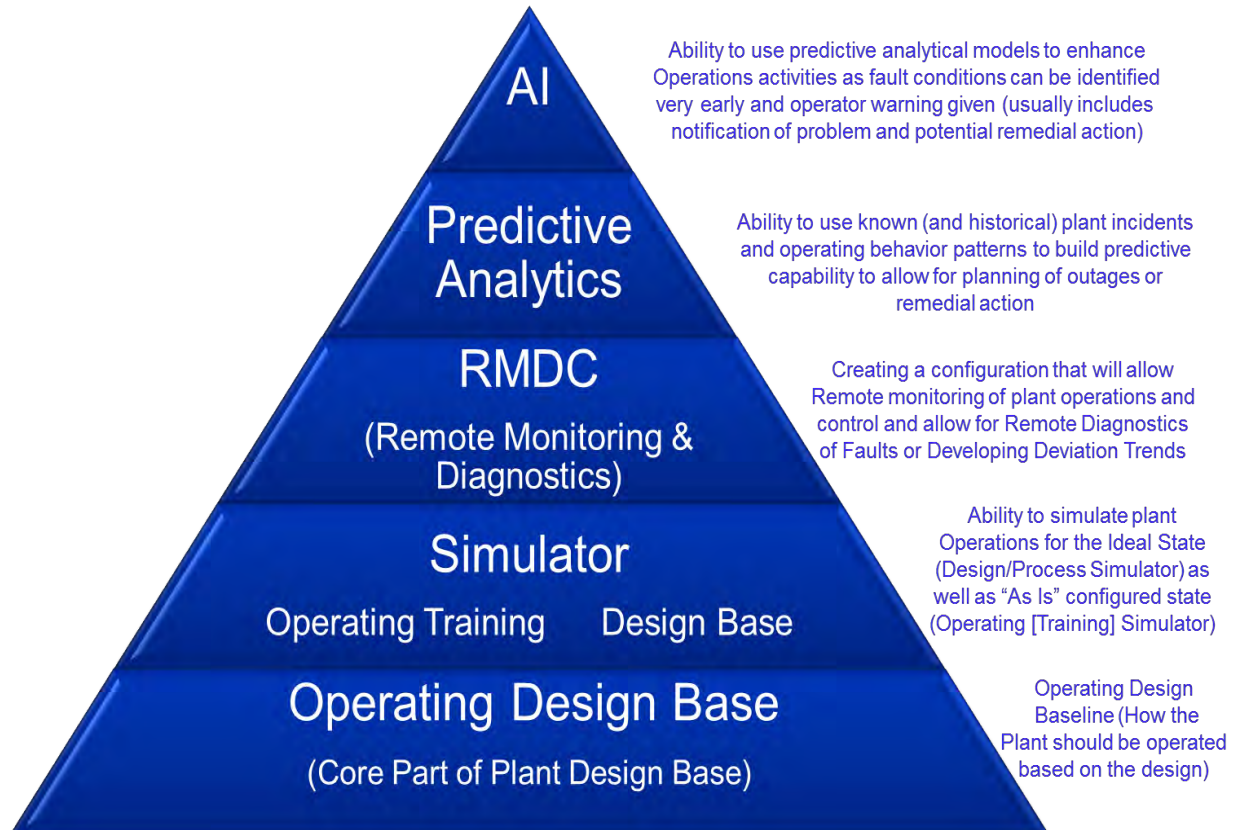
An Intergraph study [Botterill, 2007] states the goals of having core Design Base information available as being:

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

Their study points to the need of sourcing, validating and supplying that 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 specified in the Design Base.

Figure 2–26 shows how the Plant Design Base is the most fundamental requirement for creating and building an advanced plant analytics capability.

Figure 2–26: Advanced Analytics Capability Building Blocks [Swanepoel, 2014b]



The PAS–55 framework also uses the underlying principle 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 [ISO/PC251, 2014]. **This Framework also emphasizes 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 see 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 [Sun et al., 1997].

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 researcher’s view that it is important to apply rule sets in the management of information and when dealing with the ordering of large data sets for analytical analysis.

A key challenge for many plant owners would be the ability to define the core Design Base data set needed to enable this enhanced asset management capability, specifically on plants that were built before the electronic information era. A further challenge would be the ability to confirm that what has been sourced is sufficient to support the advanced analytics capability required for business improvement using plant information.

2.4.2 Consequences of inadequate Design Base Management

KPMG conducted a survey under large project owners, and reported that inadequate engineering Design Base and change control has a major impact on cost control and the ability to efficiently complete projects in time [KPMG, 2009].

An IDC Study also highlights the costs (obvious and hidden) of not being able to find or access the right information at the right time [Feldman et al., 2001].

An appropriate and validated set of core Design Base information is deemed a fundamental capability in order to deploy and use the more advanced predictive plant information analysis capability. Plant information analysis based on trusted Design Base information will enhance and improve business efficiency and decision–making; and will support the IPI–BIM and the SmartUtility Strategy desired outcomes developed by the Power Utility [Hales, 2013].

2.4.3 The Need for Managing the Design Base in an Integrated Solution

Levitt already saw the benefit of merging the CAD (visual) depiction of a design with actual Design Base information, processes and content as early as 1990 [Levitt, 1990]. At the time the software and programming complexity became the inhibitor for the researcher in question to prove the concept beyond theory, hypothesis, and basic prototyping concepts.

Despite the technology inhibitors, Levitt managed at this early stage to demonstrate the productivity savings that can be achieved working in an integrated engineering environment where the relevant information is readily available for decision-making purposes.

These savings are similar to that reported by Coopers and Lybrand that performed an independent study on the benefits of an integrated Engineering lifecycle information management system (managed environment) in 1997 [Coopers et al., 1997].

2.4.4 Design Base Definition and Maturity Levels

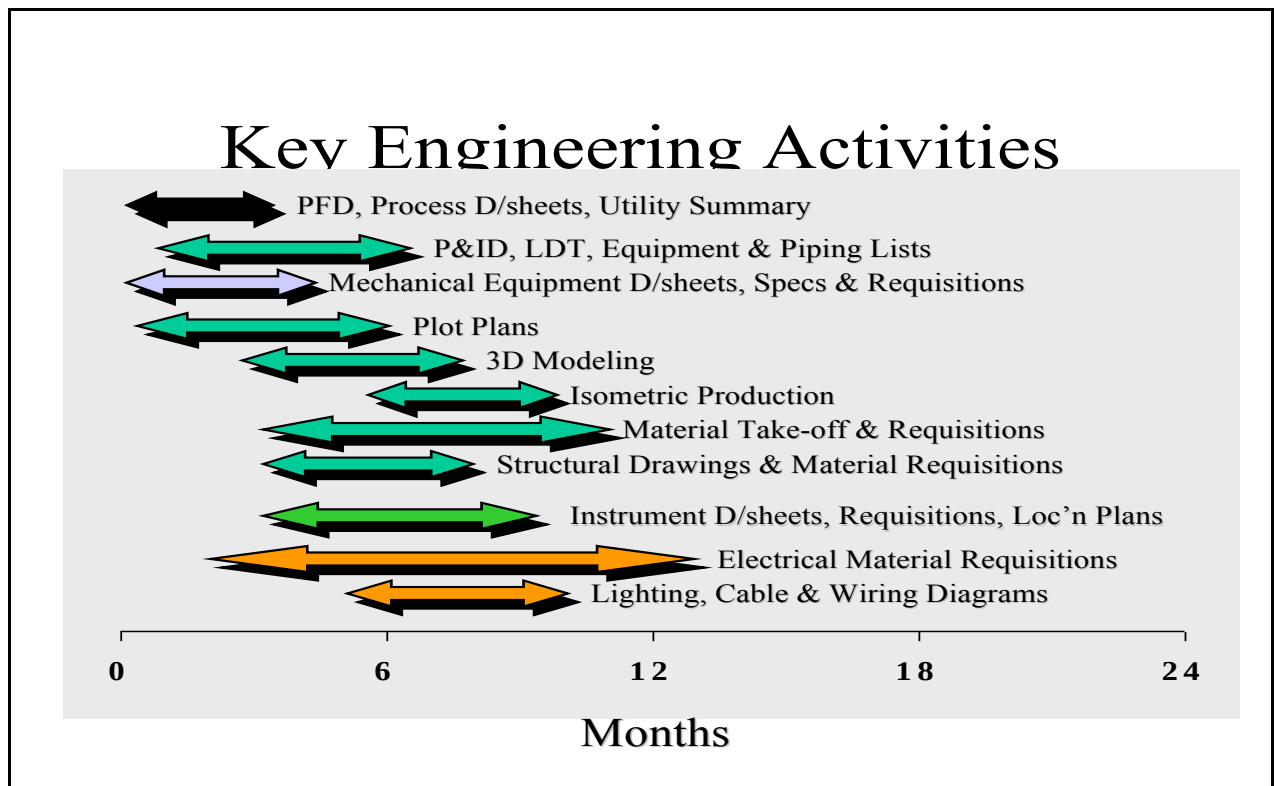
Searches of the EPRI research database [www.epri.com] returned very limited information or guidance on what is deemed Design Base information and scope in the power utility environment. The EPRI database content on the website and examples provided focused on actual design work examples rather than defining what makes up the plant Design Base.

The assumption was then made by the research that the core plant Design Base would form part of **minimum plant handover information requirements and can provide some guidance in defining core Design Base content.**

As a result, numerous examples were sourced from industry players in the EPC space in an attempt to define what makes up the typical Plant Handover URS content that Owner/Operators ask for and measure at handover of plant into commercial operation [Smit, 2009; Smit, 2008; Lewis et al., 1998/September 1998; Botterill, 2007; Intergraph, 2007].

The Intergraph Corporation further defined the impact of time delays and difficulty in sourcing value-adding Design Base content in the early feasibility and concept design stages (based on experience with their EPC clients). Figure 2–27 shows typical timeframes involved to obtain mature key Design Base artefacts like the Process and Instrumentation Diagrams (P&ID's) and electrical design diagrams [Intergraph, 2007]:

Figure 2–27: Typical key Design Base deliverable timeframes in a project timeline
[Intergraph, 2007]



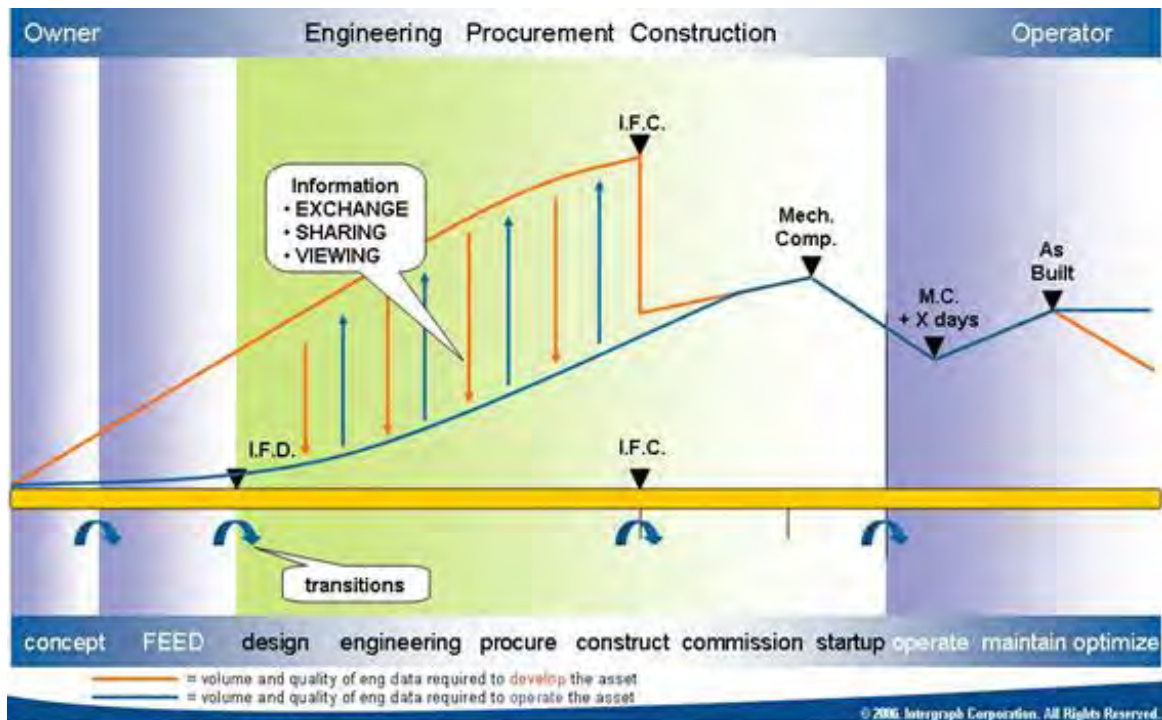
Intergraph also point out the issues around technical information supply over the EPC portion of the asset lifecycle if information exchange and handover processes are not handled properly. Continuous data and information losses can be significant if not controlled [Botterill, 2007].

This information loss will be further exacerbated by poorly defined hand-over procedures and governance. There is also a significant difference in all the project and technical information needed to create the new asset, as to what is needed by the Owner/Operator in the O&M cycle of the asset.

Intergraph postulate in their whitepaper regarding handover that the solution to this problem is incremental hand-overs based on a well-defined hand-over specification signed off between the project team and the owner/operator [Botterill, 2007].

If done correctly, Figure 2–28 shows the resultant end-state where core Design Base data delivery is eventually synchronized and appropriately exchanged, shared and viewed by all stakeholders involved in the process.

Figure 2–28: Information Volumes and Quality over Project Timelines [Botterill, 2007]



2.4.5 Design Base Classification Systems

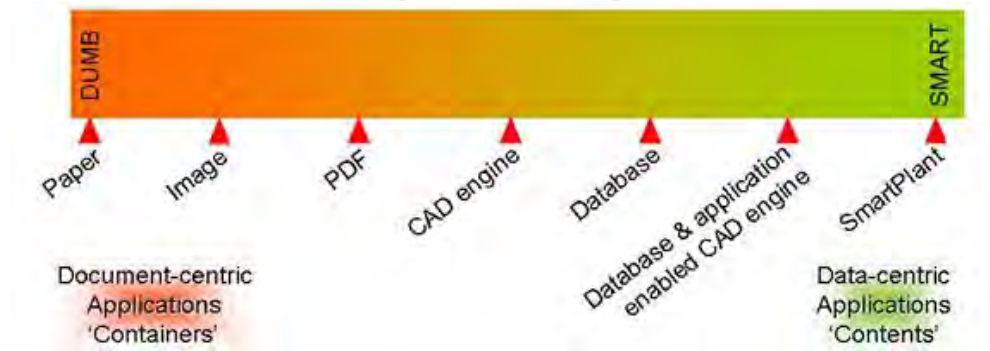
A key consideration for the research study was that plant information and Design Base management approaches prefer a document–centric approach and artefact type classification. The benefit of Document–centric data/information handovers on large projects is that it allows for a tighter QC process making it easier to measure non–compliance of information delivered.

The Intergraph study in their “Smartness Spectrum” points out the challenge with Design Base (also supported by further research literature survey findings in this research study) – i.e. the prevailing project execution preference to specify Design Base information delivery as document–centric rather than data–centric artefacts [Botterill, 2007] makes it very difficult to implement a **data-centric** Design Base where design base changes can be evaluated and compared at a data level (Figure 2–29).

The most commonly used document/drawing classification system in the Power Utility industry is the IEC 61355 framework. The IEC 61355 document classification framework defines a significant group of potential Design Base document/drawing artefacts that can make up the plant Design Base [International Electrical Commission, 2008].

Despite the current prevailing approaches and research survey findings, it can be stated that data–centric information delivery and availability should, however, remain the preferred option when it comes to advanced analytics work as it reduces the risk of data integrity issues due to data manipulation and re–creation.

Figure 2–29: Evolution to smart capability – Document to Data–centric applications [Botterill, 2007]



2.4.6 The Ideal versus a *Practical/Achievable* Plant Design Base

In 2006/7 the Power Utility defined what it believed to be the “Ideal” Engineering Baseline set of information as part of the process of defining the Plant Engineering Baseline Process and related workflow. This dataset is shown in the table in Annexure A. This data–set was deemed the starting point for the core Design Base definition scope of the research study.

Subsequent to this exercise, the Engineering System Prototype project executed in 2009–2012 [Swanepoel, 2012b] suggested a minimum set of Design Base content (indicated in Figure 2–30 below) that should be managed within its own unique business process (with its own unique set of meta–data attributes to be used for historical trending).

Figure 2–30: GEDI Project – Proposed Typical Design Base Content [Swanepoel, 2012b]



The project proceeded to categorise this content into the four primary realms of the Design Base (Figure 2–22), i.e.

- Design Base
- Operating Base
- Maintenance Base
- Reliability (Safety and Risk) Base

Subsequent to this prototype project, a further business optimisation project (The “B2B” Project) was implemented in 2010– 2012 where a new set of Design Base artefact content was proposed after giving due consideration as to the overall age profile of the organisation’s generation fleet assets and what is feasible and achievable [Phalime, 2012].

This portion of the literature survey confirmed the importance of the plant Design Base, specifically for the ability to create advanced analytics capability. The impact of inadequate Design Base management was discussed, confirming the need to manage this information better in an integrated, controlled system platform.

Challenges with Design Base content sourcing and maturity levels during the asset lifecycle were also discussed. The use of information classification systems to improve Design Base content management was evaluated. The outcome of Design Base definition work done in the Power Utility was evaluated to determine the baseline of what can be considered candidates that would define the ideal or **core** Plant Design Base content.

2.5 Information Delivery Technology

In this section of the literature survey, aspects around information delivery options and technology are researched and evaluated.

2.5.1 Value of Integrated Information Delivery

Numerous software and service providers’ report significant cost savings in plant information automation and standardisation initiatives, but the savings from taking a totally integrated information delivery approach beyond just operational control data have not been holistically documented [Emerson, 2003].

Pennwell shows with their industry survey and research what information challenges and typical business drivers are pushing energy industry (and virtually all industries) to look at more integrated and trustworthy information delivery options and solutions [PennEnergy et al., 2012].

Business Goal	0 - Not a Priority	1 - Low Priority	2	3	4	5 - High Priority
Improve business insight and	2%	1%	1%	16%	42%	38%
Competitive advantage	2%	1%	2%	18%	37%	40%
Faster handover of capital	2%	1%	6%	21%	30%	40%
Faster turnaround on	2%	1%	6%	21%	50%	20%
Provide an enterprise wide	2%	3%	2%	18%	45%	30%
Improve collaboration (Internal	2%	1%	2%	21%	40%	34%
Mitigate risks	2%	1%	3%	16%	40%	38%
Reduce costs	2%	1%	3%	16%	38%	40%
Ensure compliance	2%	1%	2%	16%	40%	39%
Optimize business processes	2%	1%	1%	16%	40%	40%
Improve operational efficiency	2%	1%	1%	14%	40%	42%

Rozados and Tjahjono state that they deem 3D Visualisation a **future capability** with little exploitation to date [Rozados et al., 2014]. A comparative review of the Gartner Hype Cycle over the past 4 years [Katzenelson, 2015] however challenges the views of Rozados and Tjahjono that 3D should be considered a future technology investment option.

8 | Technology investment priorities and their future impact on manufacturing



2.5.3 3D Laser Scanning for 3D Visualisation Platforms

Jones states that laser scanning will play a major future role in the design and construction world [Jones, 2012]. Early adoption may allow the organisation to develop a significant competitive edge over late adopters of the technology.

Jones, as well as Jacobs very effectively predict and demonstrate how 3D laser scanning will become a major enabler in design re-engineering (Design Base back-fit) and construction activities (new build/refurbishment projects). [Jones, 2012; Jacobs, 2005/2006a/2006b/2006c]

Greaves and Hohner states the numerous benefits of using 3D Laser scanning in plant design, construction and operation [Greaves et al., 2009]. Their white paper further points out the value of a 3D visual interface when it comes to the information evaluation and interpretation. The benefits of enhanced understanding and improved collaboration are also pointed out.

Despite the researchers pointing out that they observe low technology uptake because of Brownfields plant owners having an (incorrect) historical view that the technology is cost inhibitive, not mature and would not add value, they conclude their research study by listing cost savings for laser scanning showing a reduction of total installed cost for Brownfield projects by 5–7% and reduced contingencies for rework to less than 2% compared to traditional plant survey methods.

2.5.4 3D Visualisation Technology Information Delivery Complexity

Research indicates that many companies have very complex information architecture for plant engineering information management, especially if 3D Models (or visualisation technology) is included into the information data model. See example in Figure 2–34.

A PennEnergy industry survey indicated that 68% of respondents are either evaluating or implementing more effective Enterprise Content management solutions to solve the challenges of managing information for engineering, capital projects, and asset management [PennEnergy, 2012].

Figure 2–34: Sample of Complex Visual Information System Architecture [Swanepoel, 2014c]

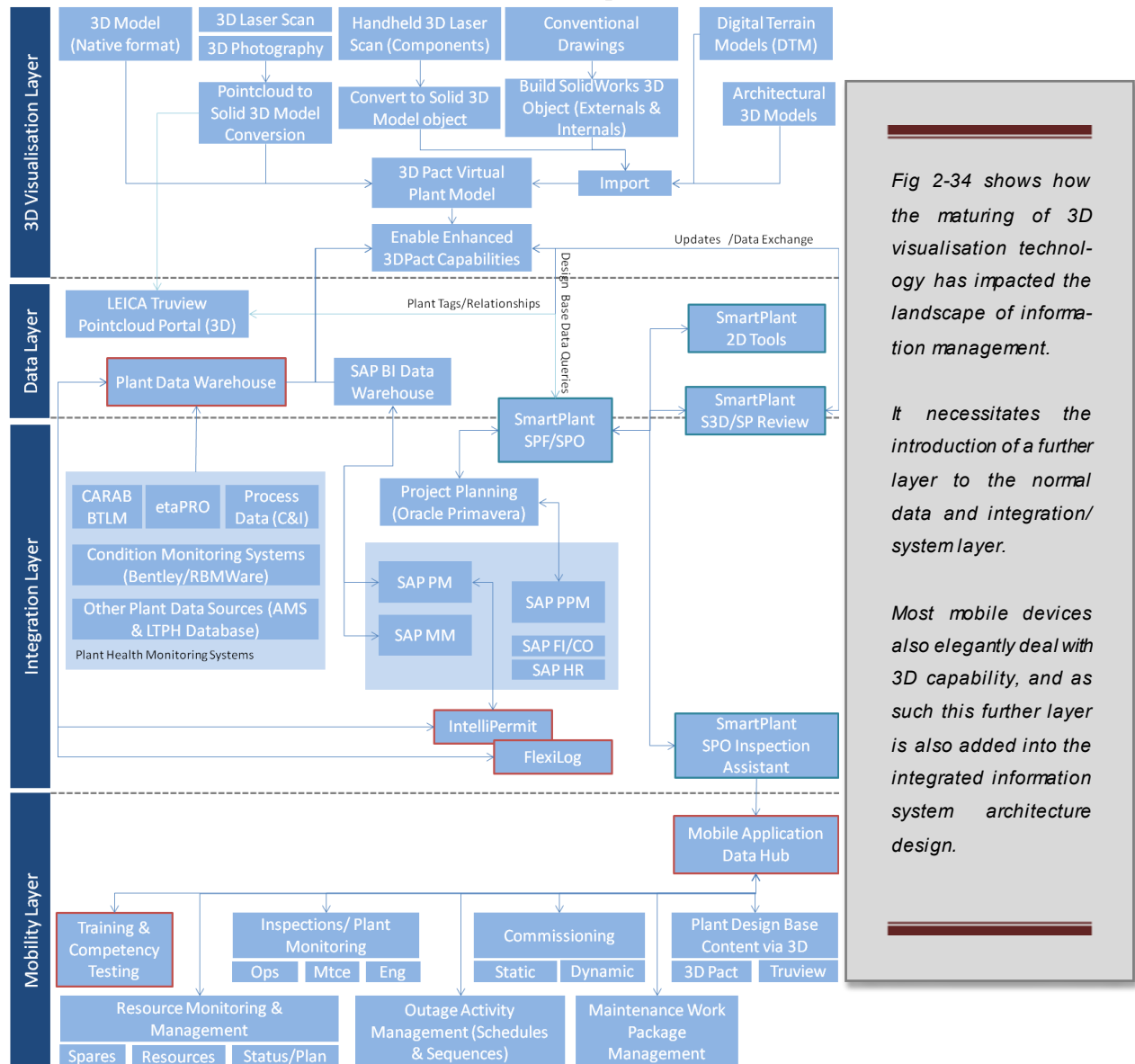


Fig 2-34 shows how the maturing of 3D visualisation technology has impacted the landscape of information management.

It necessitates the introduction of a further layer to the normal data and integration/system layer.

Most mobile devices also elegantly deal with 3D capability, and as such this further layer is also added into the integrated information system architecture design.

This complexity is usually driven by a perceived risk to the business of information that is managed in silos and not viewed in a consolidated fashion. These perceived risks many times do materialise, resulting in:

- Data quality and integrity issues.
- Poor or incorrect decision making.
- Non-optimal Infrastructure and resource planning.
- Poor resource productivity levels and duplication of effort.

This required reduction in complexity is no small challenge given the technology migration towards more worker mobility, advances in smartphone technology and capability and the “information anywhere anytime” mindset of the new generation knowledge worker.

Although Visualisation and 3D capability enablement further adds to this complexity, prototype research and information sharing projects have demonstrated that this is a much more intuitive way of accessing information and results in faster user acceptance and technology adoption.

2.5.5 Portal Technology Advances and Benefits

Wheeler states that the most obvious benefits of using portal technology are:

- Reduced infrastructure costs due to centralised administration.
- Customization capability (thus catering for the needs of different audiences).
- Increased collaboration.
- Consolidation of web sites (intranet and extranet web–presence infrastructure) is possible.
- Better security and integrity of data published and used in the organisation.
- Easier and more user–friendly technology. [Wheeler, 2012]

Daigle points out, however, that there are considerations around the implementation of portal technology that usually result in very specific policies and or instructions issued for the use of the technology. Key considerations according to these researchers are intellectual property management issues, security and access control to data and ownership of data [Diagle et al., 2002].

2.5.6 The Nerve Centre Concept

The Nerve Centre project [Reddy et al., 2013] was initiated from a Strategic Review of 2010 performance by the Utility and key operational management concerns around the performance levels [Apps, 2012]. One of the recommendations of the Strategic Review was the need to create a centralised information “nerve centre” that contains an integrated information infrastructure and associated decision model.

Research associated with “Nerve Centre” infrastructure and typical requirements indicate that it should have capabilities that allow the organisation to better manage service levels, identify and evaluate risk, have better situational awareness and the actions taken, as a result, improved predictive capability and the ability to perform real–time asset management.

The aim of the Utility’s project is to establish a national central point to serve as the intelligence gathering and information coordination hub that gives the customer and Internal Business Management a high level perspective on electricity delivery, allowing the utility to pro–actively manage various issues and risks pertaining to electricity delivery [Reddy et al., 2013].

Exposure to the thinking and approach of this Project (as part of the bigger SmartUtility Implementation Program [Hales, 2013] provided useful input for the research study regarding potential approaches for the prototyping planned for the information visualisation scope of the research study.

The nerve centre is a potential alternative to portal technology and evaluation between the two information delivery technology options formed part of the research study in order to determine the most feasible, cost-effective approach for information delivery within the IPI-BIM Framework.

The literature survey on information delivery technology evaluated the value of improving information delivery options reported in industry – specifically the value proposition of making information available in more pervasive, user friendly and reliable system platforms.

The maturity of 3D visualisation technology was evaluated to support research study scope of work and the hypothesis posed that it is mature enough to become a key enabler for information delivery and display. This included evaluation of the maturity and use of 3D Laser scanning technology in industry.

The impact of information infrastructure complexity was evaluated and the impact this will have on data quality and decision making capability.

Finally, the use of “Nerve Centre” technology and the drivers for using this technology was evaluated. This review was undertaken as it was proposed as the viable alternative to portal technology.

2.6 Advanced Analytics

In this section of the literature survey, aspects around the use and development of advanced analytics for plant decision making are evaluated. It considers aspects like maturity and advancements in advanced analytics technology, and the industry drivers that would result in a faster technology adoption. The literature survey also investigates why ERP systems have had a much more significant uptake in BI/Advanced analytics technologies when compared to Operational Technology platform systems like SCADA systems.

It also considers the impact that availability of the required plant historical information can have on analytical endeavours.

2.6.1 The Drivers for Advanced Analytics

A Study by the Energy Central organization in global power utilities in 2008 has indicated that there are significant gaps identified in managing the human capital of technical and complex business organisations [Emerson, 2003].

The study emphasizes the need to address skills losses, having improved automation and control system intelligence to assist with knowledge transfer and managing complex process plants. The Emerson study concludes that abnormal situation **prevention** is one of the biggest potential productivity gains in the operating space.

The current Power Utility age distribution of specialised skilled operators and the difficulty in training and skilling new skilled resources in time, closely align with the research findings of an Energy Central Workforce Management study [Causey, 2006]. It is anticipated that the Generation business area will lose a significant percentage of its most skilled Operators and specialists over the next 2–5 years. Finding more innovative ways of knowledge transfer and training is, therefore, becoming a key imperative.

An Emerson study confirms that some of the biggest challenges in complex process plants are overwhelmed operators and increasingly complex plant operations and control system technology that demand a new approach to managing plants more efficiently and predictively [Emerson, 2003].

The challenge of alarm management and the mass of control data generated in upset conditions is confirmed by EEMUA research and standards. Modern plant control systems in complex process plants generate hundreds of alarms in upset conditions. The chances of a positive operator response significantly decreases significantly when more than 10 alarms are activated at the same time as described on Figure 2–35 [Mayssat, 2009].

With increased automation and more elaborate and capable control systems, the amount of data and signals to be evaluated also increases exponentially, further bombarding the operator with data to be considered when making plant decisions and taking corrective steps to rectify the plant condition anomaly.

Giroti's research demonstrates how the introduction of smart technology exponentially increase data volumes— from 300 Gb per year to 3 TB within a year of introducing the smart technology, and up to 12Tb's of data by year 4 [Giroti, 2010]. Pointing to a future scenario that will get worse and not better as more and more Smart Technologies are introduced into Utilities.

Figure 2–35: EEMUA findings of Alarm Rates and Alarm Statistics in Typical Process plant [Mayssat, 2009]

Number of alarms displayed in 10 minutes following a major plant upset.	Acceptability
More than 100	Definitely excessive and very likely to lead to the operator abandoning use of the system
20 – 100	Hard to cope with
Under 10	Should be manageable – but may be difficult if several of the alarms require a complex operator response.

EEMUA 191 – Guidance on Alarm Rate Following an Upset



Sample EEMUA Results – Total Plant for One Month

One of the most efficient training methods for new operating incumbents is the use of virtual and process plant operator simulators. By enabling an operating simulator that is closely coupled to the plant Design Base data and operating envelopes, the operator can simulate and test scenarios and visually see the outcome of changes without impacting operations of the actual plant.

Gomez states that the most successful way of improving mission–level control resilience is to move real–time cognitive behaviour responsibility from humans to the system during run–time and rather focus on training and preparing/prompting the operator for the correct response during upset conditions [G’omez et al., 2007].

Columbus states that from his research and industry surveys that:

- “47% of manufacturers expect big data analytics to have a major impact on company performance making it core to the future of digital factories.
- 36% expect mobile technologies and applications to improve their company’s financial performance today and in the future.
- 49% expect advanced analytics to reduce operational costs and utilize assets efficiently”.

[Columbus, 2014]

Siemens research studies indicate predictive maintenance as the number one big data application for industry confirming the researcher's view that industry has realised the value of its plant information, but because it is generated in such large volumes, analytics to make sense of it is still seen as "locked potential" [Siemens, 2014].

The capability of unlocking this potential will become one of the key business differentiators for production and process plant performance excellence differentiators in future.

In their research study, Deloitte found that the use of big data, advanced analytics, visualisation and artificial intelligence capability are becoming significant technologies that will dictate future success [Lipták, 2006]. The industries they surveyed, in general, indicated a 50+% increase in these technologies in order to make them more competitive.

Their view is shared by Columbus who argues that augmented reality, big data analytics, 3D/augmented reality is seen as the most disruptive technologies that will start impacting the supply chain and manufacturing plants of the future [Columbus, 2014].

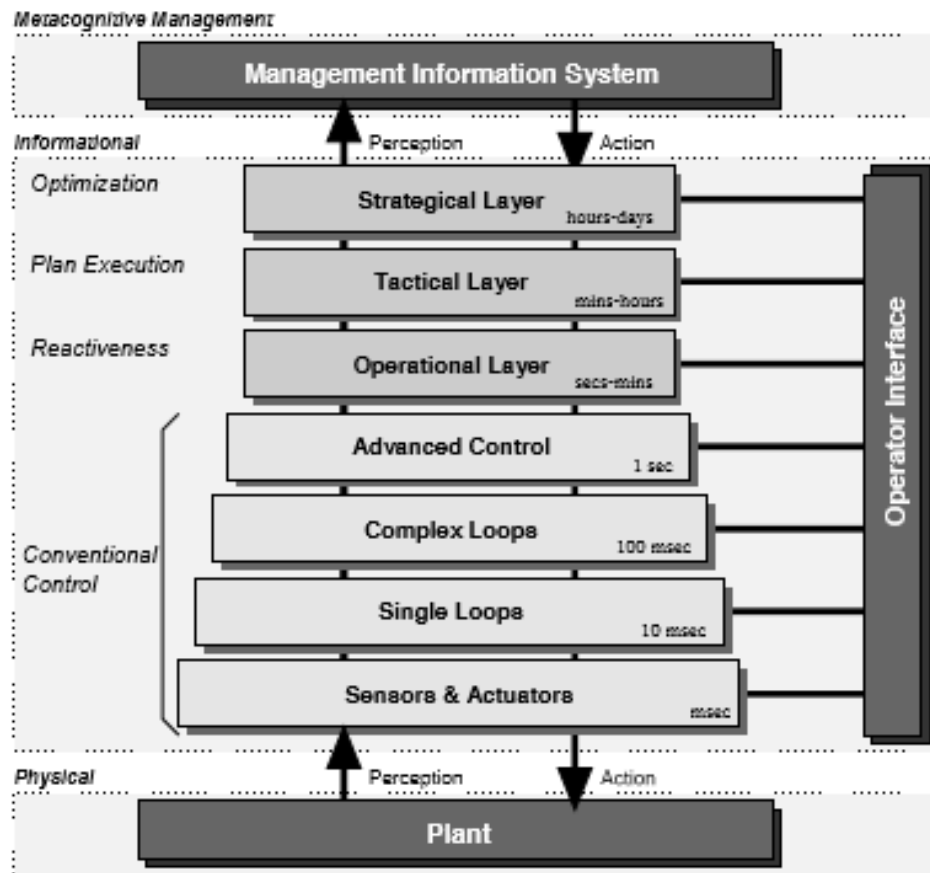
2.6.2 ERP versus SCADA System Analytics

Business intelligence (BI) and advanced analytics technologies have been applied with great success in ERP type systems. Numerous software– and IT service providers report significant cost savings in plant information automation and data analytics initiatives, but the reported savings are generally confined to a small research or focused area of plant management software application [Emerson, 2003]. The savings from taking a totally integrated approach beyond just operational control data have not been holistically documented.

From the literature survey, key issues seem to be the "big data environment" of SCADA as well as the frequency and volume of information captured in SCADA systems when compared to ERP systems. Dassault Systems and Marszal very aptly show how data capturing timeframes differ between conventional ERP systems (level 3 and 4) and SCADA systems (level 1 and 2) – from daily to monthly frequencies in ERP systems to the milliseconds in SCADA systems [Dassault, 2012; Marszal, 2002].

This demonstrates the exponentially more challenging environment of big data analytics in SCADA environments where data capture frequencies exponentially increase data volumes to be assessed. More importantly, Marszal's study indicates the typical decision response times required given the data and information layer where the data is captured (Figure 2–36), providing a clearer picture of the challenges facing a plant operator in today's very complex plant process and control environments [Marszal, 2002].

Figure 2–36: Response times to data captured at different Information Layers [Marszal, 2002]



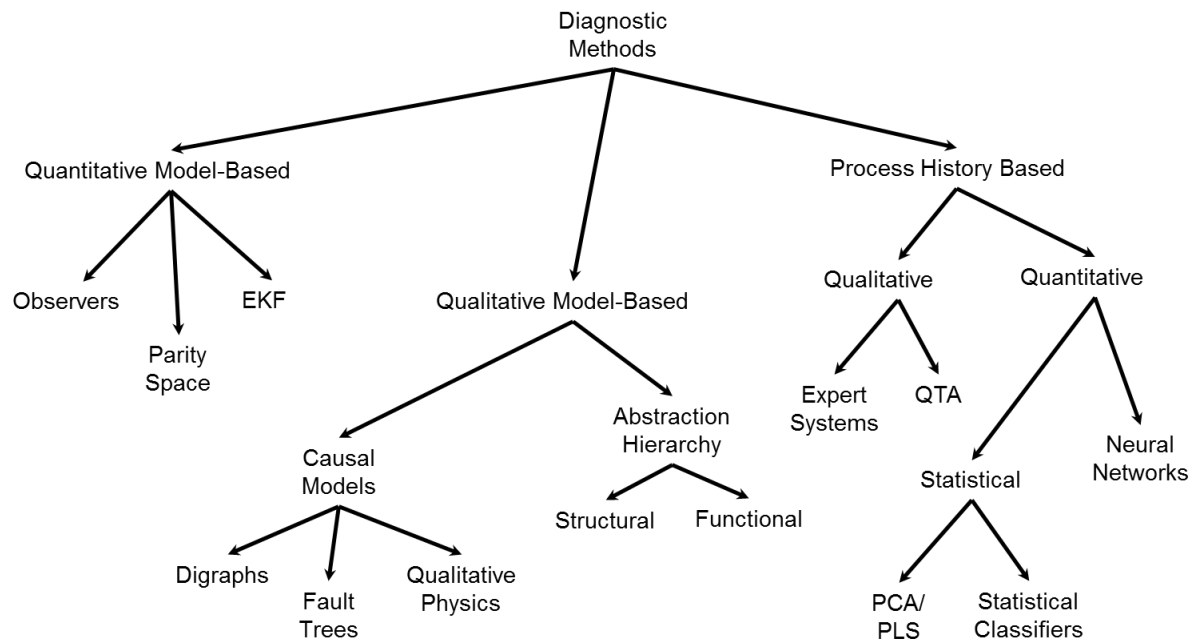
2.6.3 Potential Analytical Methods and Usage

Giroti very effectively poses the challenge for most industries – having data at your disposal (and lots of SCADA data at that) does not mean you have the means to develop the required analytical models or even do the analysis. His research proposes that a Complex Event Processing infrastructure would be required to detect system and business events [Giroti, 2010]. This infrastructure would further need to detect events “just-in-time”.

With so many data entries in a typical SCADA XC&I Control system, the detection of the proverbial “needle in a haystack” fault indicator trigger must work day after day, month after month, with little to no room for error. Giroti’s research states that the biggest challenges to building this fault analytics capability are transaction completion performance, event handling performance, and database performance [Giroti, 2010].

Venkatasubramanian demonstrates with research that a combination of diagnostic algorithms and analytical methods (Figure 2–37) would most likely be required to perform advanced analytics of plant processes, especially when the plant and systems are complex and dependent on each other [Venkatasubramanian et al., 2002].

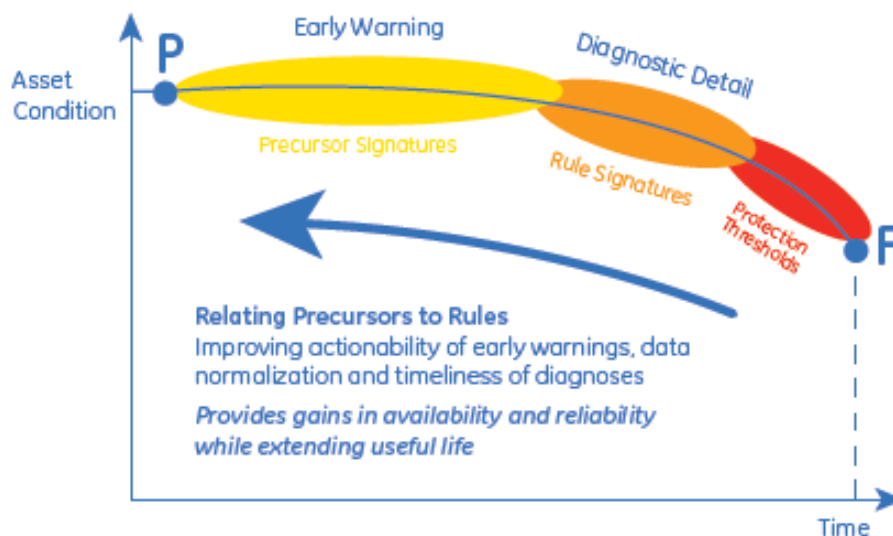
Figure 2–37: Classification of Diagnostic Algorithms [Venkatasubramanian et al., 2002]



The primary aim of advanced analytics would be to reduce potential failure risk by being able to identify, address and action impending failures earlier. The target would be to initiate corrective action in the “Early Warning” phase of failure (Fig.2–38) instead of waiting for more rule–based or protection threshold signs of a failure.

Advanced analytics would allow an operator to identify plant upsets much earlier and potentially even create the opportunity for the control system to intervene with plant process corrections to address abnormalities before it results in a unit trip.

Figure 2–38: Failure Curve in Predictive Maintenance Management Environment [Rohling, 2014]



2.6.4 Using Analytics for Plant Asset Condition decision-making

The International Atomic Energy Agency (IAEA) has developed a framework in addition to the conventional PAS-55 framework where decisions regarding assets are also subjected to an integrated risk assessment process. In this framework, the importance of taking a holistic approach to decisions on asset health is emphasised [ISO/PC251, 2014].

The PAS-55 framework also makes it clear that good decisions regarding plant assets should be balanced between deterministic **and** probabilistic analysis to provide the required insights, perspective, comprehension and balance in the decision-making process [IAEA, 2011].

It was for this reason that this research study aimed to demonstrate the importance of defining, managing and **understanding** the plant Design Base (and by direct implication the Operating Baseline) in the building of truly useful advanced analytical models for production optimisation and business improvement.

An IAEA study confirms the critical importance of a well-managed, integrated plant database where all critical plant Design Base information is contained [IAEA, 1997]. The importance of Design Base information and operational design intent understanding is also shared by Willis. [Willis et al., 1994]

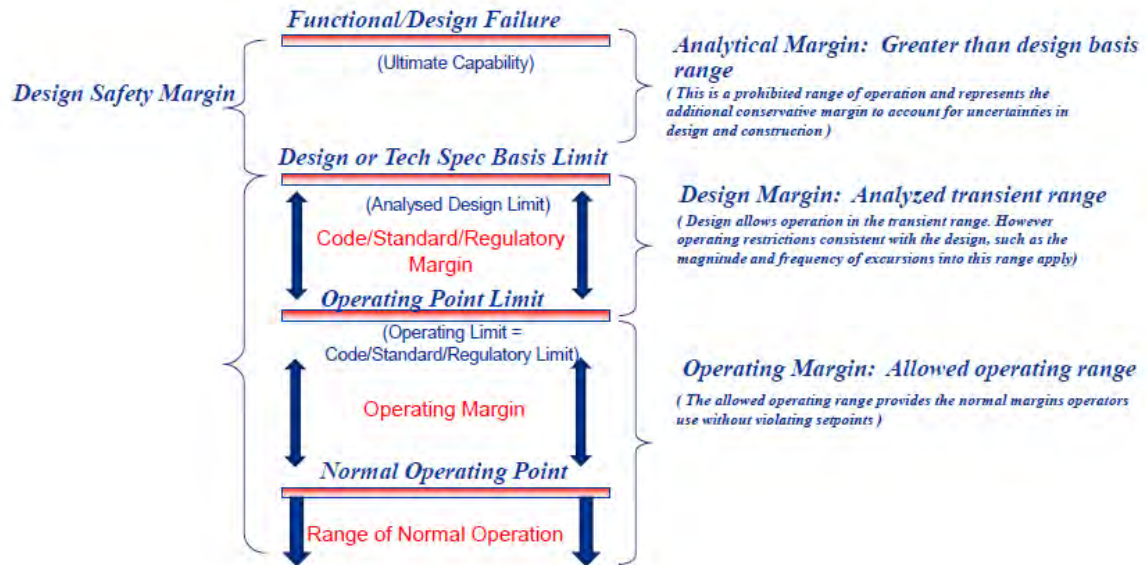
As an example, the requirement to thoroughly understand control philosophies and the subsequent control processes and system loops installed to support these is crucial for advanced analytics model development.

Similarly, having insight on the design safety margins used on older plants would define to what extent the design safety margin can be challenged to increase plant outputs (based on the presumption that plant designs in the late 1950–1970's used very conservative design safety margins).

Advanced Analytics can potentially allow for operating and control hypothesis testing beyond the Design Basis normal design limits (Fig. 2–39 below) as indicated by Parlour in his INPO CMBG Workgroup meeting presentation on Design and Configuration management practices [Parlour, 2007]. This is based on the fact that it would be a simulation of plant conditions in a virtual plant and not straining the actual plant to test hypothesized change models.

The use of advanced analytics can also further support Lipták's research recommendations that process constraints can potentially be modulated to increase production output [Lipták, 2007].

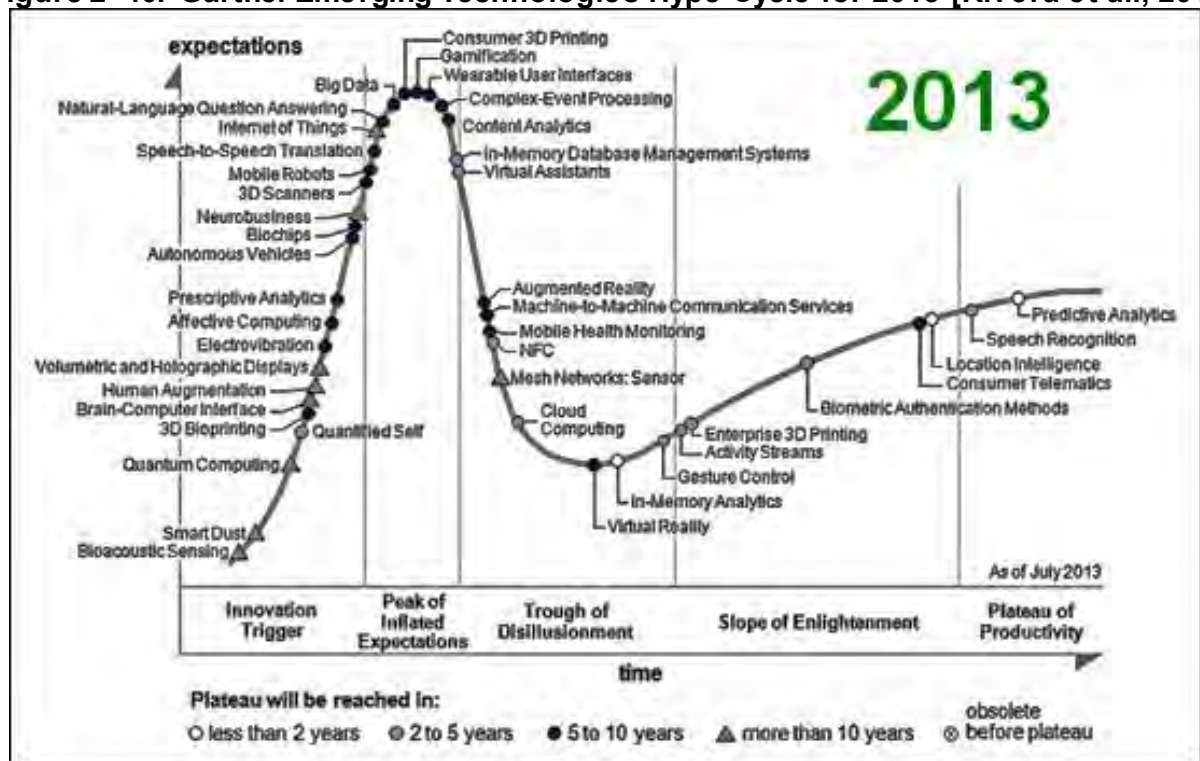
Figure 2–39: Pushing the boundaries using Advanced Analytics [Parlour, 2007]



2.6.5 Advanced Analytics and AI Maturity

The Gartner™ group has developed a term called the “hype cycle” where new and emerging technologies are tracked in terms of industry review, uptake and eventual implementation and production benefit. Since 2013, there has been significant growth in elements considered to be part of the AI environment (e.g. Big Data, Prescriptive analytics, predictive analytics, etc.) – see Figure 2-40 [Rivera et al., 2013].

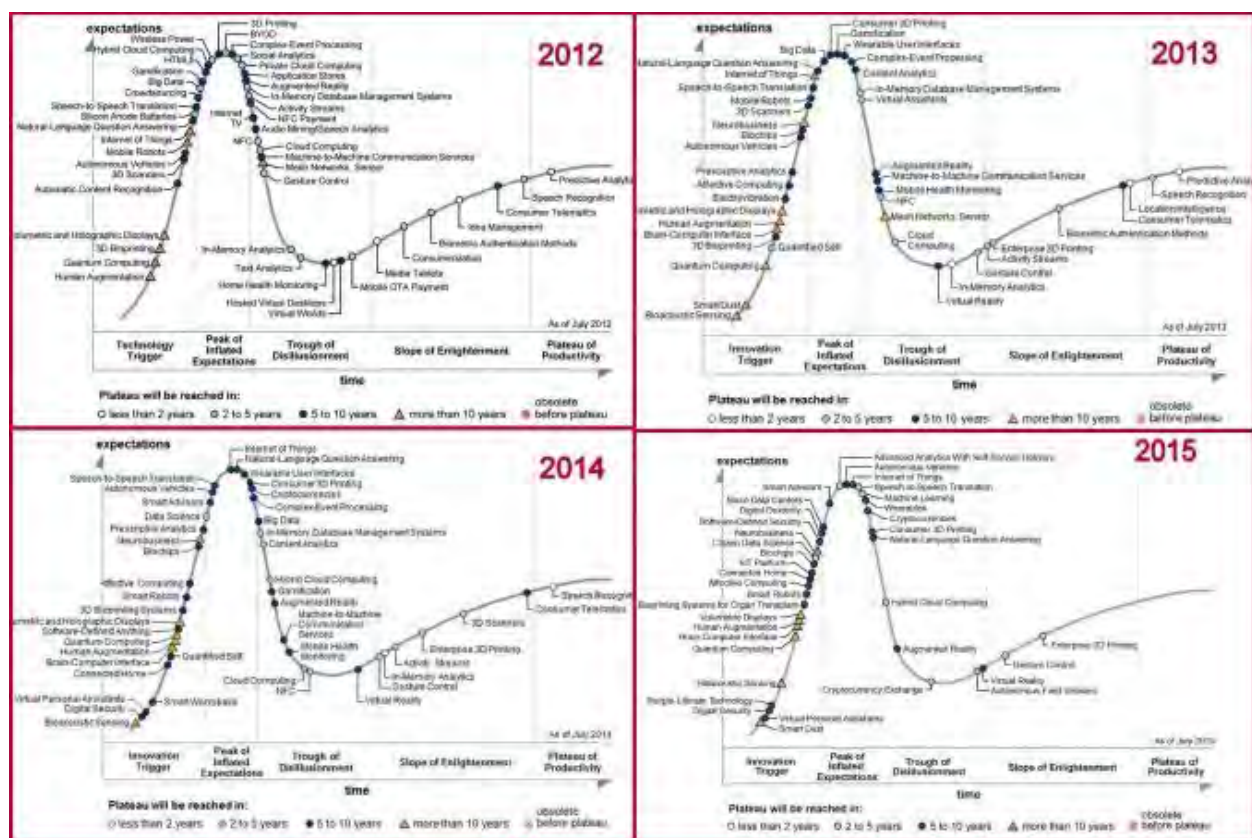
Figure 2–40: Gartner Emerging Technologies Hype Cycle for 2013 [Rivera et al., 2013]



The fast pace of technology maturation in the advanced analytics technology space is depicted in the comparative analysis of the Gartner Hype Cycle (Fig. 2–41) over a 4–year period (2012 – 2015) [Katzenelson, 2015]. It aptly demonstrates how technologies perceived to have a real business value proposition (e.g. advanced analytics, virtual and augmented reality) are fast becoming candidates that will move to the “plateau of productivity” and are maturing at a pace much faster than some other technologies.

As such, business leaders will consider investment in these technologies to be lower risk and would be open to supporting prototypes in their businesses to prove its value in an operational business environment.

Figure 2–41: Emerging Technology maturing over 4 years – Increased use and faster deployment [Katzenelson, 2015]



The Nuclear industry has commissioned a study on advanced AI on control systems, and the development of advanced algorithms and fault models is indicated in this study as exciting new future trends that can have a major impact on operator efficiency in dealing with plant upsets. [IAEA, 1997]. Sanz, however, states in his research that AI has had limited success and use in safety critical applications due to algorithm maturity, robustness and repeatability of some algorithm rules [Sanz, 2010].

The Nuclear industry study further confirms the importance of applying rule sets in the management of information, specifically when dealing with large datasets. The study indicates that although analytical methodologies like “fuzzy logic” are powerful, it needs well-defined rule-sets to be value-adding to the outcomes needed for meaningful plant health decisions – such rulesets that are usually based in the Design Base of the plant in question [IAEA, 1997].

Brummel in his research demonstrates the importance of building the correct analytical rules and models on which the fault analytics should be based [Brummel, 2006]. Most of these advanced analytical systems would still utilize the typical functional layering one will find in a complex industrial process control system. His research demonstrates the use of AI as a means to improve plant operator/controller competency.

Ibargüengoytia through their research demonstrates how the use of decision theory together with probabilistic modelling will provide more robust diagnostic capabilities [Ibargüengoytia et al., 2009].

Literature surveys [Uraikul et al., 2006; Mylaraswamy et al., 1997 and Rao et al., 2000] confirm that the holistic review and evaluation of the Operating Design Base (as stated in the research study hypothesis on core Design Base data) is critical to successful plant condition analysis and subsequent decision making.

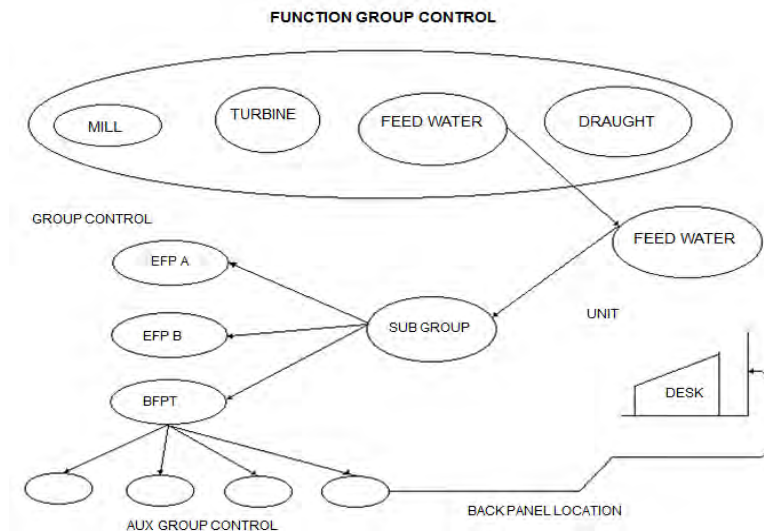
Chae’s research study very adequately prove their hypothesis number 1 that data accuracy will improve manufacturing planning quality and result in positive operational performance improvements [Chae et al., 2014].

Further analysis and research into their research conclusion find confirmation in an evaluation of the inter-dependencies between plant process systems and control in the Brownfields power station that forms part of this research study.

The ability to address multiple failure modes and failure states in the same algorithmic model is a major challenge. The dependencies of plant systems to each other further adds to the complexity of understanding failure model impact in one system on numerous other systems, as demonstrated by the high-level control philosophy of the research study Brownfields plant.

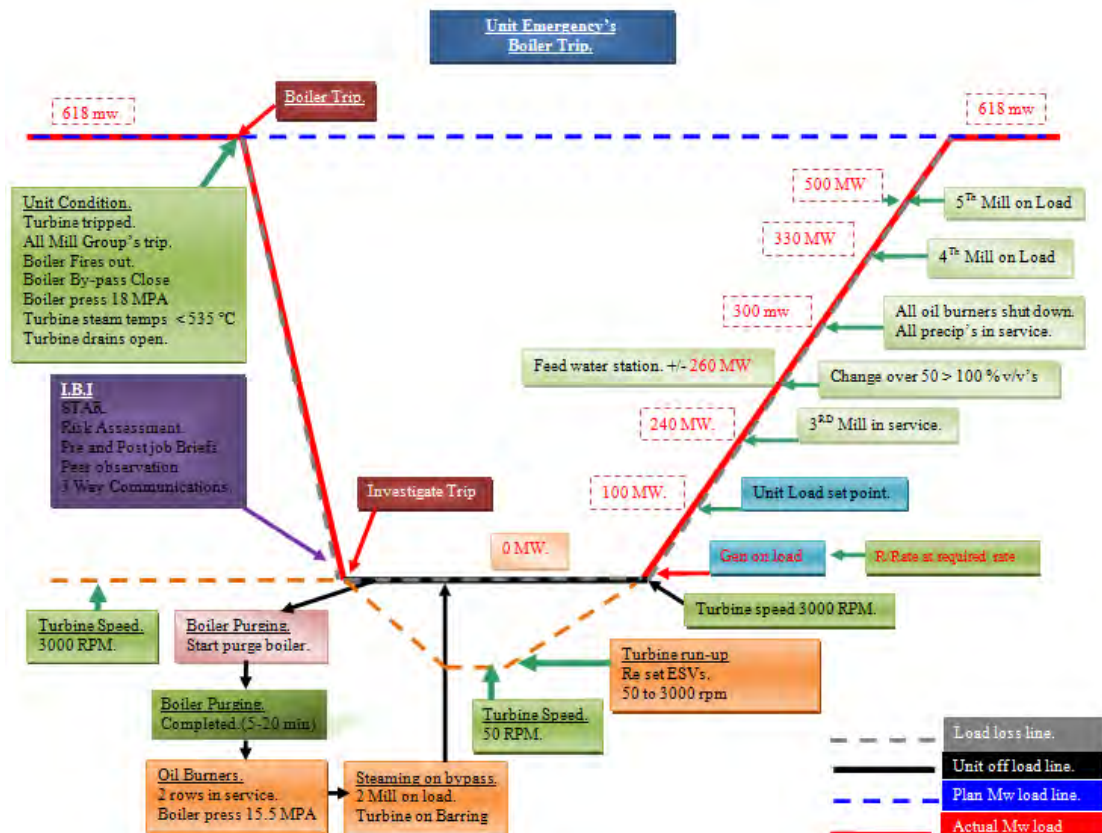
Fig. 2–42 demonstrates how different plant systems in the research study Brownfields Plant can be controlled and managed in their own right (e.g. the milling plant), but how each individual system is inextricably interlinked with other plant systems like the turbine, feedwater, and draught group systems. Many of these systems then have sub-groups and even auxiliary groups that affect control algorithms and ultimately failure mode impact and effects on the overall plant control and efficiency.

Figure 2–42: Brownfields Plant System Group Control Dependencies



Research analysis of this interdependency between systems shows the major impact it has on operating practices in that a plant upset like a boiler trip (and thus the fault analytics algorithm scope) where the number of process dependencies exponentially increases. The impact on production output should also be apparent, as much more control criteria and interlock conditions need to be met before the unit can be returned to service (Fig. 2–43).

Figure 2–43: Boiler Trip System Dependencies to return to Full Load [Swanepoel, 2014b]



Marszal states that the following issues must be resolved before advanced analytics can truly come into its operational strength of application [Marszal, 2002]:

- Incomplete knowledge basis must be addressed.
- ***Improved analytics and understanding of potential equipment failure modes are critical to analytical models developed.***
- The impact of **incomplete critical plant Design Base information** needed for advanced analytics **becomes very apparent with more complex analytical plant models.**

Some studies have been conducted in probabilistic intelligent AI type systems in industrial applications. Most of it is still in early stages with varying degrees of success. [Ibarguengoytia et al., 2009; Uhrig et al., 1997; Nath et al., 2014; Angeli, 2004 and Sanz, 2010] The focus in these studies is of specific types of plant components with limited operational variables as part of the analysis. And many of the studies are more focused on “reasoning techniques” than on statistical and algorithmic analysis of large volumes of plant data and proving the techniques or theories postulated.

Many of the studies also focus on heat and material balances to build the models for potential failure and as such may not look at all plant data [Lipták, 2006].

Tiedtke published an article on the value of building AI models in collaboration with automation systems for industrial processes. The study also shows the value of self-learning neural networks that can predict plant process deterioration [Tiedtke et al., 2010].

Spinney reports in his blog that only a small number of industries in the power utility space have managed to successfully combine the various technologies for AI usage [Spinney, 2007]. And he believes it important that neural networks, **rule-based expert systems are combined with first principle techniques such as the laws of thermodynamics to really be correct in analysis outcome** and to be of commercial value.

The issue raised by Spinney finds confirmation in the research study where steady state process analytics was initially used to determine plant behaviour/response, with limited success.

The article by Uraikul regarding analytical methods proved to be the most valuable in the analysis of the various options available to build advanced analytical models of plant operations [Uraikul et al., 2006]. Unfortunately, a large portion of the information shared is based on suggestions or theory and not many examples of practical implementation of these proposed models or approaches could be found.

The high level methodology proposed for the research study, i.e. building pattern recognition, evaluating trends in process data, determining links and dependencies, sequence analysis and potential use of history analysis and regression methodologies is very similar to that put forward and used by Uraikul in his research, providing some validation that the research study approach is indeed a workable method.

The article by Kaimal confirms the importance of understanding rule–sets needed to create the AI framework within which the required algorithms and neural networks will have to be built to do failure prediction [Kaimal et al., 2014]. This study focuses virtually exclusively on the application of root cause analysis techniques to build the rule sets and methods to do predictive process performance analysis. The importance of Data–Mining and correct interpretation is also underlined by this study.

Hales supports this view [Hales et al., 2013]. Nemeth suggests the use of both prediction based diagnostics as well as knowledge based diagnostics to achieve optimal AI analysis and results [Nemeth, 2006].

Nemeth also indicates the need for a thorough understanding of reliability engineering analysis techniques like FMECA/FMEA and HAZOP analysis to build the required failure and diagnostic models. He reports on some work done on the development of diagnostic multi–scale prediction models and points out the issues with the “big data” complexity created by such models.

Lipták demonstrates with her research survey on AI technologies that a significant number of these are already incorporated into control strategies and tools [Lipták, 2006]. She specifically cites artificial neural networks (ANN), business rules, case–based reasoning, common sense, cybernetics, data mining, data visualisation, expert systems (ES) , fuzzy logic (FL), genetic algorithms (GA), knowledge–based systems, machine learning, model–predictive control, neural networks forecasting, object–oriented networks, optimization, pattern matching and recognition, rule–based systems, statistical process control, text mining, unit operation control and numerous others as widely used techniques.

Lipták further postulates that because individual process variables can be treated as constraints and allowed to be operated within their allowable (Design Base) safe limits, the process can be modulated to increase production [Lipták, 2006], supporting the view posed by Parlour in his presentation to the CMBG Workgroup [Parlour, 2007]. She states that a fusion of fuzzy logic and neural networks seems to be the most promising advanced analytics tool for future control applications – but clearly states the proviso and key rule to plant analytics: **To control a process you must first fully understand it.**

Programming and big data issues make comprehensive (system or plant wide) analytical algorithms problematic. As such, combinations of advanced analytical methods and “grouped” big data may be required to analyse complete plant models.

Development of advanced analytics will allow the system ultimately to control minor process upsets, reducing reliance on the operator to always make control system corrections. Training focus can then shift to more critical plant upsets where intervention by the plant control personnel are mission critical.

2.6.6 Availability of Plant Historical Information and FMECA Data

A key requirement of predictive analytics would be accurate and detailed fault analysis (when incidents in plant occur) and monitoring of plant asset condition. Analysis of failure data will allow the business to focus on the problem areas identified in the plant and support the building of fault analytics models that will yield early ROI to the business.

Due to the increasing complexity of many process plants, especially for companies running more than one process plant, it has become an imperative to implement improved monitoring and management diagnostic capability.

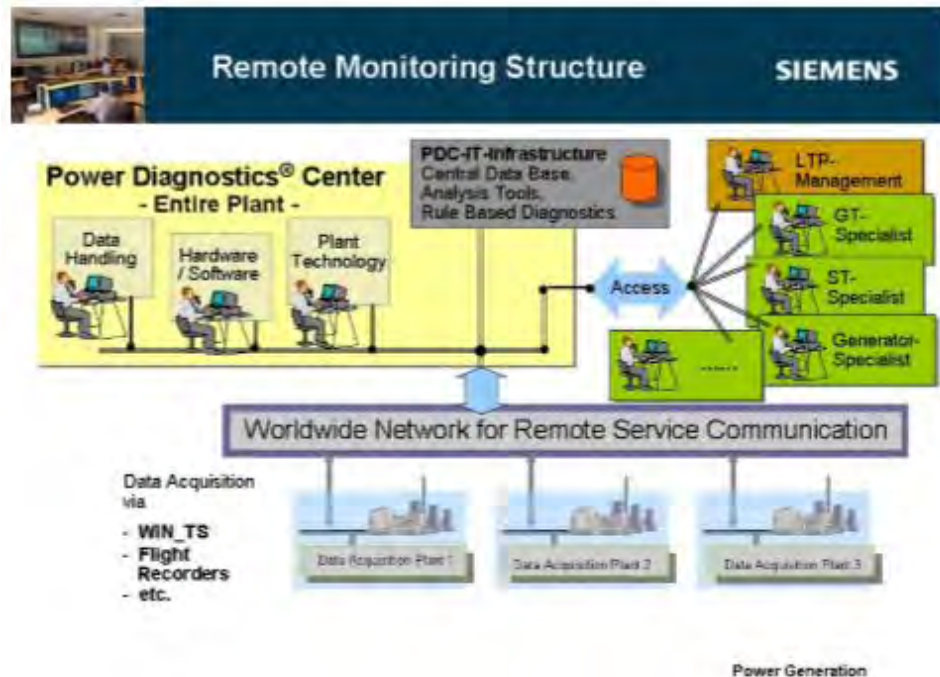
The complexity of analysing process plant and equipment performance over a vast array of different engineering disciplines and potential plant equipment designs also requires highly skilled and trained personnel in condition monitoring and similar fault diagnostic methodologies.

Generally, these individuals are in high demand and scarce, resulting in most companies reverting to centralized diagnostic centres where a few individuals can serve a larger plant scope and decision-making audience.

Similar to the model proposed by Siemens in Figure 2–44 [Siemens, 2006], the Power Utility has also elected to implement a Remote Monitoring and Diagnostics Centre (RMDC) where plant data and the information is gathered and analysed to improve plant reliability and availability. In some cases, this RMDC also provides a support function to operators on some of the power plants linked to the RMDC facility.

The value of a centralised facility found confirmation in this research study as a significant portion of the research data was collected from the Power Utility RMDC centre’s infrastructure and the research study could also leverage the utility’s advanced diagnostics software (etaPRO™) deployed as part of the RMDC software capability stack.

**Figure 2–44: Typical RMDC structure deployed for on–line monitoring of power plants
[Siemens, 2006]**



2.6.7 The Key Role of Failure Statistics in Advanced Analytics

The IPI System platform design (as part of the IPI–BIM Framework) proposes that the meta–data definition and central storage of engineering information required for failure statistics and resultant analytics are part of the overall solution. Access to this information becomes crucial in the evaluation of failures and trips on the plant – especially to ensure a consistent and comparable data set for analytics use. It also supports Internal Validation of the research scope and outcomes in Chapter 6 of this research study in that data can be critically investigated to ensure that findings can be corroborated with more than just one or two well–chosen examples.

Research into the implementation approach of an Intelligent Engineering Information System at one of the Power Utility power stations in 2007 [Pretorius, 2007] identified a base of plant historical failure analysis information that could be used to demonstrate how the correct and detailed implementation of core master data as meta–data fields in an Integrated Information Management system can yield significant benefit when it comes to failure statistics and analysis, as indicated in the examples provided below.

Consistent application of failure analysis methods and criteria allowed this power station to pinpoint problem plant areas, identify causes for trips and analyse the status of the plant when the occurrence took place, confirming the importance of internal validation of data used for analysis and decision making. In the example below, statistical analysis of incident investigations (and the resultant FMECA data) allowed the researcher to identify the top 10 problem plant areas (Figure 2–45) at the research study Brownfields Power Station.

The analysis indicated that the Ash Materials Handling plant, Common plant systems, and Milling Plant areas have the highest failure rates and plant occurrences. This data analytics allowed the research study to identify candidate plant areas for the advanced analytics and simulations prototyping covered in Chapter 6.

Figure 2–45: Top 10 Problem Plant Areas, 2006/7 (10 Year Historical Window) [Swanepoel, 2008]

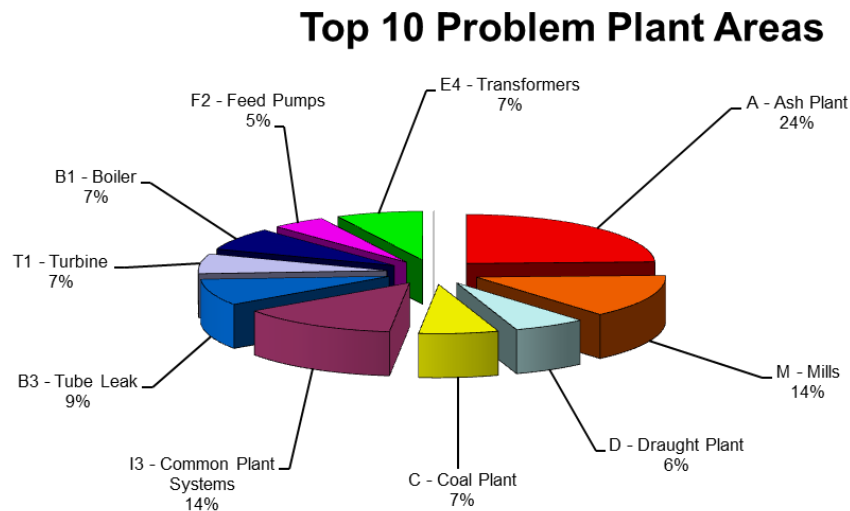
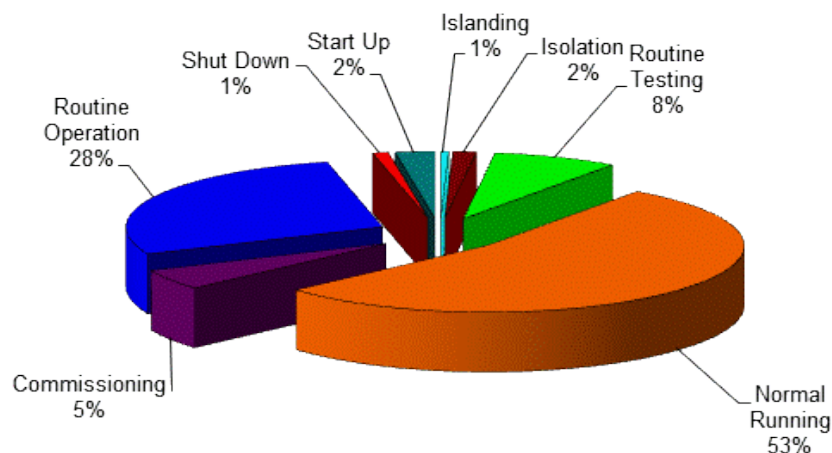


Figure 2–46 demonstrates how failure data could be analysed to evaluate when plant trips occurred most often. Since normal running conditions were the most common plant state for when failures occurred, the analysis resulted in a review and enhancement of normal operating running procedures and increased operator training at the simulator for additional pro-active actions to be taken while the plant is in the normal running mode to prevent failures.

Additional fault scenarios were also identified in this plant state (that led to the incident) and simulator use cases were developed for these as a preventative training measure. An evaluation of test and commissioning procedures was also undertaken.

Figure 2–46: Plant State during Trips (10–Year History) [Swanepoel, 2008]



2.6.8 Data Quality Requirements for Advanced Analytics

Du Toit provided sufficient evidence from initial research and proof of concept work on advanced data analytics and visualisation how current data quality can be a major threat to the success of such advanced analytics endeavours [Du Toit, 2015].

Failure to address data quality issues can have a serious impact on what is considered the beneficial use of data analytics in the Utility. From Du Toit's initial prototyping and research, he reported how data cleaning became a significant portion of the research scope of work before exploratory data analysis or advanced models and algorithms could be built [Du Toit, 2015]. Another challenge highlighted by Du Toit was access to the required raw process control data.

2.6.9 Data Availability Requirements for Advanced Analytics

A further challenge for the research study was the age of the Brownfields Plant control system deployed – it being more than 30 years old. An upgrade to the C&I system is planned but has been deferred several times due to financial constraints.

As such, there are serious limitations regarding data extraction or enhancements to the actual control system configuration. Only a fixed number of operating parameters can be stored in the system and subsequently analysed and reported on. Should any additional data be required, an existing data point must be removed. The risk of doing this was considered to be too high to even contemplate.

Due to the old technology in use, there is also still a large portion of analogue information data, as well as a fragmented control system design, making analytics more complex and involved. The most significant impact of this was the fact that the alarm recording was done in analogue format. Use of alarms data and information required conversion to digital signal mode, which is additional effort in terms of the research scope of work.

The literature survey on advanced analytics evaluated the business drivers for increased use of this capability for decision making. The challenges with data analytics in the plant control environment were investigated and highlighted. Advanced analytics methods and their maturity were investigated and discussed.

The importance of understanding plant process behaviour (and thus the design basis that defined the plant process) was confirmed in the literature surveys conducted. Availability of information like failure history and statistics was also shown to be crucial to the process of advanced analytics. Data quality and availability issues were also investigated.

2.7 Defining the Value Proposition for the Business Improvement Framework

This portion of the literature survey evaluated typical business drivers and aspects that would assist in creating a cost–benefit framework that can be used to motivate the value of the IPI–BIM framework for a process plant. It aims to evaluate value in the full asset lifecycle, considering elements in the EPC as well as O&M phases.

This value is possible across the asset lifecycle, as confirmed by Coopers and Lybrand in their independent study on the benefits of an integrated Engineering lifecycle information management system (managed environment) in 1997. The study identified potential savings across all phases of the plant and project lifecycle, covering aspects like improved design practices, more engineering efficiency and productivity and reduced commissioning and hand–over time frames (and thus faster return–on–investment) [Coopers et al., 1997].

The importance of an integrated approach was also highlighted and proved by means of a prototype during the execution of the integrated plant engineering management system in the utility in 2007–2009 [Swanepoel, 2012b].

2.7.1 Business Drivers that Unlock the Value Proposition

Research confirms the hypothesised business drivers that will dictate the scope and extent of the value proposition. The Business drivers in the Utility Space demand a “smarter” way of managing the enterprise – and as such defines the elements that will be used to demonstrate the value of the IPI–BIM Framework [Hales, 2013].

Research shows that improved information management of the operating Design Base; integration of this information asset with plant process control data and using it for daily operations have significant savings from a productivity and economic benefit point of view [Emerson, 2003]. It is therefore a keys business driver to improve operations.

Emerson states that it allows operating staff to move beyond conventional plant process control into a more reliability and plant health management focus – they can evaluate changes in process operations by simulation of control parameters and determine the impact, and on–line continuous monitoring and control allows for reduced resource usage across the entire business operations spectrum.

Chevron echoes similar sentiments that the value proposition can be found in improved asset management, design and construction capability [Watson, 2010]. Further value can be found in safer operations practices and improvements in plant reliability and efficiency.

2.7.2 The Training Value Proposition

Syberfeldt shows with their research how advanced analytics and AI technology can be very effectively used to train staff in basic production optimisation practices [Syberfeldt et al., 2010]. This supports the hypothesis that the IPIS Hub and advanced analytics is an ideal method of changing the way the technical staff is trained on future plant processes.

2.7.3 Construction Management Value Proposition

John and Itodo report with their research the impact of poor waste management practices on project cost overruns [John et al., 2013]. Their findings indicate that the percentage contribution of building material wastage is on average between 21–30% of the cost overrun.

Bossink provides further insight into the sources of construction waste, giving an indication of the typical candidates for cost saving drives during construction of plant assets [Bossink et al., 1996]. Their approach is to define construction waste and list the source/root causes for this – indicating the potential savings areas as value contribution areas.

Bernstein show with their research how the use of Building Information Modelling is becoming an increasingly popular practice to manage construction activities and reducing construction waste [Bernstein et al., 2013]. The ability to use this capability is extremely dependent on the accuracy of Plant 3D Design (CADD) models created, as site fabrication (and off-site pre-construction fabrication) work and planning are done off these models. To do so, an extensive level of Design Base information and specifications are needed. Their research indicates the typical savings areas that would be supported by creating this capability.

2.7.4 Maintenance Management Proposition

SyeD with his research into manufacturing effectiveness covers the six most notable areas of losses in the maintenance environment [Syed, 2014]. These are:

- Breakdowns
- Setup and Adjustments
- Idling and Minor Stops
- Reduced speed (output)
- Start-up and Yield Losses
- Defects and Rework

2.7.5 Engineering Productivity Value Proposition

One of the popular business improvement model approaches is 6–Sigma (or “Lean” 6–Sigma). Morais uses this approach to point towards the typical areas in engineering productivity management where potential cost savings can reside [Morais, 2014].

Morais goes on to list some very typical “time wasters” of engineering productivity with some of the most typical examples caused by inefficient engineering processes, infrastructure, and workflows:

- Printing work package deliverables.
- Generating outputs to drive production machinery such as CNC plate and profile.
- Generation of several consumable versions of the BOM such as an Excel file for various departments.
- Creation of native drawing file types for stakeholders/users which do not have the same CAD authoring tool.
- Create design review and production review models.
- Generate output for the production team work package such as assembly drawings, spool drawings, isometrics, arrangement drawings, workshop drawings.
- Creating reports for lifting and turning.
- Creating reports for purchasing and management.
- Creating new deliverables required by the owner (new drawing file types or formats).
- Creating information (3D Models and related data) for other teams such as welding, planning, and production, painting, and coating, weight management, and control.
- Creating models for subcontractors which contain the information they need to do their job but does not give any more IP than what is required. The removed IP can be relationships, associativity, catalogue information, a portion of the model, production trade secrets, etc.

2.7.6 Information Integration Value Proposition

Emerson reports notable savings to be achieved by implementation of an integrated information management system and combining it with improved plant control and process monitoring and advanced analytics capability [Emerson, 2003]. Their reported savings are feedback received from clients who implemented their IPIS technology:

“Typical savings reported by other utilities/companies that have moved towards more integrated information management systems are:

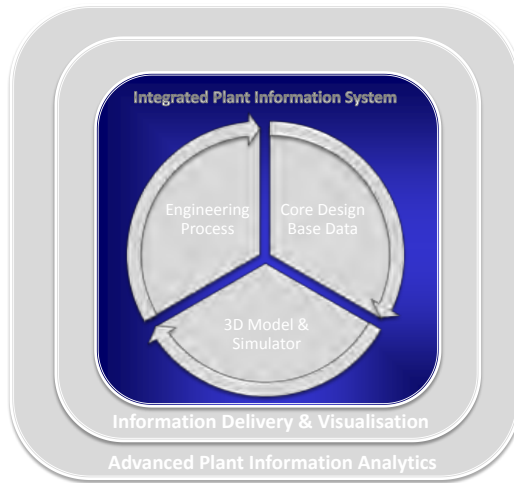
- *“Tight, consistent control helps improve conversion of fuels to energy by 6–10%.*
- *Saving \$300,000 in labor costs alone, and running more efficiently than ever.*
- *Automated documentation of instrument tests saves us an average of 40%.*
- *The time it takes to troubleshoot problems has been reduced nearly 50%, and predictive diagnostics tell us when our valves are starting to deteriorate so we can plan our maintenance activities instead of reacting to process problems and failures.*
- *Fault analytics required field work to see what was wrong. Now it is done in an RMDC environment. What used to take 40 to 45 minutes now takes 5 to 10 minutes.*
- *Elimination of 25% of maintenance downtime over a period of 2 years using an RMDC concept. Same human resource quantities retained, but the staff is now able to focus on other reliability improvement activities to make the plant more productive.”*

This final portion of the literature survey evaluated typical drivers that can be used to develop the Value Proposition Model for the IPI-BIM Framework.

It evaluated typical benefits realisation reported in industry in areas like training, construction, maintenance, operations, engineering, etc. to use as a validation and verification mechanism for the Value Proposition model built as part of the IPI-BIM Framework.

The literature survey also acted as a verification mechanism to confirm the recommended high level business areas identified for value proposition reporting.

THE INTEGRATED PLANT INFORMATION SYSTEM PLATFORM



This portion of the research study evaluates the options available regarding an integrated plant information system platform to enable the IPI–BIM Framework.

The research scope includes evaluation of a number of actual software solution implementation methodologies and evaluating its workability and capability of meeting the different business needs of divisions within the Power Utility from an O&M as well as EPC perspective.

The aim of this portion of the research study is it to propose the best implementation methodology based on hypothesis and findings of the study.

3.1 Introduction

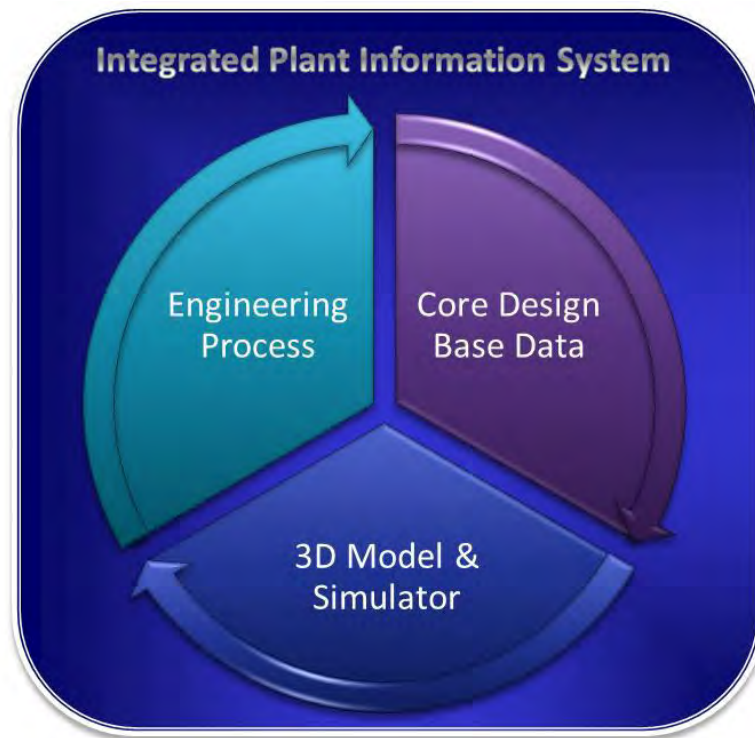
Integrated information system technologies have had limited success due to the complexity of the engineering work environment and the engineering business processes required to support it. Implementations tend to focus on only one or two key aspects of this complex, integrated engineering work environment. This chapter covers the requirements for establishing **a holistic** and optimally integrated plant information (IPI) system platform that is at the heart of the IPI–BIM Framework.

The Research scope aimed to cover the requirements for establishing the IPI–System platform and the methodology to do so in the most efficient, cost–effective and productive manner. It entailed defining and implementing a templatised, standardised, balanced implementation methodology that contains and manages the required elements of data content, workflow, process and information integration needed to enable and support the engineering organisation across the asset lifecycle.

The integrated plant information system forms the core of the IPI–BIM framework and configuration (Figure 3–1). Its configuration must be sufficient to contain the required Design Base data required to enable advanced data analytics. Design Base content contained in this

platform will also become the information feeder for the 3D interactive plant simulator and 3D visualisation capabilities enabled as part of the IPI–BIM Framework.

Figure 3–1: IPI System Platform Elements



3.2 Research Hypothesis Relevant to the IPI System Platform

Hypothesis 1: A sequential approach to developing the BIM and implementation approach will yield the most efficient framework.

Hypothesis 2: The methodology and approach taken to implement an integrated plant information management system will have a direct impact on Design Base management, system implementation, and engineering efficiency.

3.3 Scope of the Research Undertaken to evaluate IPI System Implementations

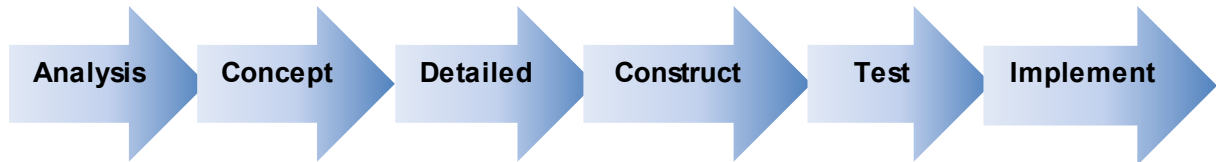
A number of system frameworks and development/implementation approaches are possible in commercially available integrated engineering information management systems, ranging from “out of the box” (pre-configured) systems on one end to highly configurable ones on the other end of the spectrum.

These approaches were discussed in detail in the literature survey (Section 2.3 and Figure 2–16) and vary from traditional IT system implementation approaches (the SDLC method) to the IPI–BIM Framework preferred RAD system implementation approach (Figure 3–2). The Research scope was confined to the Eskom Power Utility environment.

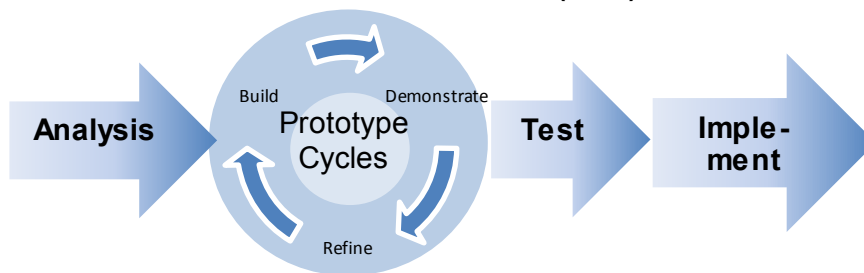
As such, software solutions that have been sold to (or are used in) the utility as integrated engineering information management systems made up the systems evaluation scope of the research study.

Figure 3–2: Rapid Application Development (RAD) vs. Traditional (SDLC) IT System Implementation Approach [Koredla, 2014]

TRADITIONAL IT SYSTEM SDLC-BASED IMPLEMENTATION



RAPID APPLICATION DEVELOPMENT (RAD) IT SYSTEM IMPLEMENTATION



The research study evaluated the results and outcomes of 4 system implementation configuration and implementation Projects in the Power Utility over a period of 5 years to characterise the successes and challenges of each.

The Projects all had the same intent (to configure and deliver an integrated plant/engineering information management system) but followed different implementation approaches and configuration methods. Table 3–1 provides a summary of the Projects evaluated.

Table 3–1: Integrated Engineering System Implementation Approaches Evaluated

	PROJECT 1	PROJECT 2	PROJECT 3	PROJECT 4
Implementation Method	RAD	Conventional	RAD	Hybrid – Mostly Conventional, limited RAD
Configuration*	70% OOTB 30% Custom Configuration	60% OOTB 40% Custom Configuration	30% OOTB 70% Custom Configuration	80% OOTB 20% Custom Configuration
Implementation Date	2006	2007–2008	2010 – 2012	2013 (Still in progress)
Implementation Timeline	6 Months	3 Years	2 Years	5 Years (Phased)
Team Size	5 Core	25 Core Team	10 Core Team	30 Core Team

**Custom configuration is to align OOTB software configuration with business terminology and processes. No changes to actual source code of the commercial software product are involved.*

Based on the evaluation of the approaches followed the research study aimed to propose and test an optimal information system configuration methodology/approach that could be tested in an operational environment over multiple implementation cycles of varying engineering business process complexity.

3.4 Evaluation of Integrated Plant Information System Implementation Approaches

Project Program/Plan and system implementation/configuration data (in the form of User Requirements Specifications) were collected from the four Projects and analysed for comparative purposes (with a summary of key analysis aspects covered in Table 3–2).

The data collected included information on:

- The organisational views that defined or provided guidance regarding the plant Design Base definition that underpinned the system configuration.
- The definition and scope of what was deemed Design Base content in each of the different system implementation projects.
- The strategic thinking on how this information would be managed within the relevant system configuration.
- Actual system implementation outcomes (Project reporting and close–out reports).

Table 3–2: Evaluation Findings – IPI System Implementation Methodologies

	PROJECT 1 METHOD	PROJECT 2 METHOD	PROJECT 3 METHOD	PROJECT 4 METHOD
Implementation Timeframe (Planned)	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	30% ^{4}	0%	60%	40% ^{5}
Extent of 3D Intelligence	25% (Point Cloud, Limited 3D Model) ^{4}	10% (Only 3D Review models, no intelligence)	60% (Limited 3D use due to refe- rence data avai- lability). 3D–Pact Ops Simulator Implemented	30% (Reference 3D Models only – reference data still an issue to enable full intelligence 3D Models)
Level of Operational System 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.	Prototype implementation only. SPO OOTB implementation favoured and	Limited use as it is still in the deployment phase. Partial Implementation at 2 sites.

	PROJECT 1 METHOD	PROJECT 2 METHOD	PROJECT 3 METHOD	PROJECT 4 METHOD
		No 2D/3D deployed in operational use.	GEDI Project closed out at feasibility study and concept delivery phase.	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 a 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 the 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.*
- {4} Initial scope excluded 2D and 3D Deliverables but was added subsequent to initial project scoping.*
- {5} 2D/3D technical work undertaken in this project was re-used in Project 4’s Implementation.*
- {6} Implementation excludes extensive Design Base data migration. These projects only covered legacy EDMS system replacement efforts.*

As can be seen from the evaluation and achieved implementation timelines, the use of the RAD methodology generally yields a much shorter system implementation timeline at lower cost while delivering a more extensive project deliverable scope.

It can be argued that the successful operationalisation of such a solution points to the most successful methodology. If this is considered the ultimate success criteria, only Project 1 can be deemed a successful implementation. Unfortunately this Project (due to financial and time constraints) only implemented the **CORE** 6 engineering processes and thus did not deliver a full-on process-centric engineering solution.

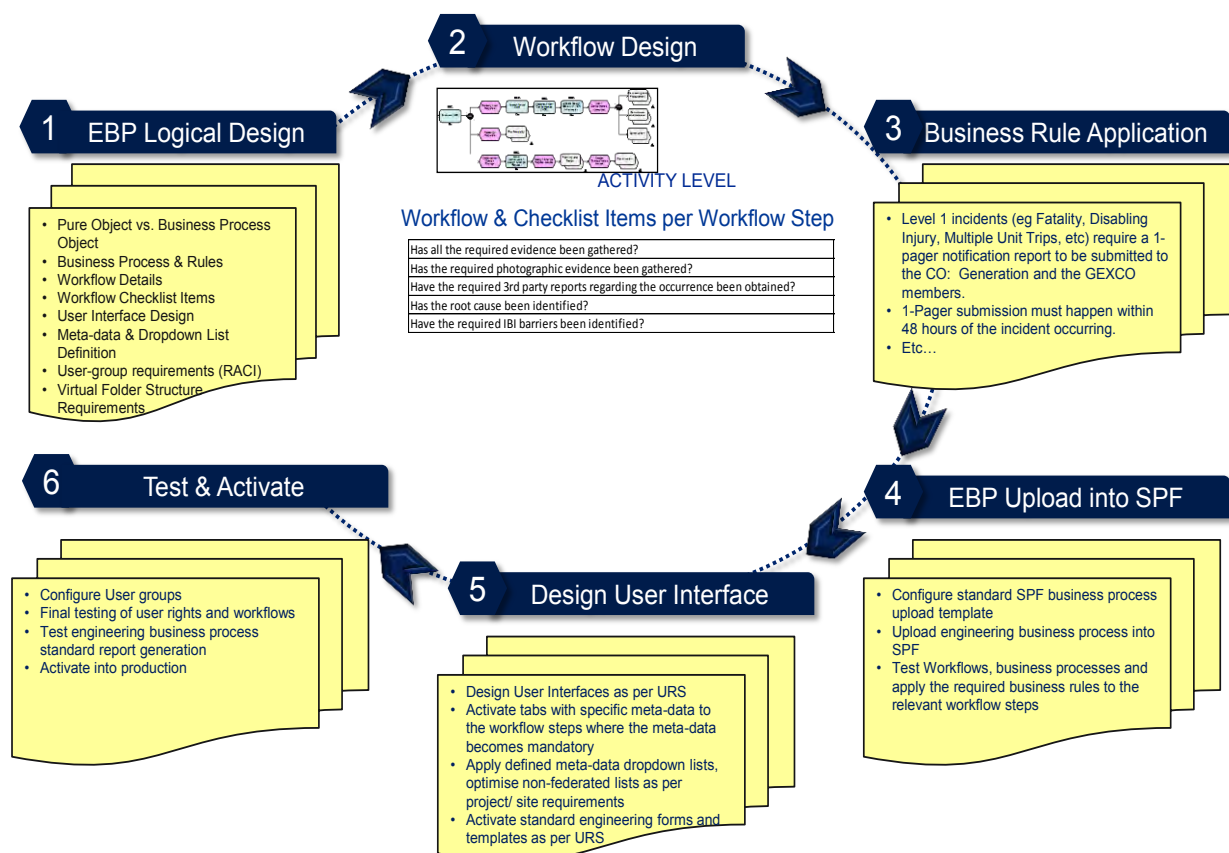
Project 3 configured all 22 Design Base management engineering processes and is therefore deemed a complete solution. Project 3 confirmed the benefit of applying RAD methodology in system design elements of data content, workflow, process and the appropriate level of information integration needed to enable and support the engineering organisation across the asset lifecycle. Project 3 was also successfully tested in a stand-alone production environment outside the Power Utility to confirm the configuration and use-ability of all system aspects configured.

This testing confirmed that the full URS was delivered and no major “show stoppers” could be identified that would have prevented this Project system implementation from being implemented successfully in a production and operational environment.

3.5 Developing an IPI System RAD Implementation Approach for the IPI–BIM Framework

Based on the successes of RAD methodology application in Project 3, the research study used the same RAD principles to develop a templatised and standardised software system implementation methodology. A 6-step Implementation Approach was developed (Figure 3–3).

Figure 3–3: 6-Step Idealised IPI System Engineering Process Implementation Approach [Swanepoel, 2012b]

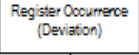
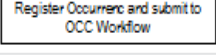
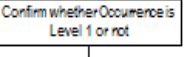
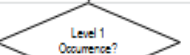
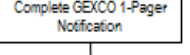
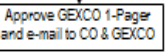
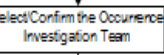
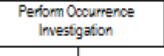
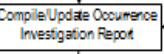
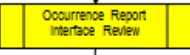


In short, the System and Engineering Business process implementation methodology depicted in Figure 3–3 entails:

Step 1: Performing Engineering Business Process Logical Design using standard templates. This covers business process definitions and rules, workflow details, checklists to be completed at the end of the workflow step, user interface concept design, and definition of the RACI structure for the process and meta–data fields required for statistical data analytics.

Figure 3–4 shows the typical workflow design template that will cover elements of workflow, the function/user responsible for the relevant engineering process step and any standard forms and templates relevant for completion of the workflow step.

Figure 3–4: Standard Template for Process Workflow Design

Figure 3-10 Standard Template for Process Workflows					RP	WORKFLOW NAME	ATTACHMENTS
800-001					Any User/Employee	800-001 Register Incident	Deviation Registration Form
800-002					Incident Process Administrator	800-002 Perform SPF Registration	Deviation Registration Form Occ 1-Pager (if needed) Occ Report Template Interface Report Templates
800-003					Lead Engineer (Package/ System/Discipline)	800-003 Confirm Classification & Content	
800-004					Lead Engineer (Package/ System/Discipline)	800-004 Level 1 Occurrence?	Deviation Registration Form
800-005					Lead Engineer	800-005 Compile EXCO 1 Pager	Occurrence 1-Pager Template
800-006					Site/BU Manager/ Project Manager	800-006 Approve EXCO 1-Pager	Occurrence 1-Pager Template
800-007					Site/BU/Discipline Engineering Manager/ Project Engineering Manager	800-007 Select/Confirm Investigation Team	Occurrence Report Template (Use template based on classification)
800-008					Lead Engineer + Team of Investigators (Level 1 & 2 incidents)	800-008 Investigate Occurrence	
800-009					Lead Engineer	800-009 Compile Draft Occurrence Report	Occurrence Report Template (Use template based on classification)
800-010					Occurrence Team Investigators	800-010 Awaiting Occurrence Report Interface Review	Final Occurrence Report Interface Review Reports

Step 2: The Workflow Process is then decomposed into a templatised format that allows for direct software system upload. Figure 3–5 shows typical workflow steps (auto-generated in the system using the MS Excel template).

The workflow decision choice the user can make at the completion of the process step (“Right Click Menu Item” choices), and if there are checklist items to be completed, it will be activated on completion. System configuration proved that even these 2 fields can be loaded into the engineering system workflow engine in an automated fashion, speeding up system configuration time.

Figure 3–5: Standard User Interface Template

WORKFLOW NAME	Right-Click Menu Items	Checklist Items
800-001 Register Incident		
800-002 Perform SPF Registration	Occurrence Registered	Is the submitted deviation form complete with all the required information to register the Occurrence in SPF?
	Previous Step	Is the sequence of events clearly described. Has the date and time of the occurrence been provided?
800-003 Confirm Classification & Content	Classification Confirmed	Is the classification level selected for the occurrence correct?
	Previous Step	Is there sufficient detail to the registration of the Occurrence and has content been correctly submitted and completed? If the classification level is changed, has the reason for this been recorded in the workflow "comments"?
800-004 Level 1 Occurrence?	Yes	
	No	
800-005 Compile EXCO 1 Pager	Compiled	Has the 1-Pager template been completed?
	Previous Step	Has the required stakeholders been notified of the level 1 incident?
800-006 Approve EXCO 1Pager	Approved	Is 1-Pager fully completed?
	Previous Step	Has the approved 1 Pager document been e-mailed to all the stakeholders?
800-007 Select/Confirm Investigation Team	Selected/Confirmed	Has a lead investigator been assigned to investigate the Occurrence?
	Previous Step	Has a team been assigned to the occurrence in the case of Level 1 and 2 Occurrences? Has external investigation team members been notified of the investigation requirements?
800-008 Investigate Occurrence	Investigated	Has all the required evidence been gathered?
	Previous Step	Has the required photographic evidence been gathered? Has the required 3rd party reports regarding the occurrence been obtained? Has the root cause been identified? Have the required IBI barriers been identified? Have all the IBI barrier selections been completed? Has it been necessary to register an insurance claim, and have this been done and the claim number added to the Occurrence Record?

Step 3: Apply and test business rule application using a number of test and use cases. Perform FAT testing and optimise template contents. Figure 3–6 shows typical business rules applicable to one of the engineering business processes.

Figure 3–6: Business Rule Application Example

Business Rules	
1	Incidents should be loaded against the lowest possible plant tag (PBS/KKS) where it occur.
2	If an incident is not related to the plant (eg a vehicle incident off site), the Occurrence should be loaded against the Project at the highest possible level (eg Kusile Project).
3	Any user can register an incident and do a preliminary classification, but the Lead Engineer (Package or System Engineer on plant in question) will confirm the classification and incident investigation requirements.
4	Incidents will be classified according to the Generation Directives and Procedures, using their classification levels as prescribed in the documents. (See column E in "Dropdown List Info" worksheet of this document)
5	Level 1 incidents (eg Fatality, Disabling Injury, Multiple Unit Trips, etc) require a 1-pager notification report to be submitted to the CO: Generation and the GEXCO members. This must happen within 48 hours of the incident occurring.
6	The Lead engineer (for the plant/package) where the incident occurred, should ideally conduct the incident investigation. If needed, an investigation team will be appointed by either the BU Manager, Site Manager or Project Manager. They will assist with the investigation and will typically be equipment and/or technology specialists that can help with fault-finding and root cause analysis.
7	Level 1 Incidents will be approved by the SGM: GBE or a Project Manager
8	Level 2 Incidents will be approved by a General Manager: Plant Engineering, the BU Manager (E-band level) or Project Engineering Manager
9	Level 3 incidents can be approved by Departmental Managers, Section Heads or Project Package Manager/Lead Discipline Engineer if so delegated (practice on production side is that Section heads can approve Level 4 & 5 incidents).
10	ALL mandatory meta-data must be completed on incidents as they are used for statistical reporting both within GBE as well as on a GEXCO and corporate level.
11	In the case of Health & Safety Incidents, specifically fatalities and injuries, corporate risk & assurance must be involved as soon as possible as there are very specific activities that must take place from their side. They will also review the submission, and re-classify the incident if they do not agree with the recommendation(s).
12	Corrective actions stemming from incident investigations MUST be linked to the incident that they stem from. The incident is not considered complete and cannot be closed out until all these corrective actions have been implemented/executed.

Step 4: The business process template contents are then uploaded to the software system's business process rule engine and the software base configuration enabled.

Step 5: User Interfaces (Screens) are designed in the MSEExcel template first and optimized in collaboration with end users. (Figure 3–7) The business process standard and the user interface are then evaluated to define the meta–data field design.

Figure 3–7: System User Interface Design

The screenshot displays the 'OCCURRENCE MANAGEMENT USER INTERFACE' with a 'Registration' tab selected. The form includes the following fields and controls:

- Eskom Project No:** Text input field.
- Eskom Contract No:** Text input field with a dropdown arrow.
- Occurrence No:** Text input field containing '[System Generated]' in red.
- History Old No:** Text input field.
- Occurrence Description:** Large text area with a dropdown arrow.
- Occurrence Date:** Text input field with a date mask 'ccyy/mm/dd'.
- Time:** Text input field with a time mask 'hh:mm:ss'.
- Occurrence Class:** Text input field with a dropdown arrow.
- Corporate/Ext Ref No:** Text input field.
- Initiator Full Name:** Text input field.
- Contact Details:** Two text input fields labeled '(T)' and '(C)'.
- Parties Involved:** Text input field with a dropdown arrow.
- Power Station/BU/Site:** Text input field.
- Location:** Text input field with a dropdown arrow.
- System:** Text input field with a dropdown arrow.
- Insurance Claim No:** Text input field.
- Plant Code:** Text input field.
- Plant Description:** Text input field.
- Nature of Damage:** Text input field with a dropdown arrow.
- Mitigation Actions Taken:** Large text area.
- Required Action(s):** Text input field with a dropdown arrow.

Due to the complexity of some of the engineering business processes, a multiple User Interface input screen design was implemented. This approach allows for the grouping of metadata – e.g. for Occurrence Investigations, the meta–data captured regarding failure analytics can be captured in one User Interface screen, thus logically grouping the failure analysis results together.

It also facilitates the building/creation of process reports as the user interface screen would typically dictate what meta–data records and data should be sourced from the system database for reporting purposes.

All the required system configuration information is then captured (Figure 3–8), which will include the use of standard “picklists” per meta–data field and in some cases implementation of dependent picklists (selecting certain information in one picklist will enable a very specific picklist choice in subsequent fields).

Figure 3–8: Business Process Metadata Definition

META-DATA FIELD NAMES						
FIELD NAME	TYPE	CHAR TYPE	SIZE	MANDATORY	EXAMPLE	MORE INFO
File Name	Text	Alpha-Numeric	30	Yes	Occ14567.doc	This will be the occurrence report template new filename that the end user will populate for the relevant occurrence incident. If possible, the "template name" should by default be renamed to the Occurrence System Generated number with a .doc extension.
Process No	System Generated Number	Alpha-Numeric	20	Yes	OCC-14567	System Generated. All Occurrence Objects created needs to be pre-fixed with "OCC-" and then a sequential system generated number that starts at "1" for each Project/Plant.
Deviation Date	Date Field	Date	10	Yes	2/20/2008	By default put today's date, but should be change-able if it occurred earlier/at a different
Deviation Time	Time Field	Time	8	Yes	15:07	By default put current computer time, but should be change-able if incident is recorded at a later stage
History Old No	Text	Alpha-Numeric	30	Yes	A/DFF/355	Previous Record Reference No (for cases where date are migrated from legacy systems)
Initiator Full Name	Text	Alpha-Numeric	30	Yes	(Dropdown list of SPF/BU Users)	Select from a dropdown list of BU users and/or registered SPF Users
Initiator Contact Number	Text	Alpha-Numeric	15	Yes	+27 11 XXX XXXX	Numerical Field
Latest Revision	System Generated Number	Alpha-Numeric	2	Yes	0	Numerical Field
Occurrence Class	Picklist	Alpha-Numeric	25	Yes	Internal Occurrence	Controlled by the Occurrence process administrator
Corporate/External Ref No	Picklist	Alpha-Numeric	10	No	AGDD/Report3	Corporate/External reference number (for cases where major occurrence actions are issued to BU's for action)
Parties Involved	Memo Field	Alpha-Numeric	50	Yes	Project Engineering; Commissioning Engineer	Dropdown List, Multiple Select
Power Station/BU/Site	Picklist	Alpha-Numeric	800	Yes	3250	Dropdown List, SAP BU Code
Location	Picklist	Alpha-Numeric	50	Yes	01 (Unit 1)	Dropdown Selection, 1st Level Plant Code
System	PBS Picklist	Alpha-Numeric	50	Yes	01HK (Generator Breaker)	Filtered Dropdown Selection, based on "Location" Selection, 2nd Level Plant Code (System)
Plant Code	PBS Picklist (Filtered)	Alpha-Numeric	30	Yes	01HK01D001-M01	Filtered Dropdown Selection, based on "Location" and "System" Selections, 3rd Level Plant Code (Plant Code)

Step 6: Perform FAT, UAT and other system performance tests. This entails a detailed process of confirming all meta–data fields and associated picklists are enabled and working as designed, testing the workflow and process step routing and confirming that checklist items at the end of a process step activate and work as designed.

Once the FAT success is confirmed, the engineering business process will undergo UAT and activated for production use. As per RAD principles, core users will provide continuous feedback regarding the process and identify continuous improvement action items.

A benefit of the templatised approach and automated loading is that RAD continuous improvement changes can be implemented very fast and without significant system downtime. A sample set of templates is available from the researcher on request as examples of what a completed engineering business process configuration template will look like at system configuration implementation stage.

The research study then proceeded to prove this methodology as the preferred implementation approach to establishing the Integrated Plant Information (IPI) system platform that will support the proposed business improvement model (IPI–BIM) and also the Smart Utility Strategy [Hales, 2013]. Using different commercial software technology, the research study aimed to provide validation that the proposed methodology is independent of any commercial system configuration requirements and/or constraints.

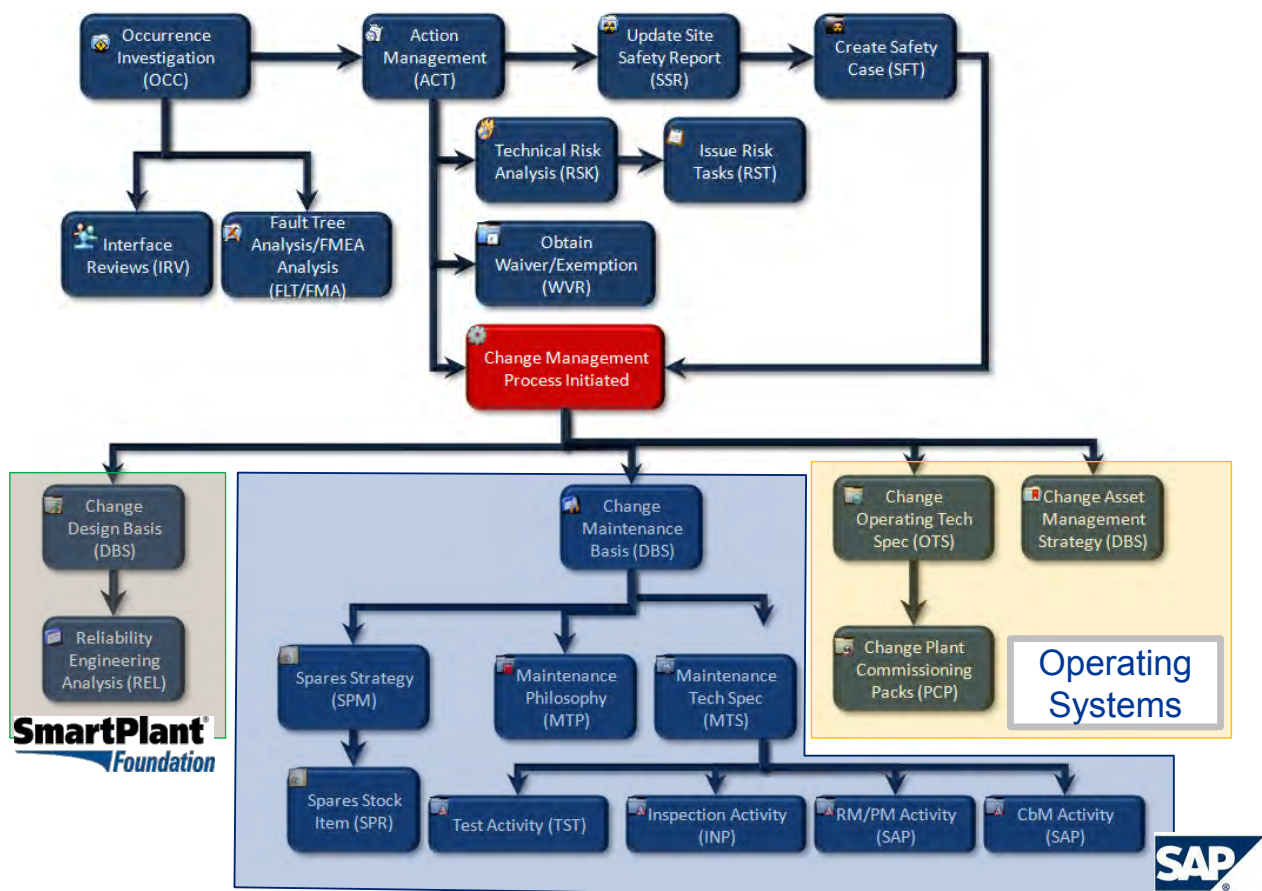
3.6 Confirming the Engineering Processes Required for Design Base Management

The research study established the engineering business processes and information integration needed to enable and support the engineering organisation to manage the Plant Design Base across the complete asset lifecycle (depicted in Figure 3–9).

The Integrated Plant Information System platform, therefore, acts as the integrated repository for these critical engineering processes (with their associated BI meta-data for analytical purposes) as well as the Design Base data that has to be managed (using these processes throughout the plant asset lifecycle) to maintain the Design Base integrity.

The methodology proposed in 3.5 was applied on all these core engineering processes to develop a templatised software engineering business process configuration baseline for each process. The aim of these templates would be that they can be used as a baseline for analysis by other process plants/industries to tweak and subsequently configure their business unique process in an IPI system platform without having to design the basic engineering process from scratch.

Figure 3–9: IPI Engineering Business Process Integration [Swanepoel, 2012d]



It should be noted that the IPI System Platform also contains the potential 3D Design Base content that will be the data feeder to 3D information visualisation platform(s) and some of the engineering processes will interact with the 3D model as an information feeder when needed (e.g. Design Review/Change Design Basis processes). Adoption of 3D capability will be a business specific consideration, based on the availability of such data and the information visualisation strategy adopted by the business.

3.7 Validating and proving the new IPI–BIM System RAD Implementation Methodology

The developed system implementation methodology was tested and validated against the engineering business processes depicted in Figure 3–9. These processes have varying complexity levels. The results of the system implementation methodology validation are shown in Table 3–3.

Table 3–3: Engineering Business Process Implementation Cycle Times Using Developed Implementation Methodology

	HIGH COMPLEXITY PROCESS	AVERAGE COMPLEXITY PROCESS	LOW COMPLEXITY PROCESS
Target Processes	1st Pass: Engineering and Project Change Management (Design and Field Changes) 2nd Pass: Technical Risk Analysis 3rd Pass: Technical Documentation Management	1st Pass: Occurrence and 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 and Implementation Cycle Time	42 Days	14 Days	6 Days
2 nd Pass Process Configuration and Implementation Cycle Time	29 Days	11 Days	4 Days
3 rd Pass Process Configuration and Implementation Cycle Time	21 Days	7 Days	2 Days
Error Rate (UAT/FAT NCR – % rework)	1 st Pass: 22% 2 nd Pass: 19.8% 3 rd Pass: 13%	1 st Pass: 15% 2 nd Pass: 7.8% 3 rd Pass: 4.5%	1 st Pass: 11% 2 nd Pass: 6.3% 3 rd Pass: 2.8%

The results from the table above show how the structured and templatised approach and methodology proposed by the research study significantly reduced business process implementation cycle times.

In addition to reduced implementation cycle times, it was also found that the templatised approach significantly reduced system configuration errors and consequently the number of FAT and UAT non-conformances that had to be addressed after each test cycle.

3.8 Research Findings Summary

From the evaluation, the Project 3 Implementation Method was found to be the ideal baseline to establish the IPI System implementation approach of the IPI-BIM. It was proposed to Project 3 to utilise the new implementation method to configure the remainder of the non-core Engineering Business Processes.

The projected business process system configuration timeline for Project 3's remaining business processes were 9 months. **This timeline was reduced by 30%** with the processes configured, tested and available for use in 6 months (Resulting in reduced project cost and earlier project scope delivery).

Re-evaluation of work done under Project 3 (that formed part of this research study) has led to a decision in the Power Utility to utilise the best practice implementation elements contained in the system configuration methodology of Project 3 in the further implementation and roll-out of the Integrated Engineering Information System configuration currently underway in the Power Utility.

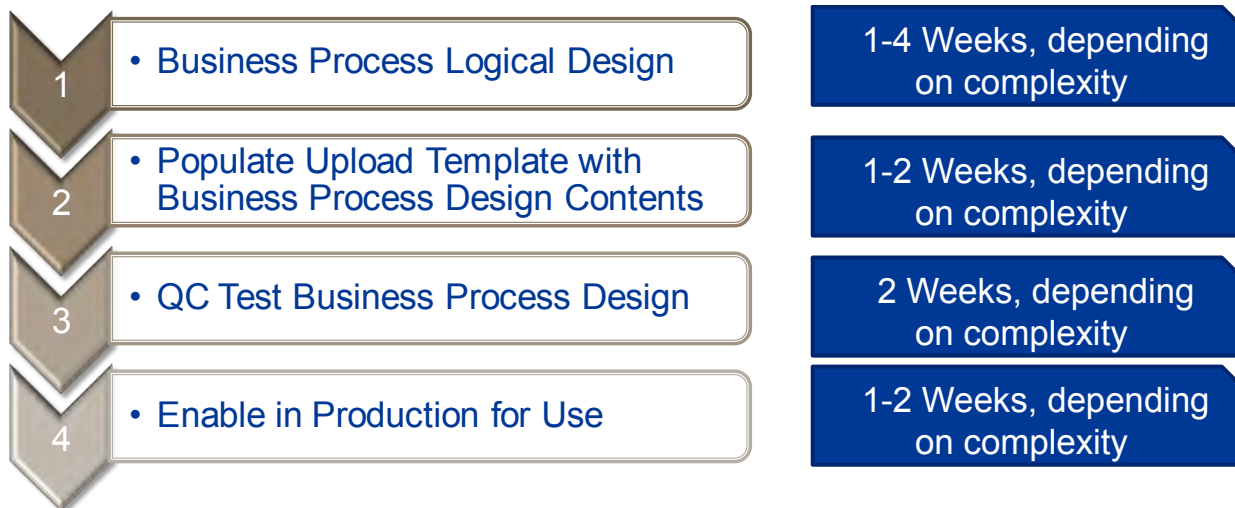
A typical example of such best-practice methodology capability re-use is the implementation of the 2D SPE tool configuration done under Project 3 scope of work. In December 2015, a successful P&ID data migration was done from the Project 3 configuration and Design Base dataset into the new Power Utility Enterprise-wide Integrated Engineering System configuration – without any data corruption or major Design Base integrity errors being identified by the software tool (that is rule-driven).

The testing and validation results from the new implementation methodology demonstrated how the structured and templatised approach proposed by the research significantly reduced business process implementation cycle times as would be expected by any RAD methodology proposed (if correctly implemented).

The approach also allows for a much more accurate assessment of business process implementation timeframes required (for new processes), allowing for better software

implementation/configuration planning when it comes to such a complex IPI system platform. Figure 3–10 depicts the typical derived timeframes that would be involved in engineering process implementation efforts.

Figure 3–10: Improved Estimation of Business Process implementation timelines



3.9 Optimisation/Rationalisation Opportunities regarding IPI System Platform

Although the system implementation methodology was designed to be system agnostic, actual software technology capability is a factor that can impact the implementation timelines and final configuration complexity.

One of the software solution shortcomings identified during the prototype was the handling of parallel workflows – at the time it was necessary to create very elaborate workflow routing and “if–then” workflow rule scripts in the system software in order to get the engineering workflows to work as designed/required (and in line with business practices and rules).

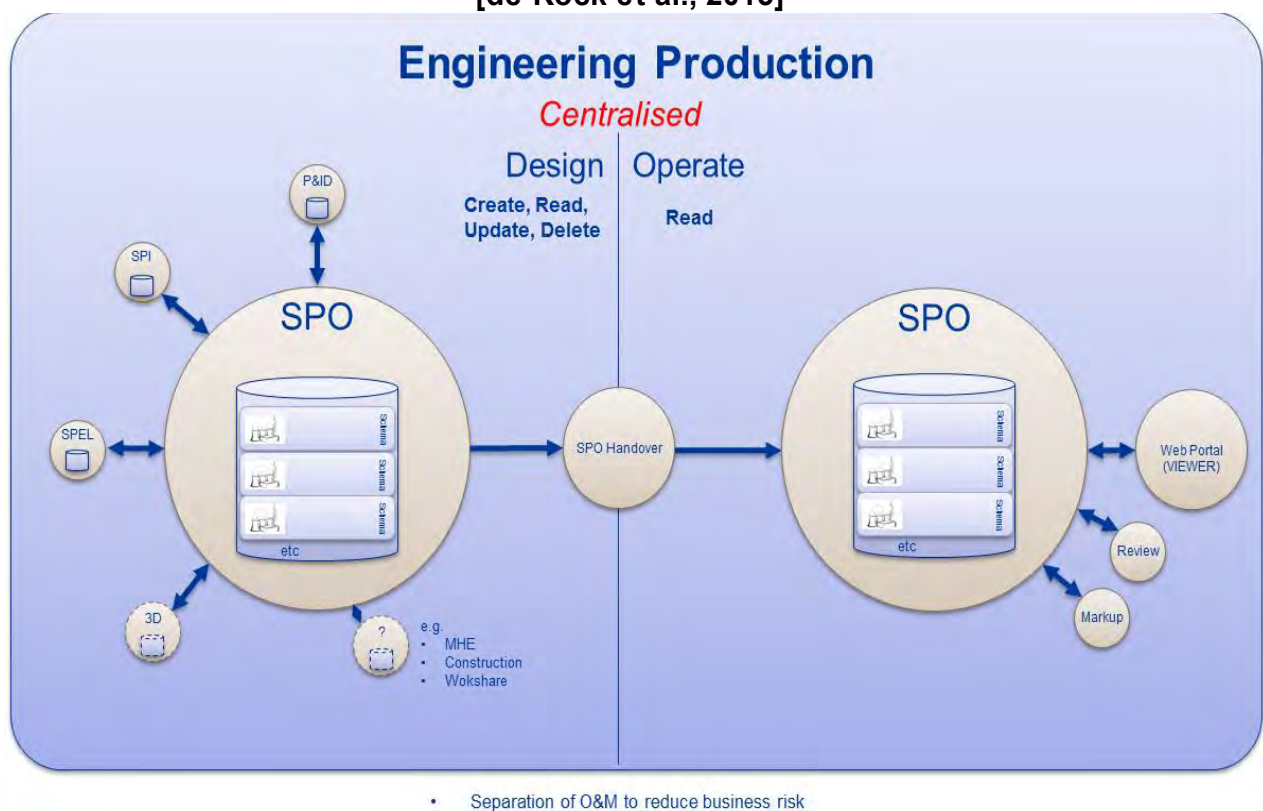
Some enhancement has since been undertaken on the software solution’s business process workflow engine – this significantly reduces engineering process workflow configuration complexities and reduces configuration timelines. Research also confirmed convergence in the workflow engine technology adopted by most software system providers.

Another challenge was the complexities created trying to cover both EPC and O&M business requirements. Business raised many concerns around user acceptance of complex software system infrastructure and indexing structures and menus (and was thus considered a business risk).

As an improvement opportunity, further work will be undertaken to enable the implementation of “handover capability” and splitting the IPI System Platform environment into a “Design Base” (EPC or Design) and separate Owner/Operator (O&M) environment.

This will allow for the sharing of only critical Design Base information to the O&M environment and also enabling only the business processes needed in O&M while retaining the full Design Base data set, design change control authority and engineering work processes in the EPC instance of the Integrated Engineering System solution (Figure 3–11).

Figure 3–11: Creating separate environments for EPC and O&M business environments
[de Kock et al., 2015]



This enhancement is currently underway in the Power Utility and the operationalisation of this design will be proven on the two plants that form part of this research study scope.

3.10 Conclusion

The research study demonstrated 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 Framework.

It also confirmed the importance to have engineering business processes to support the management of the Design Base content over the plant asset lifecycle.

Table 3–4 depicts benefits reported from implementing the templatised methodology proposed in the research study.

Table 3–4: Implementation Methodology Benefits [Swanepoel, 2010a]

BENEFIT AREA	TYPICAL BENEFIT
Speed of roll–out of the IPI system platform to a fleet of process plants	RAD 30–50% faster than conventional SDLC models
Repeatability in roll–out of IPI system and the configuration methodology	40% faster system configuration
Re–usability of configuration – suitable for both EPC and O&M portions of the plant asset lifecycle.	30–40% implementation cost reduction
Ease of customisation using system configuration templatised approach – project/plant specific processes	20–30% implementation cost reduction
Increased internal design capability – configured for the business specific needs and in line with approved process control manuals (PCM's)	40–60% faster engineering uptake
More consistent usage of design tools, higher standardisation across the plant fleet.	30–50% productivity increase using standardised “design seed files” and configurations
Better administrator–level control of software application configurations resulting in reduced IT infrastructure costs	20–40% reduction in system administrator tasks
Flexible process and system configurations enable better technology uptake by technical/engineering staff	50–75% faster technology uptake
Improved data quality management and control	30–40% improvement in data quality and consistency of design deliverables produced.

Prototyping, testing, and cost–saving quantification has proven that the standardised and RAD approach to IPI System implementation developed for the IPI–BIM Framework is not only a very workable solution but also comes at short implementation timeframes, lowest cost, and highest success rate.

Sufficient prototyping and testing confirmed that the IPI System platform needed for the IPI–BIM model can be configured to any level the organisation decides on. The extent of the Design Base information (**core** versus **full** Design Base) and the data–centric level of the Design Base will influence the system implementation and configuration timelines. Such decisions will also influence Design Base data upload efforts and timelines involved to populate the system for operational use and data analytics purposes.

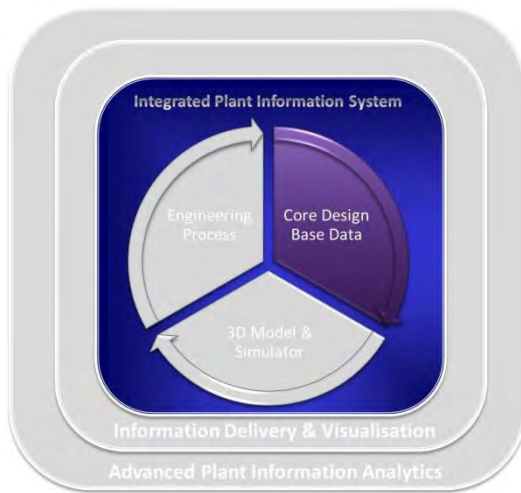
In support of the value proposition model that accompanies the IPI–BIM Framework, the cost benefit of implementing the RAD approach and standard methodology was quantified. This is indicated in Table 3–5 below.

The cost values depicted in Table 3–5 depicts **actual** costs incurred by the power station for IT and engineering systems; and by calculating engineering resource productivity loss cost based on their rate per hour and time spent on specific engineering activities (pre-RAD approach implementation). Improvements in productivity and reduced IT costs were quantified two years after implementation of the system (as part of the benefits realisation measures put in place on the project in question) and depicts **actual** cost savings.

Table 3–5: Implementation Methodology Benefits

BUSINESS EFFICIENCY AREA	COST PER YEAR
Reduced IT system complexity (combining 5 disparate systems currently used to manage engineering processes and Design Base information).	R80,000
Rework of engineering information due to inefficient business processes and loss of Design Base information needed to make plant and change management decisions.	R264,000
Time is taken to source engineering information and verifying/validating information in disparate sources.	R660,000
Inefficient knowledge management (timeframes involved to train new staff).	R320,000
IT system administration, maintenance, and infrastructure management costs.	R200,000
Prevention of Plant load losses due to unauthorised modifications to plant.	R960,000
Prevention of lost production opportunities due to inefficient maintenance activity and project work scope/activity planning.	R1,920,000

DESIGN BASE REQUIREMENTS FOR THE IPI–BIM FRAMEWORK



At the heart of the Business Improvement Model (IPI–BIM) is a **well-defined, complete and validated core Plant Design Base dataset** contained in an integrated plant information (IPI) system environment.

An Intergraph study [Botterill, 2007] 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)

This research study by Intergraph very aptly shows how poor capturing and management of Design Base information create a cascading negative business effect later on in the asset lifecycle if it is not available. It also shows the inter-relatedness of the Design Base to TTM, TIM, and OOP operational readiness measures.

The PAS–55 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 emphasises the importance of a well-managed Design Base information and data set to assist in decision making** [ISO/PC251, 2014].

The nuclear industry study on advanced AI on control systems **confirms the crucial importance of a well-managed, integrated plant database where all critical plant Design Base information is contained** [Sun et al., 1997]. **The study also stresses the importance of applying rule sets in the management of information and when ordering large data sets for analytical analysis.**

V&V of the complete Design Base can come at a major 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 funding-constrained environment.

Most of the current Power Utility Generation fleet are either mid-design life or post this midpoint in terms of the asset lifecycle [Department of Minerals and Energy, 2010]. The research scope

to define the **core** Design Base would thus be of great interest to the Power Utility who is currently undertaking a process of Validating and Verifying (V&V) their existing plant fleet's Design Base and implementing more extensive configuration control capability for the management of this Design Base.

By defining the **core elements and artefacts** that make up the critical plant Design Base for a Brownfields power utility generating plant, a standard baseline can be established that can:

- Minimise the engineering effort of data sourcing and reduce the data migration scope required to populate the proposed IPI System platform with the most critical plant Design Base information.
- Reduce the cost of validation and verification (V&V) of migrated Design Base content in the IPI System as this activity will then focus only on the V&V of **core** Design Base content.
- Enable the design data baseline needed to perform advanced analytics and set the scene for advanced analytics and future AI development.
- Improve the value proposition of establishing the IPI System Platform by reducing the time, cost and effort involved in sourcing and migrating core Design Base content into this Integrated Plant Information System.

4.1 Hypothesis Relevant to the Design Base

4.1.1 Core Design Base Definition

Hypothesis 3: A minimum set of plant Design Base content is required to enable advanced analytics. This Design Base needs to be managed in a well-designed system and engineering process environment.

In line with this hypothesis, it was theorised that the Design Base elements and content needed for a full C&I control system refurbishment would be the closest definition of what plant and technical information should be deemed **CORE** Design Base content for a plant asset. The research study proceeded to prove that this hypothesis would yield the desired outcome.

4.1.2 Reverse Engineering Missing Design Base Content

Hypothesis 4: The age of the process plant where the IPI-BIM is implemented may necessitate the need to perform reverse engineering to establish core Design Base content.

Should the proposed evaluation and prototyping activities prove that certain core Design Base content is not readily available; the research will proceed to evaluate the benefits and success rate of reverse engineering some of this missing content.

4.1.3 Brownfields versus Greenfields Design Base Establishment Methodologies

In line with this Hypothesis 3 and 4, it is theorised that there may also be a difference in the methodology required (and success rate) of establishing the Design Base content on a Greenfields Project versus an existing Brownfields plant.

4.2 Research Scope for Core Design Base Validation

The research scope regarding the Plant Design Base aims to identify the **CORE** plant Design Base; as well as define the most feasible methods of sourcing, classifying, validating and managing this content to enable advanced analytics and decision making within the IPI–BIM Framework.

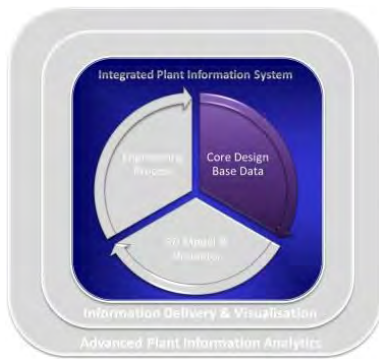
Although there would be an obvious benefit (reduced cost and V&V effort) in having a reduced core Design Base it remains important to ensure that the scaled down information set is still sufficient to support asset management, advanced analytics, Business Intelligence (BI) and plant performance reporting.

The potential Design Base scope was evaluated using a Greenfields project (construction of a 4,800 MW power station) as well as a Brownfields plant (3,600 MW power station) that has been in operation in excess of 30 years.

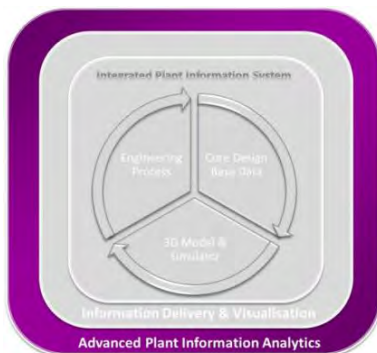
The Power Utility's New Asset Creation Build Program has been used as part of this research study's research basis (from 2008 to date). The Project execution methodologies in this Program have been used to characterise and document the typical high–level process of how Design Base information is submitted and evaluated (validated and verified) as part of the EPC portion of the asset lifecycle.

Once the core elements that make up the critical plant Design Base was identified, further investigation was done to determine whether there is any difference in content and methodology of establishing the critical plant Design Base between the research study Greenfields and Brownfields Plants.

To establish the appropriate Design Base definition for the IPI–BIM Framework, research was conducted in 3 phases:



Phase 1 entailed the classification and validation of existing Design Base content and implementing a rule validation capability using data mining techniques to automate the process of IEC document class assignment. The outcome was used to determine the extent of available information against requirements of the full ideal Design Base, and suggesting the minimum achievable **core Design Base** content for a Brownfields or Greenfields scenario.



Phase 2 evaluated the available Design Base information of a Brownfields plant and identified missing content that has to be reverse engineered. It also determined whether there is any difference in the methodology to source core Design Base content on this power station when compared to Greenfields project methodology.



Phase 3 entailed prototyping work to reverse engineer missing content identified in Phase 2. This Phase demonstrated the use of advanced analytics and simulator technology to recreate and validate missing Design Base content. The reverse engineering results required validation and were done using the Plant Operator Simulator, the Engineering Simulator (Plant Process Simulations), and Actual Plant performance data evaluation to ensure its correctness (3-Way Validation and Verification).

The completeness and appropriateness of the identified **core** Design Base dataset for Advanced Analytics would be confirmed as Hypothesis 3 in Chapter 6. Elements of the 3 phases of this research scope are covered in more detail in the following sections.

4.3 Phase 1 Related: Defining the Core Design Base Content

4.3.1 The Ideal Design Base Scope

In 2006/7 the Power Utility defined what it believed to be the “Ideal” plant Design Base set of information as part of the process of defining the Plant Engineering Baseline Process and related business process workflows [Swanepoel, 2008]. This dataset is shown in Annexure A. This information defines the departure point of this phase of the research study.

Subsequent to this initial effort to define the Design Base, a further business optimisation project (The “B2B” Project) was implemented in 2010– 2012 where a new set of Design Base

Content was proposed after giving due consideration to the overall age profile of the organisation's generation fleet assets and what Design Base content is feasible and achievable [Jansen, 2013].

Comparative research was conducted to determine the differences in approach and scope between the various Design Base back-fit initiatives within the organisation. This is summarised below:

Table 4–1: Comparison of Design Base Definition Approach and Scope

	ESKOM/B&V DESIGN BASE FRAMEWORK DEFINITION (PLANT ENGINEERING BASELINE)	GEDI DESIGN BASE CONFIGURATION	BACK TO BASICS PROJECT DEFINITION
Background	Collaborative initiative between the organization and B&V™ to define the ideal Plant Engineering Baseline (Design Base).	Project to prototype the integrated engineering information system using the most optimal plant Design Base and related engineering processes and workflows	Organisational optimization project used to re-establish best practice and simplified operational processes to manage cost and risk.
Definition	474–136: Plant Engineering Baseline Creation Procedure [Swanepoel, 2011b].	GEDI SPE User Requirement Specification Rev 7, October 2011.	Design Base Management Process Control Manuals.
Scope	Definition of contents of Design Base and how it should be managed within an engineering baseline workflow and process.	Define the Design Base content to be managed in the integrated engineering management system and the workflows and processes required to manage it through the asset lifecycle.	Capture engineering workflows and processes and document it in standardised process control manuals (PCM's) within the Organisational Framework for Business Capabilities and Outputs (eHPUM).

In addition to reviewing this baseline information, numerous examples were sourced from industry players in the EPC space to establish the typical Design Base Handover scope that process plant Owner/Operators ask for and measure at handover of process plant into commercial operation [Botterill, 2007; Fallon et al., 2006; Lewis et al., 1998; Port, 2002; Smit, 2009; Smit, 2008].

A period of three years was used in the early stages of the research study to evaluate the submissions received from EPC contractors on the 4,800MW New Build Power Plant Project against the defined Design Base (Annexure A). During the same period, a prototype and detailed search/sourcing of Design Base content on the Brownfields 3,600MW Power plant site was also undertaken.

A summary of the outcome of this evaluation is indicated below (using comparative analysis between the Greenfields and Brownfields Scenarios):

Table 4–2: Brownfields Design Base Artefact Volumes per Discipline

Level 1 Discipline		DWGS	DOCS	Quantity
A	General/Administrative	17	660	677
B	Technology Specific	114	2 135	2 249
C	Civil	30 439	3 095	33 534
D	Electrical	41 773	6 250	48 023
E	C&I	70 445	3 588	74 033
M	Mechanical	5 092	6 227	11 319
P	Process	3 478	3 095	6 573
X	Unallocated	2 608	0	2 608
TOTAL		153 966	25 050	179 016

Brownfields power station data volumes (Table 4–2) compare relatively favourably to the Design Base content supplied to the Greenfields Power Station Project over the same period of time (Table 4–3).

Table 4–3: Greenfields Design Base Artefact Volumes per Discipline

Level 1 Discipline		J05	J07	Quantity
A	General/Administrative	0	56	56
B	Technology Specific	0	5 246	5 246
C	Civil	8 187	70 881	79 068
D	Electrical	3 922	13 174	17 096
E	C&I	495	8 565	9 060
M	Mechanical	11	10 850	10 861
P	Process	1 189	11 066	12 255
X	Unallocated	0	0	0
TOTAL		13 804	119 838	133 642

Notes:

J05 refers to Greenfields Project Information System module that contains Design Base information provided by the implementation partner as the Design Authority for specific areas of the plant. J07 refers to the Greenfields Project Information System module that contains Design Base information provided by other EPC's that act as Design Authorities for their specific areas of the plant.

Analysis findings are summarised per IEC Engineering Discipline and discussed in the notes of Table 4–4.

Table 4–4: Greenfields vs. Brownfields Data Volumes

IEC Level 1 Class	4,800 MW Greenfields Power Plant	3,600 MW Brownfields Power Plant
Overall Management	56	677
Technology Specific	5,246	2,249
Civil/Structural	79,068 ^{6}	33,534
Electrical and C&I	26,156 ^{{2}{3}}	122,056 ^{3}
Mechanical	9,060	11,319
Process	12,255	6,573
Unallocated (Not resolved)	5,952 ^{4}	6,119 ^{5}
TOTAL	133,668 ^{1}	179,016 ^{1}

Notes:

- {1} The table shows the similarity in data volumes (the 3,600MW Brownfields Plant Volume based on a large portion of “common” drawings provided).*
- {2} The low C&I and electrical Design Base artefact volume on the Greenfields Project due to maturity of design and stage of delivery on the design outputs in these disciplines.*
- {3} In the GEDI Project, differentiation was made between electrical and mechanical artefacts, although IEC 61355 standard groups them together in one high-level assignment (IEC Level 1 – Discipline).*
- {4} Unallocated drawings were either drawing records that have not been IEC assigned yet due to delivery timeframe of data, or drawings in “superseded state” (and thus not used anymore) or “reserved drawings”*
- {5} C&I Control system design authority requested a sequential number of drawing numbers to be reserved (but have not used them yet).*
- {6} High volume of civil/structural drawings generated on the Greenfields Project is because of the utility’s decision to do the civil design scope of work in-house. On the older plant, this was outsourced resulting in fewer information Design Base artefact deliverables at plant handover.*

4.3.2 Defining an Achievable Core Design Base Scope

Given the limited success of sourcing the **full** Design Base artefact list (Annexure A) in the research study, a further literature survey was conducted that concluded that the Design Base elements and content needed for a full C&I control system refurbishment may be the closest definition of what plant and technical information should be deemed **CORE** Design Base content for a plant asset. A review of the C&I Design Base elements indicates a primary focus on the Operating Design Base aspects of the plant Design Base.

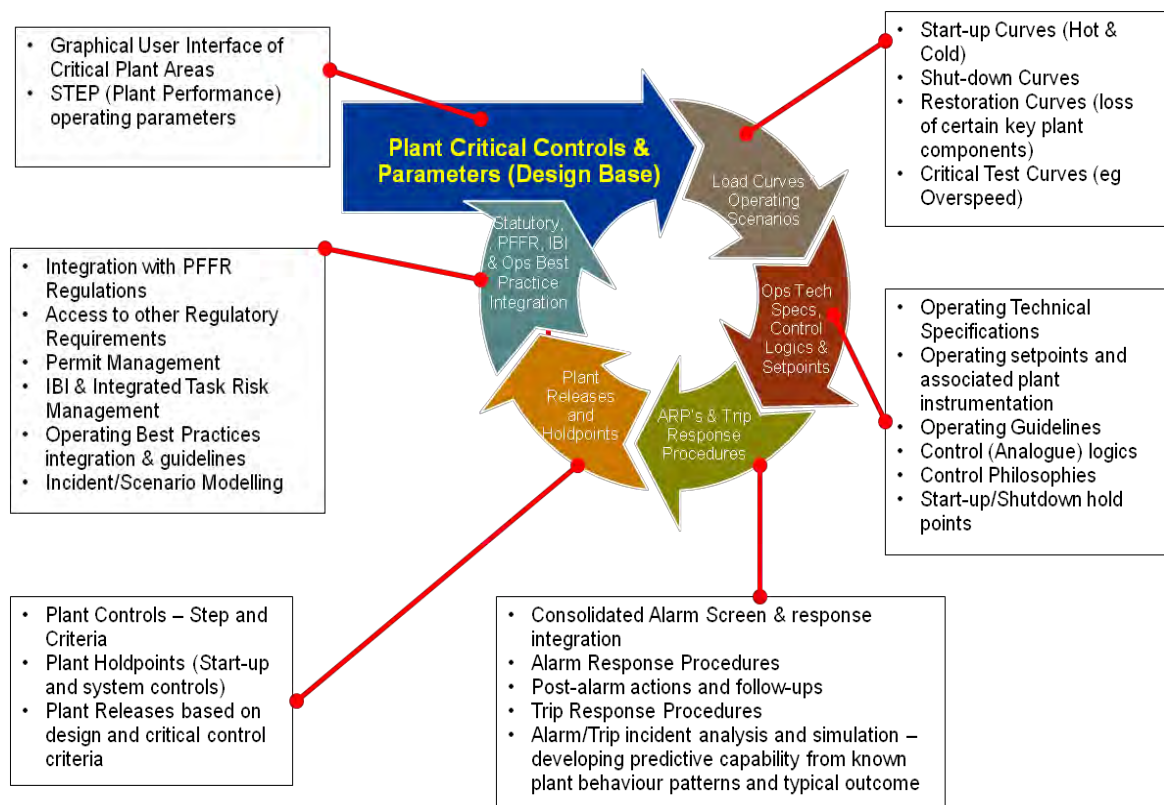
This Operating Design Base would generally be augmented by the Maintenance Design Base for the plant asset. This Maintenance Design Base would be focused on the maintenance strategy and work scope needed to ensure that the plant Design Base criteria with regards to design– and operational life can be met.

The Maintenance Baseline is dictated by the criticality classification of the plant equipment, and the resultant maintenance strategy chosen (based on the equipment classification). As the Power Utility was already undertaking a generation fleet-wide project to verify and validate the Maintenance Design Base of the power stations (the BPP MS/MW Project), the research study could exclude these aspects of core Design Base definition from the scope of work.

The research study proceeded to have detailed discussions with C&I Control System upgrade specialists. A collaborative evaluation process was used to evaluate the full set of Design Base elements to determine which of its elements would be mission critical for C&I Control system design, configuration and implementation. The result is depicted in Figure 4–1.

As a validation method, the completeness of the new list proposed was compared to the typical information needed and used to configure the Brownfields Plant operating simulator. On confirmation of alignment, a revised **core Design Base content artefacts list** was established and used as the new baseline for data sourcing on the research study Brownfields and Greenfields plants.

Figure 4–1: Core Design Base Content needed for C&I Upgrades



The initial research data-sets (summarised in Table 4–4) were further analysed in terms of IEC Level 4 Assignment (a lower and more distinct classification level that pinpoints exactly WHAT the Design Base artefacts are – e.g. Single Line Diagram or P&ID). This analysis was then utilised to extract statistics regarding the availability of this identified critical (core) Design Base content and also to evaluate the success rate of sourcing this content.

4.4 Phase 1 Related: Improving the Efficient Structuring of Core Design Base Content

The Literature Survey in Chapter 2 confirmed that one of the most common Design Base document classification standards in use in the Utility industry space is the IEC 61355 Document Classification standard [International Electricity Commission, 2008].

This Standard was implemented and adopted as the engineering documentation and information classification standard for the Power Utility (as part of the B2B Project initiative). The research study power stations were the first to implement this standard to properly define and group their Design Base content.

4.4.1 Development of the Data Mining Automation Tool

The first pass IEC Document Class assignment was done manually – this proved to be a very time-consuming and arduous task.

The manual exercise also pointed out that a limited understanding of the IEC classification system and artefact definitions can result in an incorrect or inconsistent assignment that would affect correctness and success rate of the exercise undertaken. It became clear that manual IEC Document Class assignments should be done by an individual that understands the various engineering discipline Design Base artefacts and can assign them to their correct class correctly and consistently.

Evaluation of Advanced Analytics techniques [Lustig et al., 2010] during the literature survey prompted a theory that it should be possible to define data analytics rule-sets and utilise data mining techniques on the titles of documents and drawings. There was even potential to extend its use to content *within* documents in order to assign IEC classes to the documents automatically (internal content analysis comes with the proviso that Optical Character Recognition [OCR] have to applied to the document content).

The “keyword criteria” used to do the initial manual IEC assignments were used as a basis to define the initial analytical rule-set and associated data mining algorithms. Table 4–5 below shows an example of the typical data-mining rule-set developed for one of the technical/engineering IEC document classes.

Once the data mining rule-sets were built and configured, an actual dataset was identified for testing purposes. This could be used as a research verification mechanism to ensure that the rule-set was correctly defined and built. The refined IEC Rule-set query was run individually per IEC document class and the findings analysed.

Table 4–5: Typical example of a data mining rule–set developed in this research study [Tullis, 2013]

Priority	IEC level 4 Doc Class	Rule Set	Comments
34	D00206 - Excavation Plan	*unit* piling* *area* surf* bed* *surfa* bed* *excavation* *floor* slab* detail* *trench* detail* *trench* arrange* *back fill* *terrace cut and fill* *trench*sections* *excavat* plan* *site preparat*	
35	D00208 - Reinforcement drawing	*rein* *PLTHS* * rebar* *bndg sch* *rnfrng* *bending Sched* *bend sche* *bending * RNF* *rnfrmnt* *piling plan* *reinft* det* *list* steelwork* *steelwork*arrangem* *steelwork* mark* plan* *formwork* *steel loading*diagr* *reinforcement schedule*	Bending schedules could potentially fall under D00212 - Item lists. However, when you look at the actual drawing, bending schedules are often placed in a drawing title block and classified as a "Reinforcement Drawing" as part of the drawing tile. Therefore it will probably rather be searched under this classification.

Verification analysis indicated that some document/drawing titles contained content that can dictate assignment to more than one IEC class. From the analysis, it also became evident that correct sequencing of data mining rules per IEC type will play a significant role in the accuracy achieved. It was thus required to identify such instances in order to define the correct rule sequence and to then re–test and optimise it under the prototyping stage of this research phase.

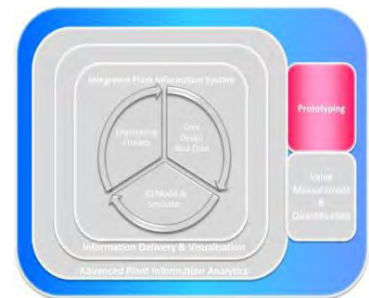
The adjusted analysis methodology used during the prototyping was as follows:

- Each IEC document class was first run as a “select” query to be able to first review the results/outcome before finalizing the IEC assignment.
- An evaluation was done based on the results achieved to confirm that the allocation is consistent and correct.
- The results were then evaluated to determine if there is any possibility of identified records being classified as a different IEC class. If this was the case, the sequencing of select queries was then tested to determine predecessor and successor query rankings.
- If results were correct and no ambiguity with IEC class assignment existed (or was resolved with query succession resolution), the query was changed in the database to an “update” query and Level 1, 2, 3 and 4 of the IEC document class was updated.

- Such assignments were then locked to protect them from potential changes emanating from subsequent query runs.
- If only selected records were found to be correct within the query algorithm executed (i.e. the rule–set does not yield any level of trustworthy consistency) – the records were evaluated and updated manually within the database instead of running an “update” query.
- If any new data mining keywords were identified during the manual assignment, they would be added to the mining algorithms as part of a continuous improvement drive.

4.4.2 Testing and Validating the Data Mining Automation Tool

Iteration 1: This iteration used the manual IEC document class assignment on the Greenfields Project as a baseline and developed the data–mining rule–sets based on keywords in titles and some actual document content. By choosing this dataset, the research study had the advantage of a validated and verified set of 68,324 technical/engineering documents and drawings that were already manually assigned to an IEC document class prior to running any analytical rules engine.



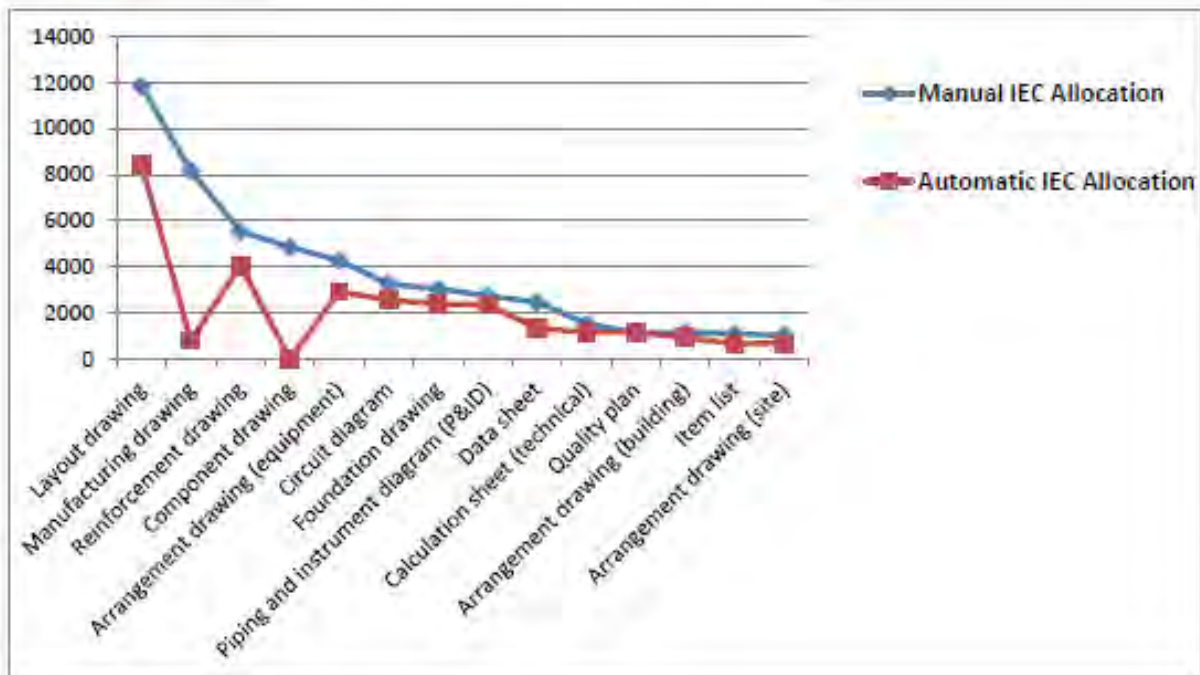
Using this validated dataset and running the automated analytical data–mining rule–sets against it, it was possible to measure the automated assignment success rate against the manual assignment as a research verification method. In the first pass run, a success rate of 53.7% accuracy on IEC level 4 assignments was achieved.

By having manually validated data as a reference, it enabled the researcher and validation tool designer to fine–tune the rule–sets when assignment did not yield the desired result (e.g. enabling data analysis of why automated mining of manufacturing and component drawings yielded very low accuracies when compared to other classes – see Figure 4–2).

Although it was accepted that a 100% accurate assignment rate may not be possible with automation of data–mining rule–sets, the accuracy level achieved in iteration 1 (53.7%) was of concern as it was believed that such a low accuracy level would not significantly reduce the engineering effort and time spent on technical document/drawing classification, nor would it be a viable solution to facilitate and increase the efficiency of the Design Base back–fit process due to the increased need to validate and identify the items not accurately assigned.

Figure 4–2: Data Mining Rule–set Validation: 1st Iteration vs. Manual Assignment
[Tullis, 2014]

Expected accuracy on automatic IEC allocation:



Further iterations of data mining tool enhancement were subsequently undertaken to improve the accuracy level. In order to contain the number of research study iterations in developing and optimising the data mining tool, it was decided that a minimum accuracy level of 80% assignment across identified IEC classes should be achieved consistently for the tool to be considered a viable engineering productivity enhancement tool for Design Base back–fit activities.

Iteration 2: The 2nd iteration used the manual IEC document class assignment on the research study Brownfields Plant to enhance the initial rule sets defined and optimised in Iteration 1.

As the Greenfields project was in early design phases (FEED, Feasibility and Early Design), only about 75% of expected Design Base IEC Document Class types were submitted by the EPC's at the time of conducting the research study and this resulted in an incomplete rule–set in the data mining engine (when compared against the full set of IEC Level 4 Document Class Types). Using the Brownfields plant, the research study could define mining rules for these Design Base documents covering a larger scope of technical documents as defined in the IEC 61355 standard.

This iteration included a second test–run of the improved ruleset against the original Greenfields Project dataset to determine the percentage improvement (if any). The test run also created the opportunity to perform further rule–set optimisation given the additional data–mining experience

gained over time and the larger volume of documents subsequently received and reviewed on the Greenfields Project.

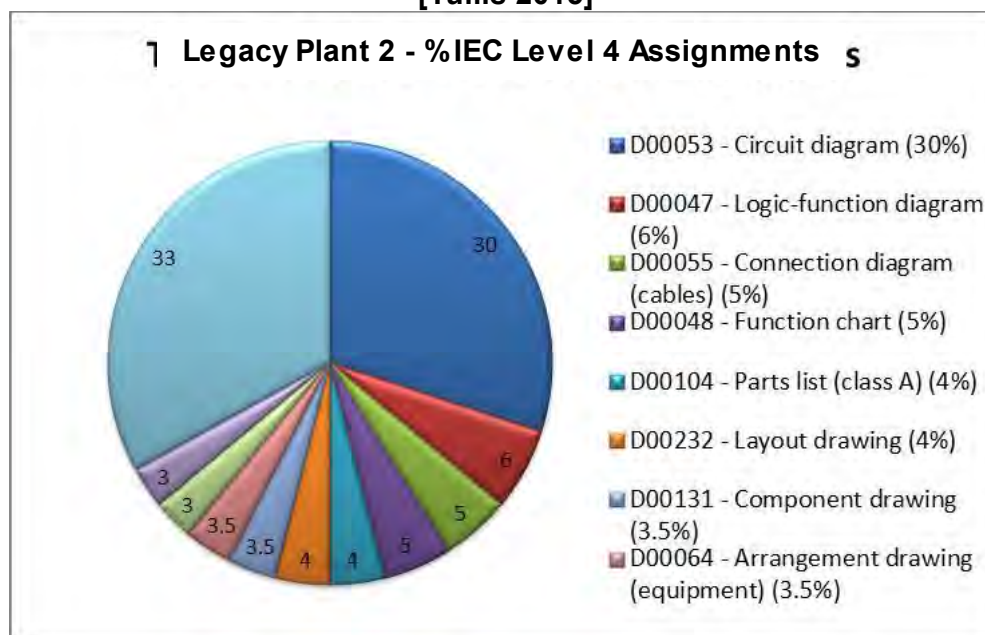
Results from this enhancement indicated that a total of 107 IEC Level 4 technical/engineering document classes could be identified and assigned successfully, at an accuracy level of above 90%.

Iteration 3: In this iteration, a 3rd unrelated plant document/drawing Design Base data set was used for the purposes of **external validation** to test the enhanced data–mining rules definition and evaluate the automated class allocation success in an unrelated power station scenario.

The results of this test–run could then also be used to compare the two Brownfields plants (which are of similar age, capacity and Design Base configuration).

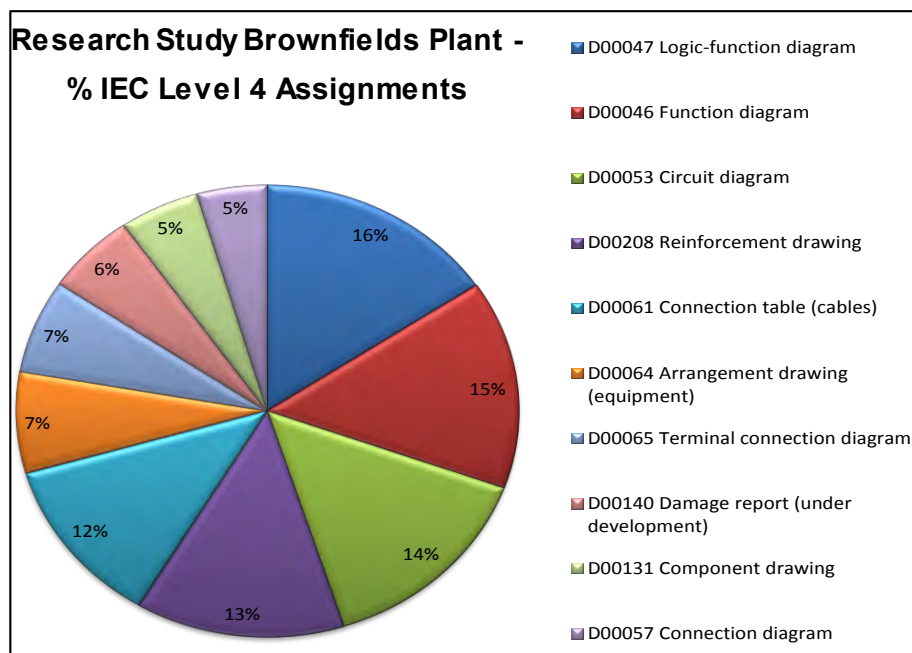
Figure 4–3 depicts the findings of the Top 10 IEC assignments of the 3rd plant's data set when analysed with the IEC Automation data mining tool, while Figure 4–4 depicts the research study Brownfields power station.

Figure 4–3: Top 10 IEC Assignments using Automated Rule–set: Brownfields Plant 2 [Tullis 2015]



Similar results were achieved between the two Brownfield Plants in that fairly similar document types and volumes of specific classes were found, as can be seen when comparing Figure 4–3 to Figure 4–4. Careful consideration should obviously be given to factors like the Design Base maturity and data quality content at the different power stations before doing such a comparison and making a call on core Design Base maturity.

Figure 4–4: Top 10 IEC Assignments using Automated Rule–set: Research Study Brownfields Plant Outcome [Tullis, 2013]



Once the data mining rules were confirmed to achieve the desired IEC assignment accuracy, a final comparison was done against the **core Design Base** defined by the research study to ensure that the data–mining rule–sets focus on the correct Design Base artefacts.

4.4.3 Data Mining Automation Tool Success Rate

Table 4–6 summarises how the initial data mining analytical success rate was improved using further iterations of rule–set enhancement using both Brownfields and Greenfields technical/ engineering plant documentation. It demonstrates the very high success rate of IEC Level 4 document class assignment that is achievable with effective rule–set implementation (and using working plant datasets).

Table 4–6: 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%
<i>*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</i>		

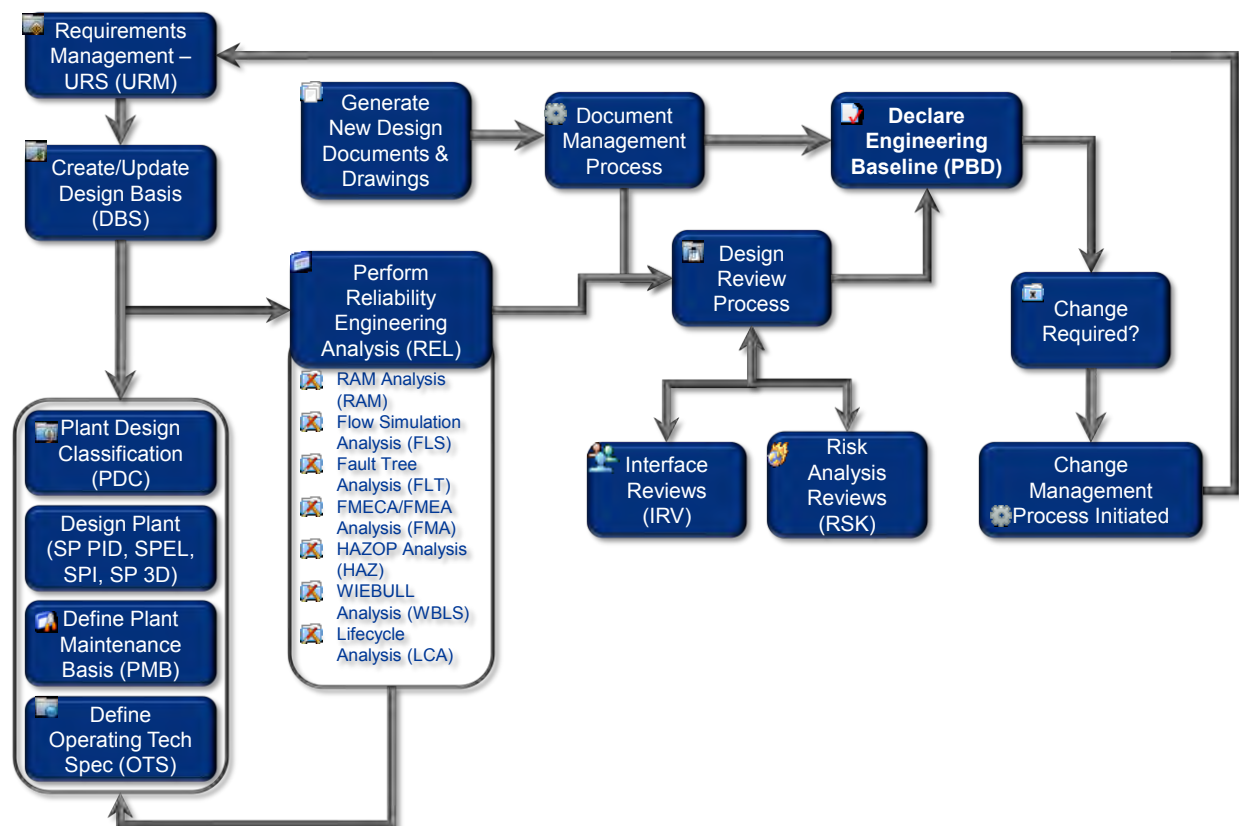
The comparative approach taken by the research enabled further uses of the data mining technology. Where low volumes of information are found with data–mining it may be indicative of a need for reverse engineering to source/re–engineer missing data (especially if other plants indicate much higher volumes of the same Design Base artefact types).

Conversely, by comparing the information volumes between different (but similar technology) Plants, it can also indicate cases where actual volumes of information in a specific IEC class are by nature low in a process plant/project.

4.5 Phase 1 Related: Comparing Greenfields versus Brownfields Plant Methodology

Research of the Greenfields Project of the Power Utility Asset Creation Program confirmed that Design Base information sourcing is still mostly a document–centric process that is very reliant on delivery of Design Base artefacts (in the form of documents and drawings) by EPC's (Figure 4–5). Consistent delivery of these artefacts in electronic format at least allows for a higher success rate to extract data–centric Design Base content if required.

**Figure 4–5: Using incoming documentation and data to build the Design Base:
Greenfields Project [Swanepoel, 2012d]**



Diverse scenarios for Design Base delivery (document–centric versus data–centric delivery) were evident when comparing the Greenfields Project used in this research study against the Brownfields Plant.

Evaluation of Design Base content at the Brownfields Power Station indicated that it is predominantly document–centric in nature. As an example, the design criteria and data for the Brownfields Plant had to be extracted from hardcopy documents and manuals into electronic database format in order to be used [and to be available] for advanced analytics model building in the Virtual Plant™ module of the etaPRO™ software.

It was found that the Brownfields plant had more than 85% document–centric Design Base content, while the Greenfields Project content hovers around 40% document–centric deliverables, with a notable quantity of Design Base deliverables provided in a fully data–centric manner.

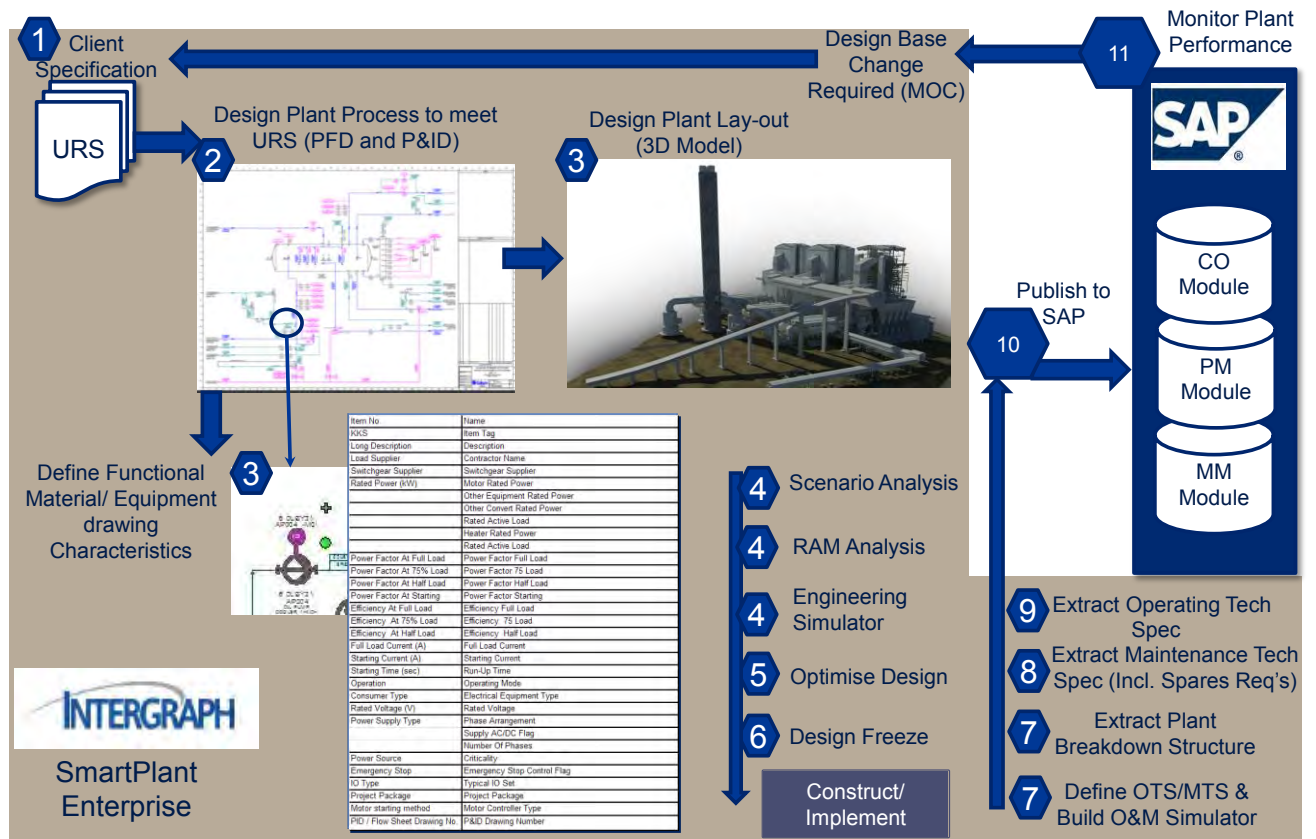
The decision by the research study Brownfields plant in 2007/8 to embark on an intelligent P&ID re–draughting exercise and limited digitisation of the Plant 3D Model (using 3D laser scanning technology) extended the Design Base for this plant into a more data–centric configuration, but this capability is the **exception in the Power Utility** Brownfields power station fleet (rather than the norm).

4.6 Phase 2 Related: Design Base Content Sourcing and Completeness Evaluation

4.6.1 Greenfields Project Design Base Sourcing

Because of the involved nature and dependencies of many plant Design Base elements on each other during the plant design phase (Figure 4–6); as well as these Design Base artefacts being core inputs into Construction phase design review sessions, sourcing the identified **core** Design Base content on a Greenfields project proved fairly easy.

Figure 4–6: Design Base Content creation process for Greenfields [Swanepoel, 2012d]



A notable challenge in the Greenfields scenario was core Design Base **artefact maturity** due to the project lifecycle stage the research study Greenfields Project was at. The issues around maturity of such documentation (as well as the timelines involved) were pointed out by Intergraph in their research white paper [Intergraph, 2007].

The Greenfields project at the time of the research scope execution was still in concept design and detail design lifecycle phases. As such many core Design Base documents/artefacts were at low levels of maturity and some Design Base artefacts were not being available at all as the design was not at the stage yet where these could be defined/supplied.

A further shortcoming from a Design Base data perspective was the limited availability of operating baselines (captured at commissioning), occurrence and plant modification data as the plant is still under construction.

4.6.2 Brownfields Power Station Design Base Sourcing

Significant work was required as part of the research study to convert numerous elements of the Brownfields Plant core Design Base dataset to a more data-centric and consistent data quality format. The process also pointed out the inherent risk of data integrity issues being introduced in the data conversion process, confirming the value proposition of obtaining engineering/design deliverables in the data-centric format during the EPC phase.

Another challenge in the Brownfields plant scenario was the use of disparate information systems to capture and manage Design Base information. It was a key contributor to having limited success in sourcing the full Design Base artefact list (as depicted in Appendix A). Meta-data quality for documentation and consistency in capturing this information across multiple system platforms was found to be poor, and documentation was seldom linked to the plant breakdown structure.

As would be expected (due to the age of the Brownfields Plant), the practice of supplying “typical/common drawings” was also found to create a skew picture of actual Design Base content versus “as built” plant status. An assumption at the time of plant construction was that all six units on the plant would be similar in design and construction and that there would not be a need to “unitize” the drawings or technical engineering content.

The P&ID re-draughting project at the research study Brownfields power station in 2007/8 demonstrated, however, that there are indeed differences in final “as built” status on the Brownfields plant (due to improved enhancements during construction, modifications on the plant, and some of these modifications only implemented on some units but not done/abandoned on others).

This confirms the importance to have centralised change management and control processes enabled on the Design Base to ensure it reflects the plant “as built” status at all times.

Large volumes of Design Base information were also only available in poorly maintained hardcopy formats, scattered across the site in offices of engineers, which made sourcing and digitising to good quality electronic copies more difficult.

4.6.3 Sourcing Core Design Base Content

These initial evaluation findings supported the research hypothesis that a **CORE** Design Base dataset would be the most feasible approach to take. As such, the research study focused any further efforts in this area on sourcing the **core Design Base artefacts and content** for both plants, with the outcome depicted in Table 4–7. (Taking this approach also assisted in confirming the ability to source the artefacts identified for the plant in question).

Interpretative notes at the end of Table 4–4 explain anomalies or large differences found with the comparative analysis done in the research study.

Table 4–7: Core Design Base Content Value – Brownfields vs Greenfields Plant

CORE DESIGN BASE CONTENT	QUANTITIES OF DESIGN BASE ARTEFACTS	
	GREENFIELDS	BROWNFIELDS PLANT
Process Flow Diagrams (PFD's)	144	122
Process and Instrumentation Diagrams	4,467	3,198
Material, Mass and 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 and Operating Philosophies	1	7
Control Functional Specifications	272	32
System Functional Specifications	793 ^{9}	42
Operating Manuals	0	135
Process Alarms List – Alarm Response	2	1,578
Plant Trip and Interlock Schedule	2,817	12,695 ^{2}
C&I Set–point List	165	55
SIL Report (Safety Instrumentation List)	17	1
Instrument Schedule (Preferably including Locations)	101	304
Plant Control and Protection Logic (Including Interlocking)	0 ^{2}	0 ^{2}
Automation Concepts/Strategy	0	2

CORE DESIGN BASE CONTENT	QUANTITIES OF DESIGN BASE ARTEFACTS	
	GREENFIELDS	BROWNFIELDS PLANT
3 rd 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 and 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 and Inspection Plans	723	399 ^{5}
Operating Technical Specifications	0 ^{13}	33
Operating Check sheets	591 ^{11}	202
Commissioning Check sheets (Running, Start–up and 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 and Detail	355 ^{10}	1,726

Notes:

- {1} Operating Envelopes are typically described in the OTS and not found as a stand-alone/separate document. Operational/ Performance Requirements documents identified that to some extent equate to 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, 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. The number reflects the quantities of these registered under the project.

- {11} *Issued as Operating Instructions*
- {12} *Safety Study artefacts, 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.*

Table 4–7 shows that there are very similar volumes of information generated when comparing a single generating unit data set on the Greenfields Project to the data–set of the Brownfields Plant.

C&I and Electrical discipline artefact analysis indicate that these discipline–related engineering artefacts make up the biggest volume of Design Base data that will be generated on a project of this nature (Brownfields comparative data volumes). Further evaluation confirmed the issue of availability of such information in the early stages of the project execution lifecycle and the dependency on the maturity of the overall plant design.

Analysis of the success rate of sourcing Design Base data between the two scenarios reveals that some information forming part of the Design Base is problematic on the Greenfields project due to additional asset lifecycle dependencies – e.g. completion of commissioning activities and involvement from the Owner/Operator to develop certain Design Base artefacts (e.g. maintenance philosophies, operating envelopes, etc.).

Unlike the Brownfields Plant, the Greenfields project furthermore had limited occurrence/incident information. Subsequent to conclusion of this research study scope, the Power Utility initiated a formal EPC engagement process to source reliability engineering studies from the Design Authorities in order to get access to this type of information (e.g. RAM Studies, FMECA Studies, HAZOP studies, etc.)

On the Brownfields plant, access to **original** FMECA data was also problematic as delivery of this information was not part of the original scope of information delivery by EPC contractors. Subsequent organisational initiatives (RCM Project and the BPP MS/MW Project) and their outcomes mitigated the potential risk of not having this core Design Base information.

In some cases, industry statistics and EPRI guidelines regarding typical failure modes on power plant equipment could be used to provide a fairly accurate set of FMECA failure modes to consider in the advanced analytics portion of this research study.

In conclusion, the overall analysis review of Design Base maturity confirmed that using the Brownfields power station for advanced analytics would be the better choice due to maturity and availability of Design Base information considered key to the advanced analytics research scope of work.

4.7 Phase 3 Related: Design Base Reverse Engineering

The research study anticipated the need for potential reverse engineering activities to re-build and validates any key missing Design Base content identified with the Design Base sourcing exercise.

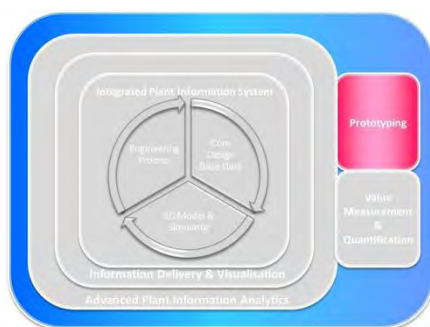
Further, it was important to understand what happens to certain key operating design criteria and operating output values in instances where reduced asset performance capability (against the original Design Base) is identified (e.g. due to the ageing of the plant and increased failure rates on certain plant systems and/or components). Access to such information can provide guidance for potential design criteria adjustment(s) that may be required to the original Design Base (to compensate for reliability/availability issues and plant ageing aspects).

4.7.1 Reverse Engineering Design Base Candidate(s)

A low volume of information and data was found on operating envelopes, design operating limits and safety factors and expected plant process response behaviours on the Brownfields Plant. This Design Base element was therefore earmarked as an ideal candidate for the reverse engineering scope of the research study.

The Rankine Cycle is the most commonly used depiction of the process flow of a coal-fired power plant (usually delivered as a “Process Flow Diagram”). This process cycle depicts the most fundamental critical operating values of the operating envelope (and will best reflect the process behaviour response to deviations against the desired plant Design Base). It was thus crucial that the Rankine Cycle for the plant in question is correct and confirmed against actual plant process parameters and performance trends.

4.7.2 Reverse Engineering Methodology and Research Scope



The aim of the reverse engineering research scope was to demonstrate that the re-creation of the operating envelopes and the expected plant process response behaviours of the Brownfields Plant using Simulator Technologies would be a viable option in cases where the information is not readily available or cannot be sourced with conventional information gathering methods.

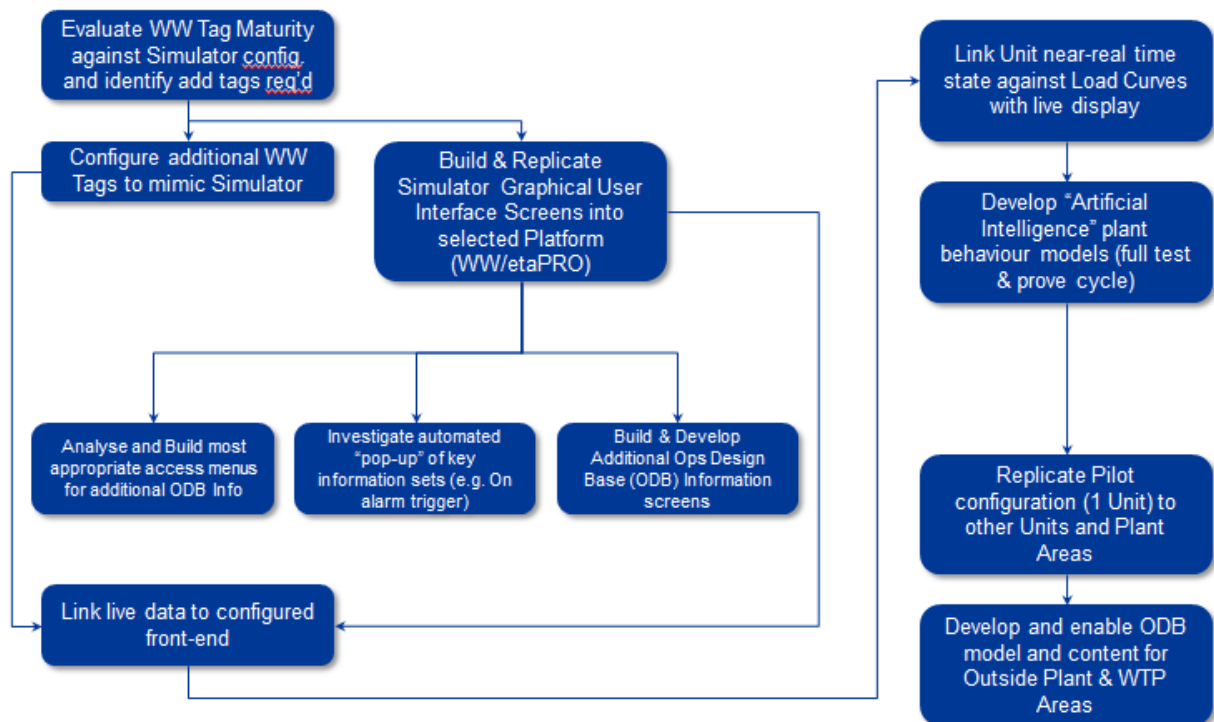
The research process and methodology of reverse engineering the operator simulator Design Base content are indicated below (Figure 4–7). The scope of the research study was restricted to the verification and validation of operating Design Base data on **one plant generating unit**.

Replication to the other generating units would be future work and configuration enhancements to the research outcome.

The operating simulator configuration was compared to the documented and known plant Design Base and it was confirmed to be closely aligned to stipulated operating parameter Design Base values specified by the Original Equipment Manufacturer (OEM). This simulator configuration was then used to replicate the Operating Design Base environment into the Engineering Simulator advanced analytics tool used in this research study (etaPRO™).

Actual plant data for this Engineering Simulator is sourced from the current plant data historian at the Brownfields plant (a WonderWare™ system platform). This data historian acts as a repository of all plant control data and information. Data capturing in the historian occurs on a near–real–time basis.

Figure 4–7: Reverse Engineering Design Base using Plant Operating Simulator



Part of the research methodology and scope was to confirm alignment between data sets used in the operating simulator, the advanced analytics (Engineering Simulator) tool, and the plant data historian. Internal data validation methods like triangulation were used to ensure that multiple source data–sets are used for results comparison and outcome verification.

An example of this was the research study scope of work that was required to ensure close alignment of core Design Base data elements like the Plant Breakdown Structure (PBS) in the various system platforms indicated above. Evaluation of the engineering and operating

simulator configurations showed an inconsistent approach to plant tag assignment and naming conventions, necessitating a data alignment exercise between the systems before proceeding with further research work.

Once corrected, the research proceeded to evaluate the plant load and operating curves (currently in paper format) against actual control system data to confirm that the Operator Simulator load curve configuration and outputs mimics real life conditions and expected behaviour. Once validated, these curves were configured into the Operating Simulator.

This preparatory work formed the foundation for the advanced analytics scope of this research study (plant behaviour models were built and evaluated against developed content from this phase). This is discussed in more detail in Chapter 6 of this thesis.

4.7.3 Design Base Data Quality Challenges and Enhancements Required

In evaluating the configuration and information architecture of the systems to be used in the research study, significant discrepancies were found in the naming conventions used between the plant data historian and the 2 simulator environments (when compared to the official Plant Design Base PBS). Using the official plant Design Base PBS, the data points in the three systems were standardised and aligned on a one-to-one basis. Of the 4,971 plant tag titles reviewed, 2,611 required data alignment and correction.

Misaligned data also pose the risk of misinterpretation of data or comparison of incorrect data sets against each other during the research methodology execution (and hampering attempts to use the 3-way system validation as the internal validation mechanism for Design Base data content reverse engineered in the simulator).

As a case in point, very generic data point names like “Exit Temperature” were used in the Plant Historian, without a clear indication of where exactly this exit temperature is measured in the plant process. Once these mismatches were resolved, improvements in data quality and analytical outcome were notable as the Engineering Simulator previously either used “interpreted values” or incorrect data extraction points from the Plant Data Historian due to the anomalies in plant description and tag naming conventions.

System configuration analysis identified a further 1,350 data points that were not configured in the Plant Data Historian (reducing the usability of this platform for feeding the engineering simulator and advanced plant performance analytics database engine). These data points were added as part of the research study and deemed a crucial activity to bring alignment between Design Base and simulator configuration in preparation for advanced analytics prototyping work undertaken in Chapter 6.

This Design Base data quality enhancement enabled tight integration with the plant Design Base, and facilitated data validation across the system platforms, something considered a crucial requirement for the research study outcome. It further assisted with effective data and results comparison.

Following the data alignment, the Operating Simulator screens were replicated and rebuilt into the Engineering Virtual Plant Simulator. This exercise identified a number of plant operating parameters that were calculated in the back-end of the Operating simulator and does not use any actual or process-derived data. Part of the research data analysis process was to then determine whether these data points exist in the Plant Data Historian (where there would be actual plant data captured against it).

In most cases, the data points did not exist in the Data Historian. This is deemed a control philosophy design anomaly and constitutes a significant improvement to the current Plant C&I Control system configuration that should be addressed with the future plant control system upgrade. These shortcomings have been raised with the C&I System Upgrade Project to be addressed as part of the future upgrade.

4.7.4 Operating Envelope and Alarm Criteria Limitation Challenges

One of the biggest challenges of the current plant control system platform is that the operating envelope alarm triggers are captured in analogue format in a system external to both the legacy plant C&I control system and the Plant Data Historian software.

Reliability of the very old field instrumentation devices feeding this C&I Control System also proved a major constraint to get continuous data inputs for analytical purposes.

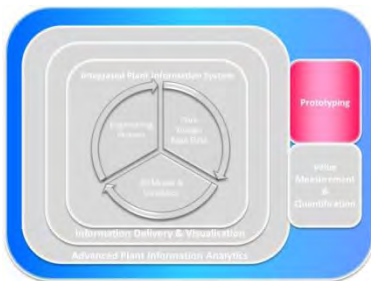
In the Operating Simulator, the alarm response and activation are immediate (as data is read off a defined data set and internal algorithms and calculations supply the information needed to trigger and evaluate alarm conditions as well as to determine whether interlock and start criteria was met or not).

In direct contrast, the engineering simulator is dependent on information it can extract from the Plant Data Historian. As such, data comparison and analytical capability in the engineering simulator ended up being more complex and resulted in additional research work scope as the alarming and interlock information had to be imported from the alarm system first and converted to digital signals before it could be used in the Engineering Simulator, resulting in a loss of the near real-time capability.

A benefit of building automated alarm triggers in the historian and engineering simulator environments was that it enabled the capability to give a visual indication when the plant moves out of the allowable operating envelopes, something that would support the Information Delivery (and visualisation) scope of the research study (Chapter 5).

A list of these shortcomings and additional data capturing requirements were forwarded to the C&I Control System Upgrade project to ensure that the URS for the new system is adjusted to include these additional enhancements and requirements.

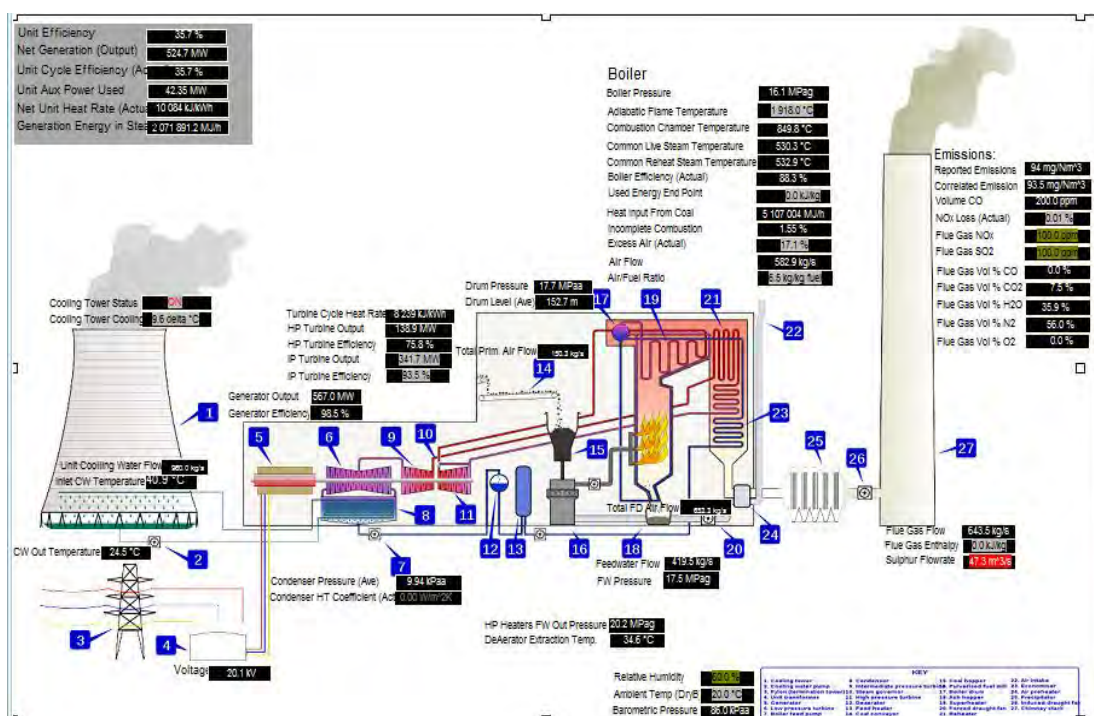
4.7.5 Research-based Enhancements to the Engineering Simulator



The research study anticipated that additional screens may have to be designed and built in the advanced analytics system of the Engineering Simulator to provide more insight into operating envelopes and behaviour.

Figure 4–8 below indicates the screen developed in the Engineering Simulator displaying live plant data for the various Rankine Cycle data points used in calculations and process reliability analytics. (This was also identified as one of the reverse engineering candidates due to the core Design Base parameters this Cycle normally uses for efficiency calculations).

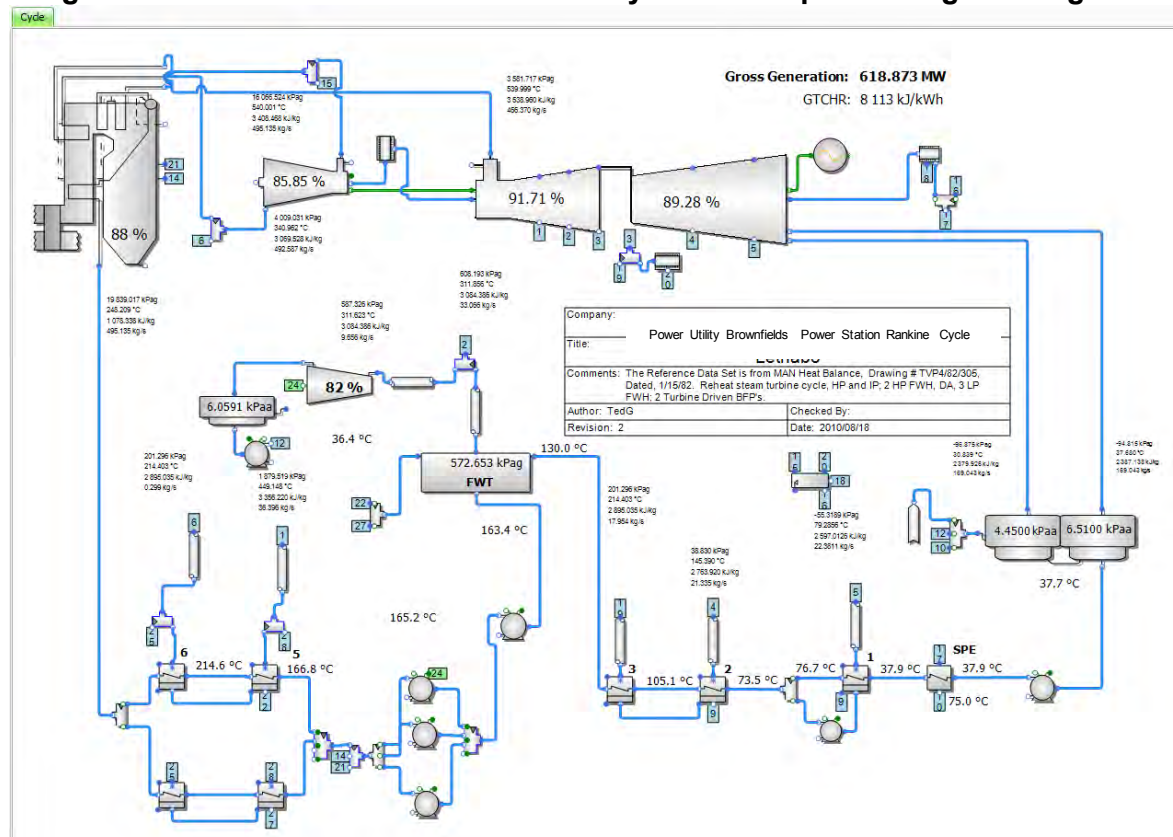
Figure 4–8: Brownfields Rankine Cycle Critical Data Enablement in Engineering Simulator for Analytics



4.7.6 Reverse Engineering Results: Design Base Candidates

The research study Brownfields Power Station Rankine process cycle and analytical model for ideal plant design conditions and configuration were built in the Engineering Simulator Analytics Tool (Figure 4–9). This model was based on the original plant Design Base as provided by the OEM of the Plant. From this ideal Design Base configuration, additional operating Design Base information could be calculated, extracted and missing operating envelope values determined.

Figure 4–9: Plant Ideal State Rankine Cycle developed in Engineering Simulator



This ideal model could further be used as a validation reference in order to compare actual plant process performance values (using data from the Plant Data Historian) and behaviour to this idealised state of the plant. Plant deviations and changes to the ideal design behaviour could be evaluated and the impact of these anomalies to plant output and efficiency studied (more information regarding this is provided in Chapter 6).

For data validation, the required calculations and comparison against Design Base was undertaken. An example of this is given in Annexure B of this research study. This ideal model was then used to build additional data monitoring user interface screens where Design Base operating parameters could be monitored, compared and trended in the advanced analytics tool.

Figures 4–10 and 4–11 show samples of these additionally developed screens and how deviations from ideal operating curve and parameters can be very efficiently trended and identified. Figure 4–10 depicts the core operating parameters trended for the boiler plant area, while Figure 4–11 covers the steam generation and specifically turbine performance and operating parameters.

Figure 4–10: Boiler Operating Parameter Performance monitoring (Design Base vs Actual)

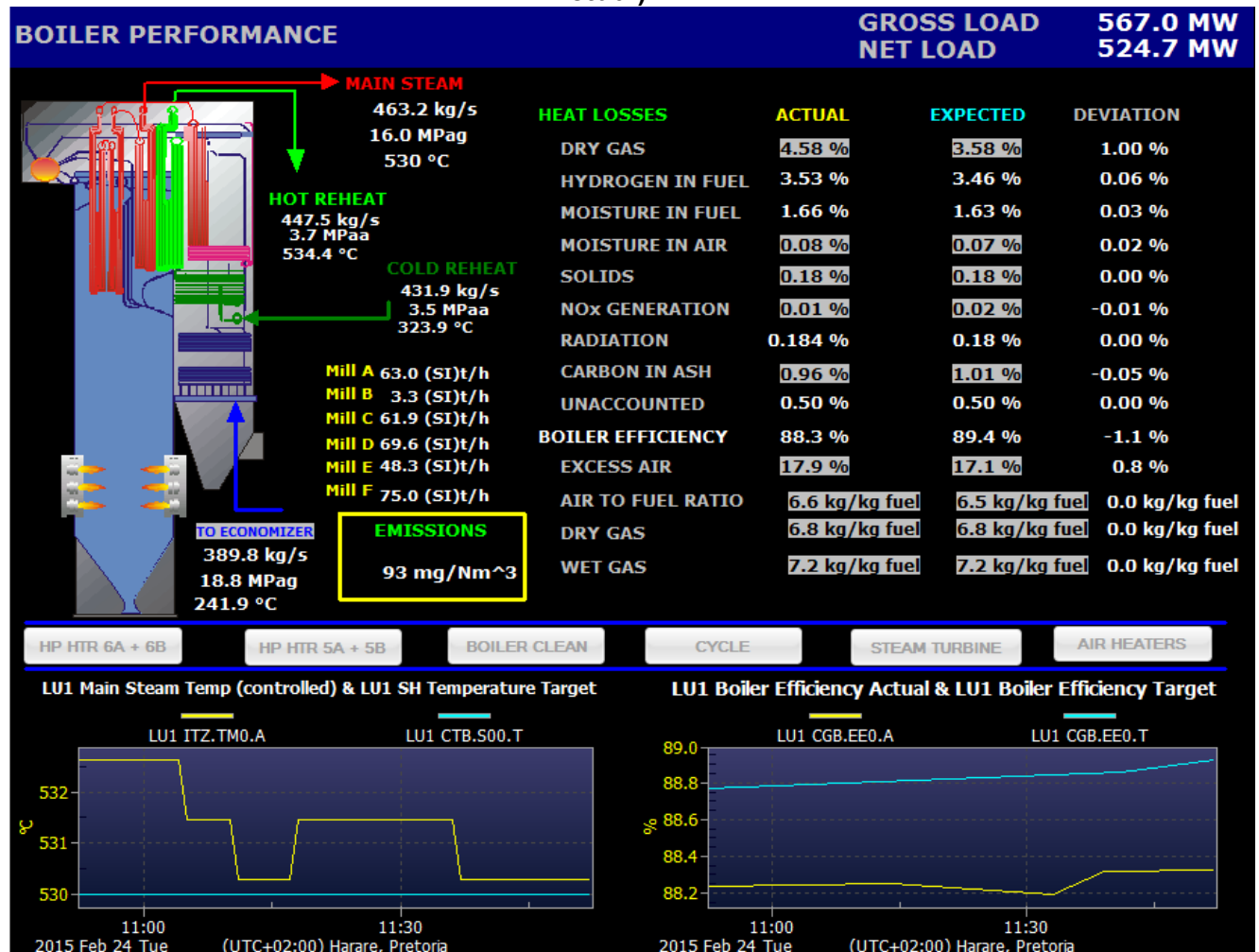
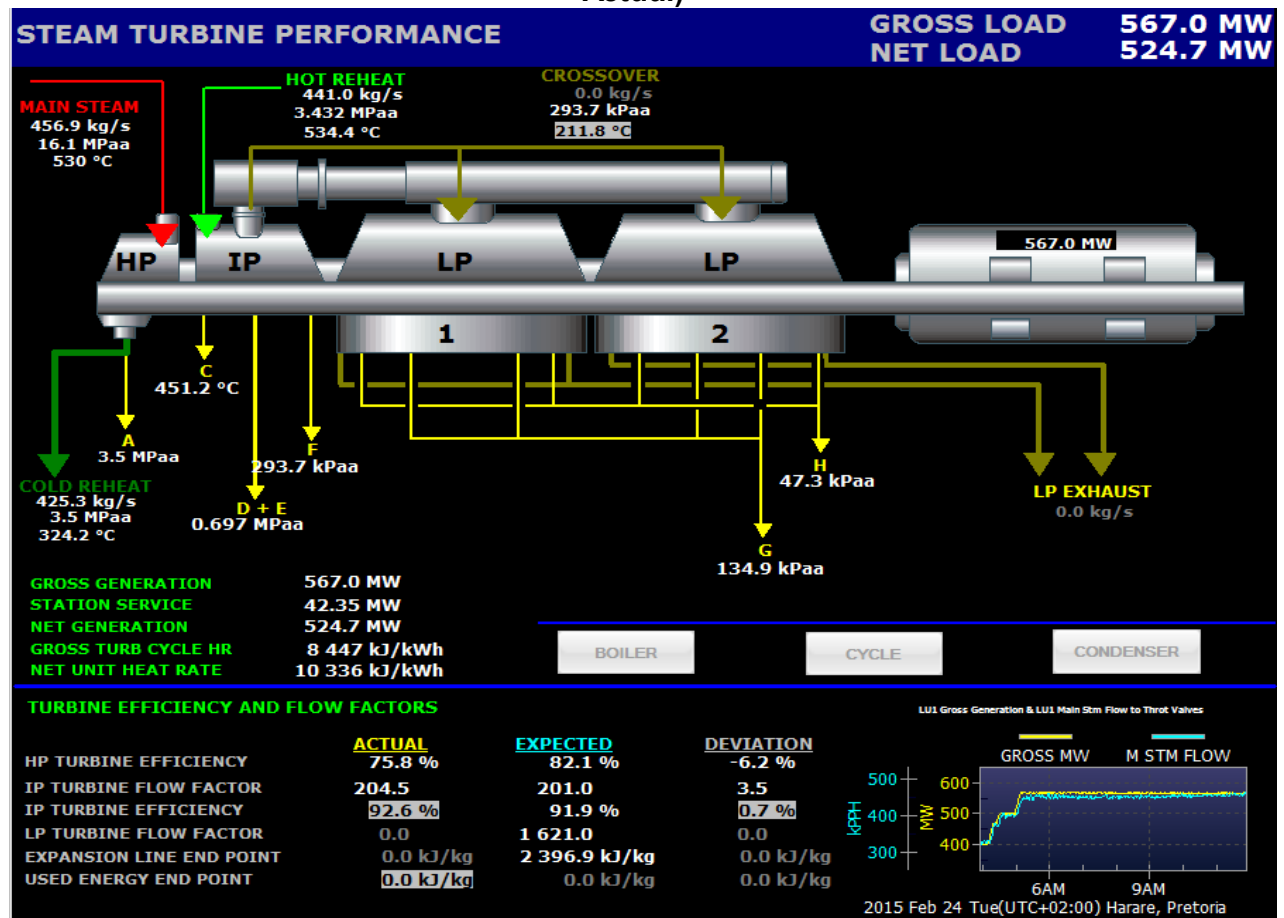


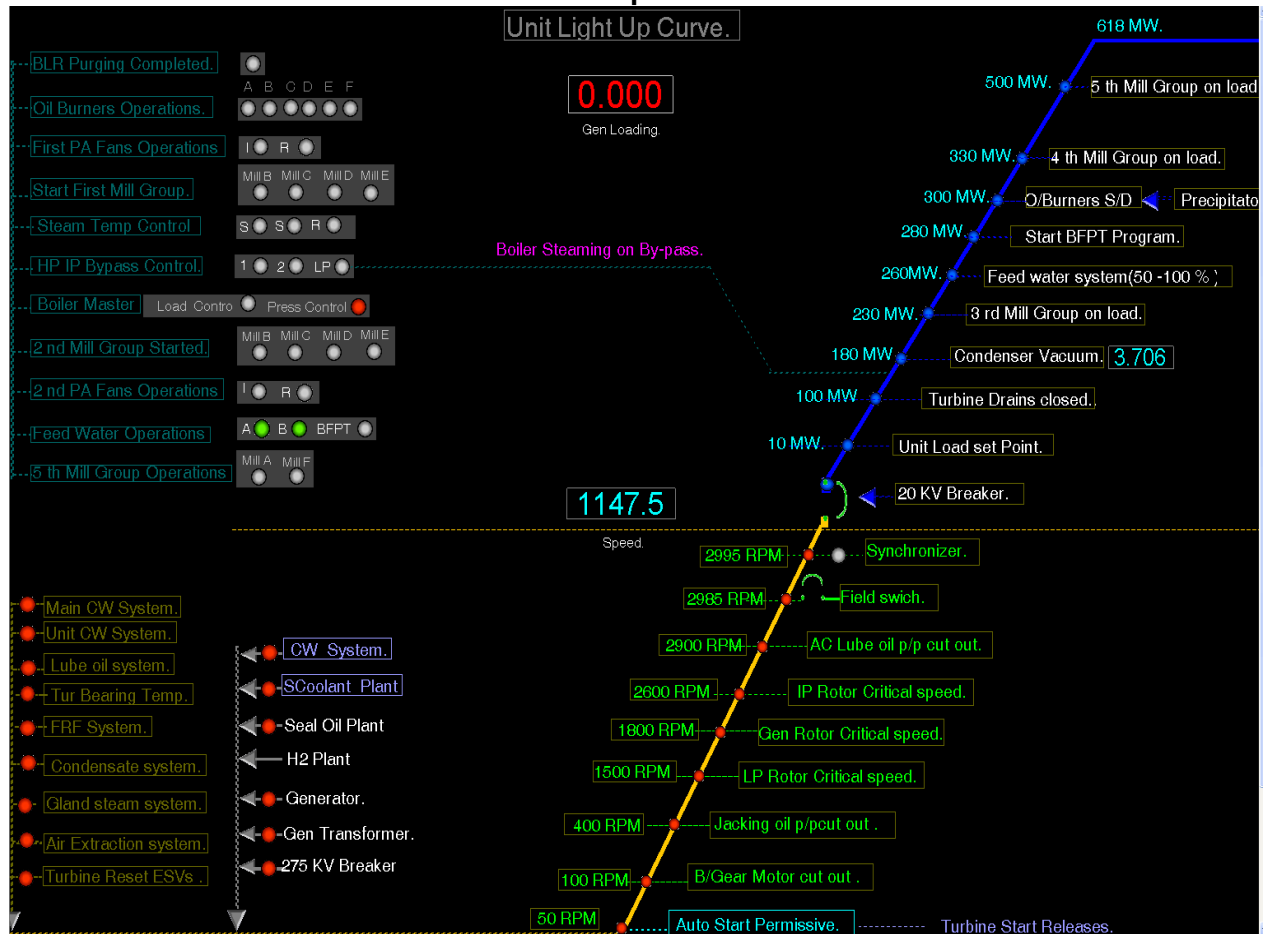
Figure 4–11: Turbine Operating Parameter Performance monitoring (Design Base vs Actual)



As indicated, the research scope included evaluation of the plant load curves and automating these in the Operating Simulator. Using actual plant datasets and start-up scenarios, the operating curve was defined and evaluated against control system data to confirm that the Simulator load curve configuration and outputs mimics real life conditions and expected behaviour.

The outcome of one of these operating curves is shown in Figure 4–12, which covers unit start up from 0 MW load right up to the full load capacity of 618 MW, together with all the criteria that have to be met to achieve full load. These curves could then be used to monitor operator actions during the start-up process to ensure they adhere to the correct operating sequences.

Figure 4–12: Unit Start-up Curve in Operating Simulator showing key operating curve hold-points



4.7.7 Reverse Engineering Outcome Validation and Verification

Part of the research methodology was to confirm a 3-way alignment and validation between data sets used in the operating simulator, the advanced analytics tool and the Plant Data Historian (as the primary validation and verification mechanism). This strategy allowed for a comparison of reverse engineered operating Design Base values against actual plant behaviour and operating system data values to confirm that analytical models are correct.

The methodology could also be used to prove that the operating curve models behaviour under simulated conditions mimics similar actual plant behaviour (by means of historical C&I system data comparison).

This strategy provided a high level of confidence that the reverse engineered Design Base data and information can be deemed representative of original Design Base content and that it can be considered the validated Design Base content to include into the IPI System platform of the IPI-BIM Framework.

A drawback of the etaPRO Virtual Plant system™ identified in the initial stages of the research study was that it only provided a static analysis of plant process conditions and did not cover transient conditions and the subsequent process condition normalisation usually experienced when significant changes to plant process conditions occur.

This became evident after reviewing the etaPRO model iterations and end–state condition against the typical plant behaviour values observed during actual plant operations.

The introduction of transient process analytics capability (Flownex™ system platform) in the research study scope enhanced the simulation capability as it more closely and accurately reflected the plant process behaviour dynamics.

4.8 Research Findings Summary

4.8.1 Design Base Classification System

The research demonstrated the benefit of Design Base data and information structuring into a well–controlled classification system. The use of a document/drawing classification system like the IEC 61355 Framework was proven a feasible approach to productively and accurately classify the Plant Design Base artefacts. This classification exercise supported the evaluation of Annexure A content and from there identifying the **core Design Base** candidates.

Using the research to further develop and introduce an effective and accurate classification automation tool for IEC document type classification significantly increased the value proposition of Design Base artefact classification. Significant improvement in productivity levels of staff involved with Design Base back–fit or V&V exercises were reported and documented. Having automated IEC classification ability will be of great value on Brownfields plants where the Power Utility still needs to assess the maturity of the Design Base of the plant in question.

A noted drawback of the IEC classification structure was the assignment of artefacts to what can be considered large “common” IEC classes (resulting in a potentially large grouping of certain Design Base specific documents in use by the Power Utility into this one category). A case in point would be where the plant operating philosophy, operating manuals, operating technical specification, etc. would all fall under the “D00034 – Operating Instruction” IEC Class.

This shortcoming necessitated the introduction of additional document type classification (based on Power Utility terminology) to break down common IEC groupings to a more granular level of detail that would pinpoint the desired Design Base artefacts defined as **core** elements.

4.8.2 Core Design Base Definition

The hypothesis posed of C&I Control System Upgrade requirements making up core Design Base content has been proven to be correct and also proved to be the most feasible solution.

The Design Base content required for a typical C&I Control System upgrade could be sourced with relative ease in both Greenfields and Brownfields cases (considering maturity of the Design Base on the Greenfields Project), and where it could not be sourced, sufficient alternative information was available to reverse engineer and/or re-build the missing information.

The productivity benefit and use-ability of using predictive analytics methods (data mining) to create an automated classification tool in an operational environment was demonstrated and enhanced the process of identifying and sourcing the core Design Base artefacts.

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.

The insight and outputs of the Design Base classification research scope further provided a very clear indication of what core Design Base information is actually available on a plant.

Comparison of information volumes between Greenfields Project and Brownfields Plant also enabled evaluation and comparison of **core Design Base maturity** between Power Utility plants.

From research, **the Design Base artefacts listed in Table 4-7 are recommended as the core Design Base content needed for a power utility plant.** Further research conducted in Chapter 6 confirmed that this is sufficient for plant asset management as well as advanced analytics and plant health trending/monitoring.

The research prototyping also demonstrated how effective Design Base 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 for business improvement initiatives.

4.8.3 Design Base Data Sourcing – Greenfields vs Brownfields Comparison

Comparative validation of Design Base content classification between the two Power Utility plants indicated a fairly similar distribution of documents within the key engineering disciplines. The typical construction (EPC) Design Review process could be used to effectively identify Greenfields Project core Design Base artefacts.

Sourcing sometimes did prove problematic on the Greenfields Project due to insufficient levels of data and engineering/technical information supply specifications (e.g. the issued “Information

Handover Specification” did not specify or scope contractor submissions at a granular enough data quality level).

From research it became evident that although an ideal (total) Design Base can be defined, chances are very slim to successfully source all this information on a Brownfields Plant Utility that was designed, built and commissioned before the electronic information era.

The research methodology and approach that was taken has provided sufficient evidence to prove that the identified core Design Base content is available for a Brownfields Project (albeit sometimes known under different legacy business terminologies). Core Design Base information on the research study Brownfields Plant was (with rare exception) contained in a controlled EDMS with change management enabled. The latest copy of the approved version could be obtained with relative ease.

A key learning point for any organisation that owns process plant is that Design Base data and information supply requirements **must be specified very clearly upfront** (at EPC contract conclusion) and to a very extensive level of detail to all the EPC contractors involved to be able to receive a full Design Base data set.

This implies plant Design Base data/information handover specifications to a level of detail that may have to contain actual examples of what the content should look like and very implicit data quality requirements.

4.8.4 Core Design Base Reverse Engineering

Sourcing some Design Base content proved to be very problematic on the Brownfields plant that is more than 30 years in operation. In many cases, the Power Utility ended up developing or re-engineering the Design Base artefacts themselves. As re-engineering work comes at a cost, this type of engineering work should be limited as far as possible to only the most crucial missing Design Base information in a cost-constrained environment.

A major benefit of the reverse engineering process followed was that data could be verified and validated against actual plant behaviour in similar scenarios and also in the operating simulator environment.

The research demonstrated how identifying and resolving data quality issues in analytical systems results in a notable improvement in the outcome and accuracy of the advanced analytics (e.g. where engineering simulator previously used “interpreted” or estimated values instead of real-time data values from the plant).

The research identified a low volume of information and data on operating envelopes and expected plant process response behaviours on the Brownfields Plant. These Design Base elements/artefacts were identified as an ideal candidate for reverse engineering prototyping. The advanced analytics model built off the Brownfields Plant Rankine cycle also created a useful and powerful plant performance management and monitoring capability.

The research further demonstrated that sufficient alternative information was available to reverse engineer and/or re-build the missing information using Plant Control Systems, Operating Simulator, and Engineering Simulator Capabilities. A process of three-way Validation and Verification between the three systems could be used to confirm that reverse engineering data outcomes are correct.

The benefits of transient process plant simulation in addition to the etaPRO System analytics was demonstrated as it enables analysis of dynamic/transient plant process conditions. This allows for further validation and verification of reverse engineering data.

4.9 Optimisation/Rationalisation Opportunities regarding the Plant Design Base

The only rationalisation opportunity identified for this research scope is to narrow the data mining capability to the core Design Base artefact selection list only. As indicated earlier in the chapter, the Simulator-based plant models and user interfaces developed as prototypes in the research study will have to be replicated to the other 5 generating units of the Brownfields plant as future enhancement work.

4.10 Conclusion

4.10.1 Design Base Classification System

The research demonstrated the benefit of Design Base data and information structuring into a well-controlled classification system. This assisted in evaluation and identification of **core** Design Base candidates.

Using the research study to introduce an effective and very accurate automation document type classification tool sped up the process of this classification exercise significantly. This significantly improved the productivity of staff involved with Design Base back-fit or V&V related activities (Table 4–8).

Table 4–8: Core Design Base Content Value – Brownfields vs Greenfields Plant

PLANT AREA	DESIGN BASE ARTEFACT VOLUME	BEFORE AUTOMATED IEC DOC CLASS DATA-MINING	AFTER INTRODUCING AUTOMATED IEC DOC CLASS DATA-MINING
Brownfields Power Station (not part of research study)	738,000	9 Months ^{1}	7 Weeks
Greenfields Project – Data Dumps 1–7	148,000	6 Months ^{2}	8 Weeks
Greenfields Project – Incremental Data Dump 8–11	29,000	2 Months ^{3}	2 Weeks
Brownfields Project – Information Systems Content	158,000	4 Months ^{4}	3 Weeks
Brownfields Project – Design Base Back-Fit Project Contents	654,000	7 Months ^{5}	6 Weeks

Notes:

- {1} The automated data mining tool was not available and the assignment was done manually without any clear rule assignment. Review of the work indicated low levels of accuracy and consistency in IEC Document Class Allocation. The automated data mining tool was re-applied on the data-set and was executed in a much shorter time with very high accuracy levels.
- {2} First pass allocation of IEC Document Class Allocation was done manually and was used as “data ruleset” baseline. After the tool was developed, the allocation was automatically assigned to test the accuracy of the rules-engine which confirmed the high level of accuracy in a much shorter timeline.
- {3} Given the volumes involved, this is an estimated timeline. More than 60% of artefacts in this data dump from the project were totally new deliverables, so manual assignment would have taken significantly more time to complete.
- {4} The automated data mining tool was not available or optimised yet, so assignment at this project was also done manually. In preparation for migration to the Utility-wide integrated plant information management system being implemented currently, the dataset was re-run via the Data-Mining tool to confirm accuracy.
- {5} The automated data mining tool was not available and the assignment was done manually without any clear rule assignment. A different project team was assigned to this power station, and again reflected low levels of accuracy and consistency in IEC Document Class Allocation. The automated data mining tool was re-applied on the data-set and was executed in a much shorter time with very high accuracy levels.

The use of data mining analytics and rule-sets was proven to be a very efficient and effective method of categorising, analysing and grouping Design Base artefacts. This allows for a faster analytical process of determining what Design Base information is not available and need to be reverse engineered.

The following are considerations, however, in the use of the automated data mining rule-set:

- The rules will be site specific – different legacy document type terminologies are sometimes used for the same IEC document class which will require adjustment of the rule-set(s).
- The tool set will always be dependent on the availability and quality of available Design Base information on the site, and the quality and accuracy of the document/drawing titles captured.

- On certain document types, a priority principle in running algorithms and scripts will have to be followed.
- There are specific document types which can not be automated and will have to be allocated manually.

Improved plant Design Base data and information classification and further data analytics of engineering business process plant information (e.g. occurrence history), allowed the Brownfields Plant to identify the top 10 problem plant areas and assisted the research study in identifying candidate plant areas for advanced analytics prototyping.

4.10.2 Core Design Base Content

The defined Design Base scope in Annexure A can be considered the *ideal* scope of information and data delivery specified for new projects, and should be included into future URS's issued to the market for the construction of new plant assets. The issues with this ideal scope has been pointed out, as well as the steps that need to be taken to ensure this content is delivered in a format suitable and useable to the plant owner.

In the absence of successfully sourcing this ideal full Design Base information set, the research managed to successfully define and source the **core set of Design Base information** required for advanced plant condition analytics and associated improved business intelligence.

By approaching Design Base data gathering from a C&I system upgrade perspective; it was possible to narrow the extent of Design Base content to be sourced. The C&I Control System Upgrade Design Base requirements were shown to be a feasible scope for Design Base, regardless of whether it is a Greenfields Project or Brownfields Process Plant.

Table 4–9 reflects the difference in volumes between the full Design Base versus the CORE Design Base as proposed by the research study.

Table 4–9: Core Design Base Content Value – Brownfields vs Greenfields Plant

	4,800 MW GREENFIELDS PLANT PROJECT	3,600 MW BROWNFIELDS POWER PLANT
Full Design Base	133,668	179,016
Core Design Base	51,115	59,214
% Reduction in Design Base Validation Scope and Effort	61,76%	66,92%

The benefit of this reduced Design Base is less engineering time spent on validation of the core content, as well as reduced cost in executing detailed V&V of such Design Base content.

4.10.3 Design Base Reverse Engineering

The research demonstrated the successful reverse engineering of Design Base data and plant process control parameters using Plant Control Systems, Operating Simulator, and Engineering Simulator Capabilities. It demonstrated how the ideal Design Base state (the “Ideal Rankine Cycle”) could be very effectively reverse engineered.

From this key analytical Plant Process model other missing operating Design Base and operating envelope data could be sourced, calculated and/or documented.

The outcome of this reverse engineering exercise enabled the capability for additional advanced analytics covered in Chapter 6 of the research study.

By synchronising Design Base data sets across multiple systems and simulator environments (ensuring Construct Validation via data triangulation), a very effective 3-way validation and verification mechanism for core Design Base data was established.

Availability of this Plant Process model in a simulated environment further enables the ability to obtain insight into the number of adjustment(s) that may be required to the original Design Base of the relevant plant after it has been in operation for many years and subjected to plant ageing and equipment condition deterioration. (This is covered in detail in Chapter 6).

INFORMATION DELIVERY AND VISUALISATION OPTIONS



Pennwell shows with their industry survey and related research how information management challenges and business drivers are pushing the energy industry (and by implication all process plant industries) to look at more integrated and trustworthy information delivery options and solutions [Pennwell, 2012].

The survey indicated that 68% of respondents are either evaluating or implementing more effective Enterprise Content Management (ECM) and information delivery solutions to solve the challenges of managing information for engineering, capital projects and asset management.

Gentile states from his research that there are notable benefits from using data visualisation in an effort to reduce perceived and actual information/data complexities [Gentile, 2014]. Typical benefits listed by his research are:

- Understanding and absorbing complex technical engineering concepts when visually described.
- Better visualisation and understanding of relationships and behaviour 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 language or bring about a change in business paradigms.

5.1 Hypothesis Relevant to Information Delivery and Visualisation

Hypothesis 5: An optimal information delivery capability needs to be enabled to make information available in the most efficient, productive and clear manner to support decision making.

5.2 Research Approach regarding Information Delivery and Visualisation

The research study proposes a future portal-based Information Management Framework and Infrastructure for a Power Utility/Process Plant and sees this as an integral part of the IPI-BIM Framework. By prototyping and testing the proposed portal technology, it aimed to demonstrate that this is the most viable and preferred method for information delivery and display for the IPI-BIM Framework.

There should be obvious business benefits (and a good value proposition) in creating a single information access portal, most notably proving the theory that it should lead to improved business operations and reduction in cost of ownership (used by many vendors as selling points for portal technology) [Intergraph, 2007 and Wheeler, 2012]. This research study intended to test this “selling point” by means of prototyping and evaluating the business value of creating the integrated portal infrastructure.

5.3 Information Delivery Research Scope

Inherent to defining the optimal information delivery capability, certain aspects around the information delivery options have to be considered. These are:

5.3.1 User-Driven Information Delivery

Identifying the most efficient methods of information delivery should be based on user needs and specific business requirements, the drive being to design an information delivery mechanism that meets the needs of the widest possible technical audience.

Although a single-entry user access point (like a portal technology) is proposed, it would still be important to ensure that data content is managed in the most appropriate source system platform. To adhere to Information Management CARAT principles, it is crucial to identify the source system that will provide the “one version of the truth” for the portal platform.

Due to the diversity and nature of engineering work undertaken in a Power Utility, a large number of system technologies are required to accurately capture and manage engineering activities and data. The identified source systems will become the control area of all engineering and technical master data it contains, and will be the provider of this information to the integrated technical information portal within the IPI-BIM Framework.

Based on literature surveys, the research study theorised that Portal technology may be a better value proposition than a “Nerve Centre” (Centralised operations centre) based on the view that a much wider user base and stakeholder audience can be served with the technology in question and that technology deployment may be more cost efficient and feasible.

5.3.2 Information Delivery Options

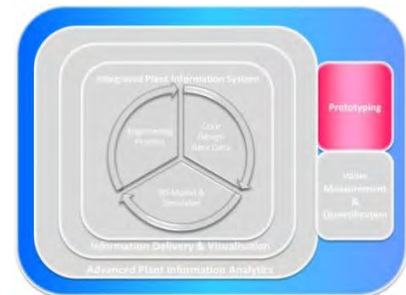
The research study postulated that there is an optimal information delivery design possible combining visual (3D) and conventional 2D hierarchical data display methods. The theory being that a combination of these information delivery methods would most likely become the preferred method of engineering technical data interrogation in an integrated engineering information environment in the future.

The research study also intended to demonstrate that visualisation (and specifically 3D) technology has matured to the stage where it is a viable, stable and cost-efficient option for both Greenfields and Brownfields power plants.

The research and prototyping aimed to demonstrate how 3D CADD Models can be used to create a visual 3D plant environment for the information delivery platform, and further prove that 3D Laser scanning technology has matured to the stage where similar 3D visualisation capability can be created and enabled for Brownfields plants. The research study aimed to prove via prototyping that this is indeed viable and a cost efficient/workable option.

5.4 Scope of Information Visualisation Prototyping

From literature surveys and technology capability evaluation, the research study proposed portal technology as the preferred medium of information delivery in a diverse organisation with different needs and uses for the information contained in business systems.



This most feasible way to prove this hypothesis would be with prototyping and “technology constraints” comparison against the alternative option available (Nerve Centre Technology).

5.4.1 Integrated Information Delivery Option Research Scope Constraints

Due to funding constraints, the research brief was constrained to evaluating only the integrated information delivery options currently available in the Power Utility approved software technology stack – these being portal technology or “nerve centre” technology. The research brief did not allow for the introduction of more source systems or for additional data mining or warehousing technology to be introduced (other than those already deployed and in use in the organisation).

The scope had to be focused on critical business processes and activities, and due to the nature of this specific research study, more focused on the technical and engineering aspects of the business when demonstrating information delivery capability.

5.4.2 Integrated Information Delivery Options

The IPI-BIM operational research included an evaluation of the various information delivery technologies available within the Utility considering user requirements, the types of information users and specific business requirements; and from this defining the most appropriate infrastructure to use.

The research had to demonstrate and practically evaluate the ease of configuration portal technology to display critical business, plant and technical information from a disparate base of information sources within such a “SmartPortal”.

A core business requirement for prototyping activities was to ensure that technology platforms were selected according to the intended use and user audience, and that the solution proposed is underwritten by the approved Power Utility e-HPUM Process Control Manuals, the source systems required to provide the data for the portal, and the organisational business structure and information requirements of different business areas.

The frequency of data storage in source systems varies 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. Research had to consider the impact of timing and delivery of data required and had to identify any negative impact this could have in delivering the required information delivery capability.

5.4.3 3D Information Delivery Capability Evaluation

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. The research had to evaluate the capability of portal technology to also deliver 3D-based information and data successfully.

Based on the outcome of the literature survey and indications that 3D laser scanning technology has matured significantly from a capability and cost-effectiveness point of view, the initial research study scope (using conventional 3D CADD models only) was extended to a small prototype to prove that a workable 3D virtual environment capability could also be enabled using 3D laser point cloud scanning technology.

The business driver for the extended research scope was that proving the viability of 3D point cloud capability could position this technology as a key 3D visualisation enabler for Brownfields plants that do not have access to modern CADD-based 3D Models.

The research prototyping scope thus evaluated conventional 3D CADD models as well as 3D Laser scanning point cloud data.

5.4.4 Evaluation of Advanced Analytics Capability in Portal Technology

As part of the information delivery research portion, a Proof of Concept (PoC) study had to be undertaken to demonstrate that the outputs of advanced analytics engineering software (like the 2D Flownex™ capability) could also be successfully be integrated into the 3D Plant Operating and Engineering Simulator User Interface and eventually the portal–based information delivery platform.

Research into the availability of advanced analytics information for business intelligence purposes indicated that such data was mostly contained within engineering analytical software solutions that are often not readily available to the general engineering or business user base of the Power Utility to assist with decision making. The research study could, therefore, add significant value if this information could be made visible in the integrated information delivery portal.

Discussion with the Brownfields Plant Power Station Manager (PSM) in the course of the research study indicated a dire need for visibility of plant control and plant state information on the materials handling plant systems (Coal and Ash Handling Plants). At the time, significant load losses were experienced in these plant areas without visibility of plant condition or timeous failure indication to high–level decision makers.

Note: Interestingly enough, occurrence data analytics in the Design Base establishment phase of this research study confirmed the fact that the Ash Plant (at 24% of total failures) is the most problematic plant area for the Brownfields Power station (and that it operated far below the required Design Base reliability and availability levels).

On request from this key stakeholder, the research study included visualisation of materials handling systems on the Brownfields plant as part of the scope.

The aim was to provide visualisation of plant status, operating envelopes information display and fault/alarm triggering in real–time (or near real–time).

If proven, this additional scope could be used to **practically demonstrate the value contribution of this operational research** and business improvement framework by making immediate positive production impact and increasing business intelligence capability.

5.4.5 Plant Data Availability for Online Monitoring

An evaluation was required of the availability of high–level plant performance data for on–line monitoring and information visibility via the proposed Portal technology. The research study had to demonstrate that the display of this type of information in the portal is possible with minimal effort.

With the addition of the Materials Handling Plant to the scope of the research study (to prove plant visualisation capabilities in a portal), an evaluation of data availability from control systems deployed in these plant areas was required. The current configuration of the advanced analytics tool (etaPRO) was analysed to determine data availability.

The analysis found more than sufficient near real–time process and control data available on what is generally deemed the critical plant areas like the boiler and turbine plant. But the analysis confirmed that since the initial etaPRO system configuration was focused on the main steam and water cycles of the power station, virtually no data points or information/data was configured or available for the material handling systems.

To address this shortcoming, the research study proceeded to configure and enable the required data points and data/information capturing mechanisms in etaPRO to provide the additional visualisation and plant data needed for visualisation prototyping. (Covered in Chapter 4) This configuration enabled the research study to continue with the prototyping of additional plant conditions visualisation capabilities in the portal environment.

5.4.6 Complex Information Simplification and Increased Plant Information Visibility

The research study ended up extending its prototyping scope after engagement with typical portal users on the release of the first pass design. The users identified a need to have access to simplified plant process simulation models of complex engineering processes.

Advanced analytics engineering software are usually very complex at a user–interface level and the requirement was to simplify the simulation outcome and analytical models into easier–to–understand displays that would only share relevant information with the information recipient in order to make the required decision using the information at hand.

5.5 Information Technology and Infrastructure Constraints

The research study had to demonstrate that plant and business data inputs can be pushed seamlessly from source systems into the portal/nerve centre software technology platform. In line with the Power Utility Corporate ICT strategy, no replication or storage of a duplicate set of the same source information was allowed in the portal technology platform itself.

It had to be demonstrated that the portal technology allows for real-time data mining using defined rulesets/algorithms and standard portal technology information “drill down” capabilities. If required, source systems visualisation capabilities had to be utilised, as these systems had more powerful “big data” management engines.

Point cloud 3D data are typically considered a “big data” candidate and the large data volumes were easier managed in software technology specifically geared in dealing with this information.

5.6 Research Prototyping Methodology

5.6.1 SmartPortal Capability

Detailed architecture review and analysis sessions were undertaken as part of the research study and scope of work. This was done in collaboration with the Information Technology Group in the Utility as part of the larger SmartUtility initiative [Hales, 2013].

This entailed a review and analysis of critical business (and specifically engineering) activities and their resulting information requirements, assigning or confirming data ownership of datasets needed for the prototype and identifying sources of data and information for the portal prototype.

Once the scope was defined, the research study prototyped a PoC “Smart Utility” information portal for demonstration purposes. The results of the PoC were also used to draw the comparison regarding effort, perceived benefit, cost and timeframes involved in the implementation of a Portal versus “Nerve Centre” capability.

The research proceeded to evaluate to what extent existing data sources can be exposed to business decision makers with better information delivery technology and methods. The prototype was used to demonstrate to business that a mix of static and dynamic (real-time) data will most likely be required to enable effective decision making.

The PoC portal was enabled and integration with the various source systems was tested, configured and enabled to prove that the required source information is available for integration within the portal platform; and that it can be efficiently and seamlessly displayed.

5.6.2 3D Visualisation Capability Evaluation

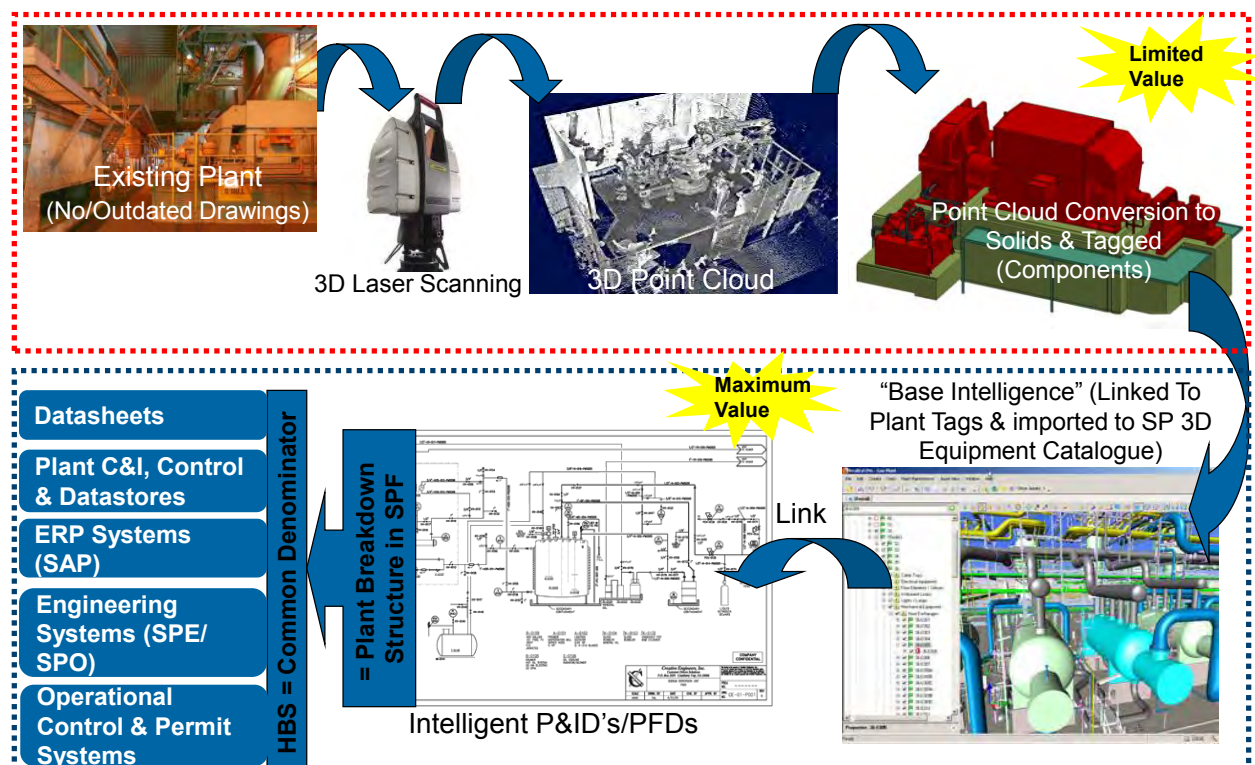
Once the fundamental portal technology and framework capability was proven, the research study proceeded to evaluate what capabilities are available to create 3D visualisation and information display capabilities in this environment.

Research prototyping evaluated the ease with which 3D visualisation capability for a Greenfields plant can be created using the plant Design Base 3D CADD models. It then proceeded to evaluate and test the viability of creating 3D visualisation capability on the Brownfields Power Station using 3D Laser scanning technology and data outputs.

The research also evaluated to what extent this technology would enable 3D laser scanning data beyond conventional use (typically used for CADD model recreation or plant “as built” data comparison to CADD 3D models). The intent was to demonstrate with the prototype that it has application in business areas like maintenance planning, operating training and engineering modification planning.

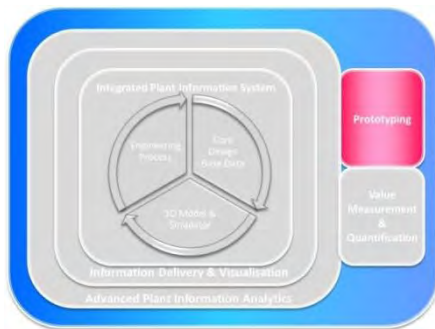
Figure 5–1 shows the methodology followed to prove the viability of creating the 3D visualisation capability to cover CADD as well as 3D Laser scanning capabilities evaluation.

Figure 5–1: Methodology to establish 3D Visualisation Capability in a Brownfields Plant [Swanepoel, 2012c]



Successful execution and demonstration of this capability using this methodology proposed would prove the hypothesis that 3D Laser scanning and associated visualisation technology have matured to the point where it has relevant and notable beneficial use in a production and process plant environment.

5.7 Information Delivery and Visualisation Prototyping Results

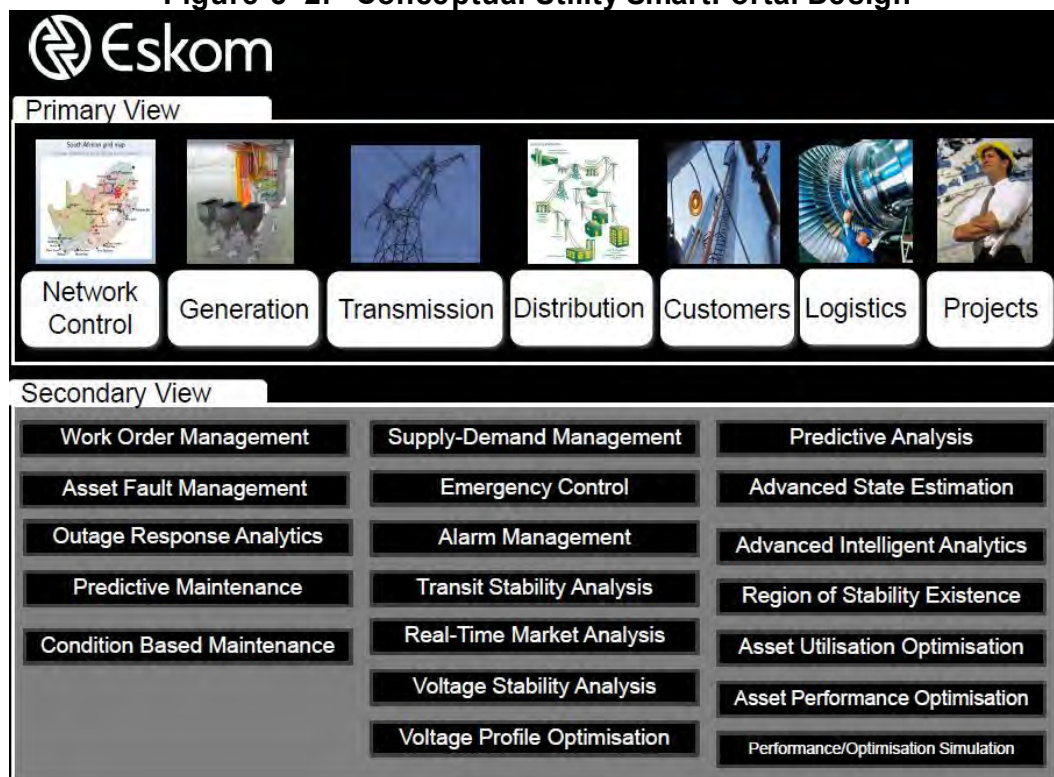


This section demonstrates how prototyping and scenario testing was used to provide the Information Delivery and Visualisation capabilities proposed for use as part of the IPI-BIM Framework.

5.7.1 Portal Capability Evaluation

The research study defined a conceptual “SmartPortal design” for a typical Power Utility in line with the elements of the end-to-end electricity supply chain (Figure 5–2). For each for the Primary business areas depicted in the Primary “Utility Supply Chain” View, a key set of information sources and key business information datasets had to be identified and scoped as “secondary Portal views”.

Figure 5–2: Conceptual Utility SmartPortal Design



The prototype used the baseline definition, high-level concept and baseline scope of Nerve Centre Project as the starting point to define the conceptual design of the Smart-Portal user interface [Reddy et al. 2013]. This resulted in the development of a high-level taxonomy depicting the SmartPortal contents (Figure 5-3).

Figure 5-3: Implemented Taxonomy of key business data and information

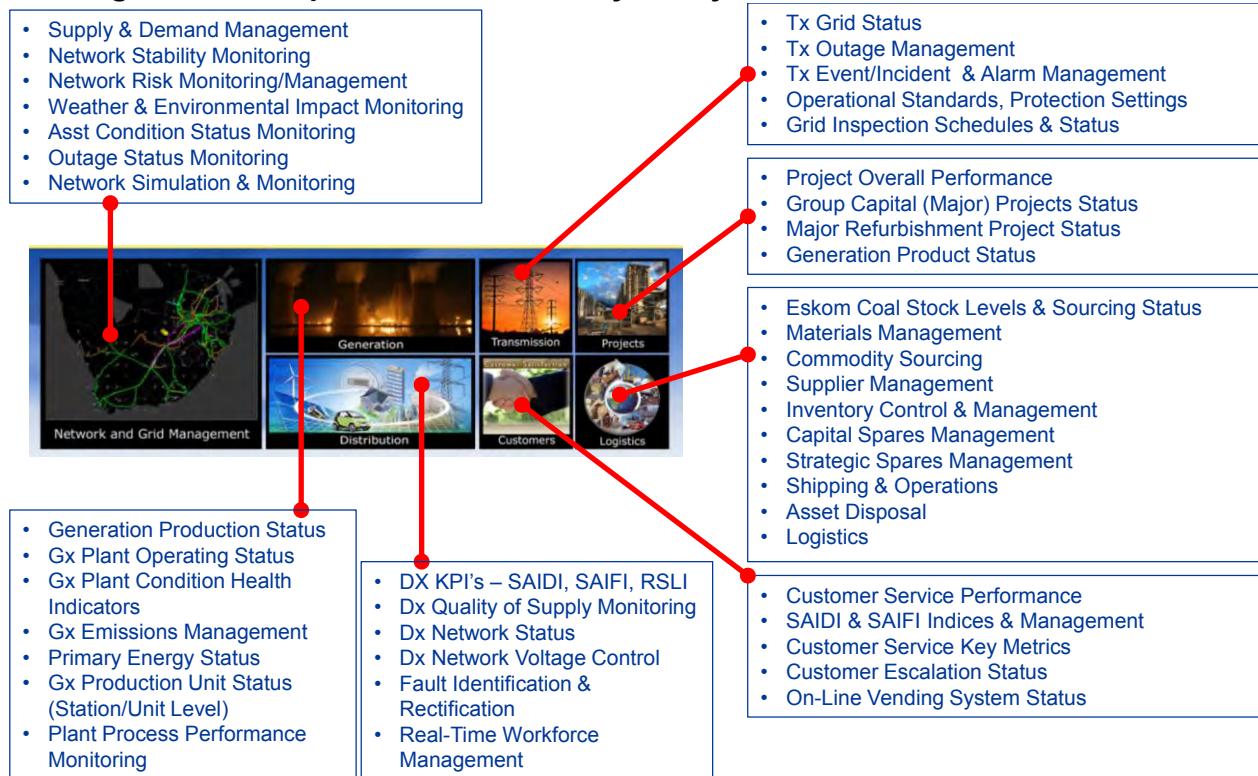


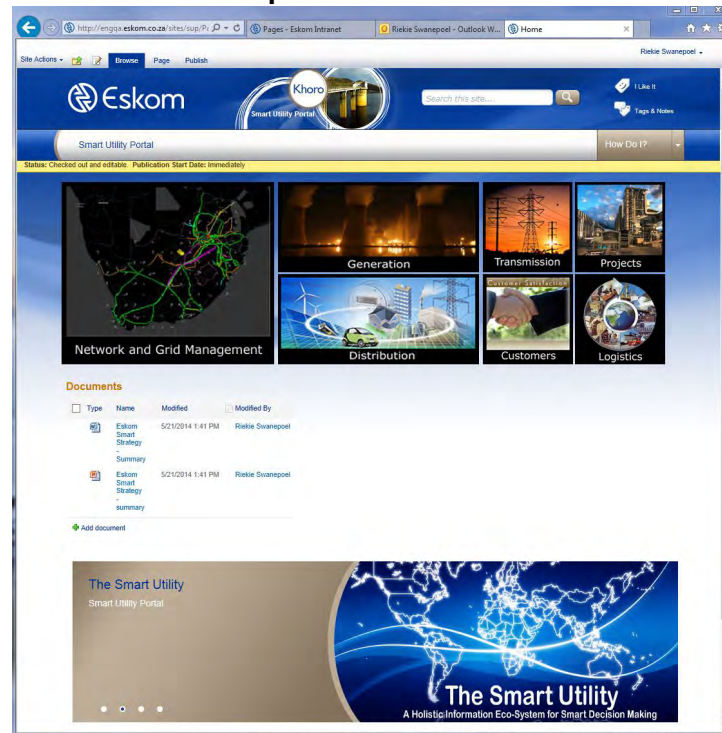
Figure 5-3 demonstrates how the information delivery solution had to consider a diverse set and scope of business information – utilising both static and dynamic data sources within the Power Utility, and even sources external to the Power Utility.

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.

The research study designed and enabled the PoC portal on the MicroSoft SharePoint™ software technology platform. Figure 5-4 indicates the visual outcome of the prototype undertaken.

This final prototype was used to evaluate whether the proposed portal can deliver on the requirements set forth by the business (and thus meet the hypothesis posed by the research study).

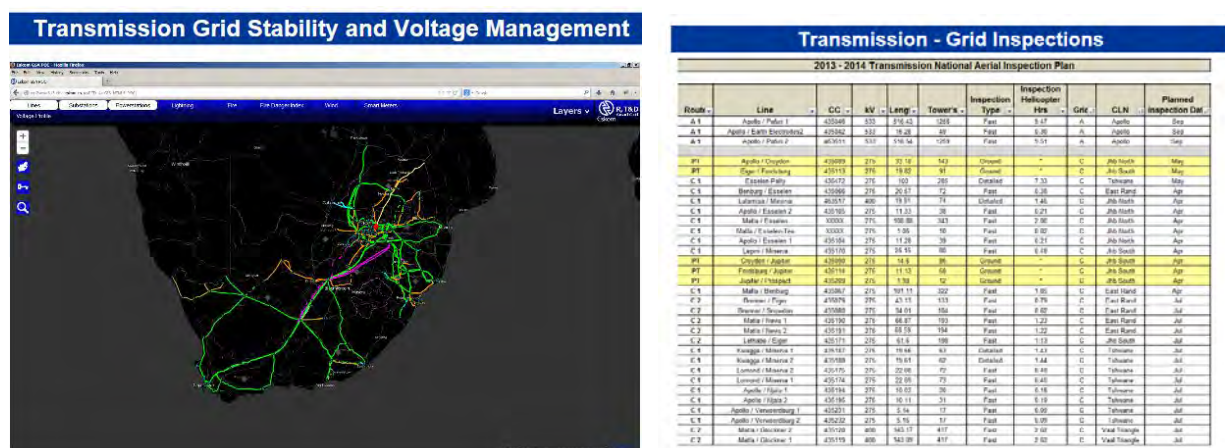
Figure 5–4: SmartPortal Concept PoC enabled in SharePoint System Platform



Figures 5–5 and 5–6 show an example of how a combination of real–time/near real–time as well as more static data and information were required (and used) in the portal to provide business with the information needed for decision making.

In this case, grid availability (Figure 5–5) would be directly impacted by planned grid inspections – reflected in a Grid Inspection Schedule (Figure 5–6). As such, the on–line display of grid status (Fig. 5–5) has to be evaluated in conjunction with the grid inspection schedule before making decisions regarding plant status and potential fault conditions that have to be acted on.

Figure 5-5: Sample of Real-time Information Figure 5-6: Sample of static information



The portal was shown to very effectively extract information from real-time plant control and information systems like weather, fire monitoring, air quality monitoring and lighting monitoring

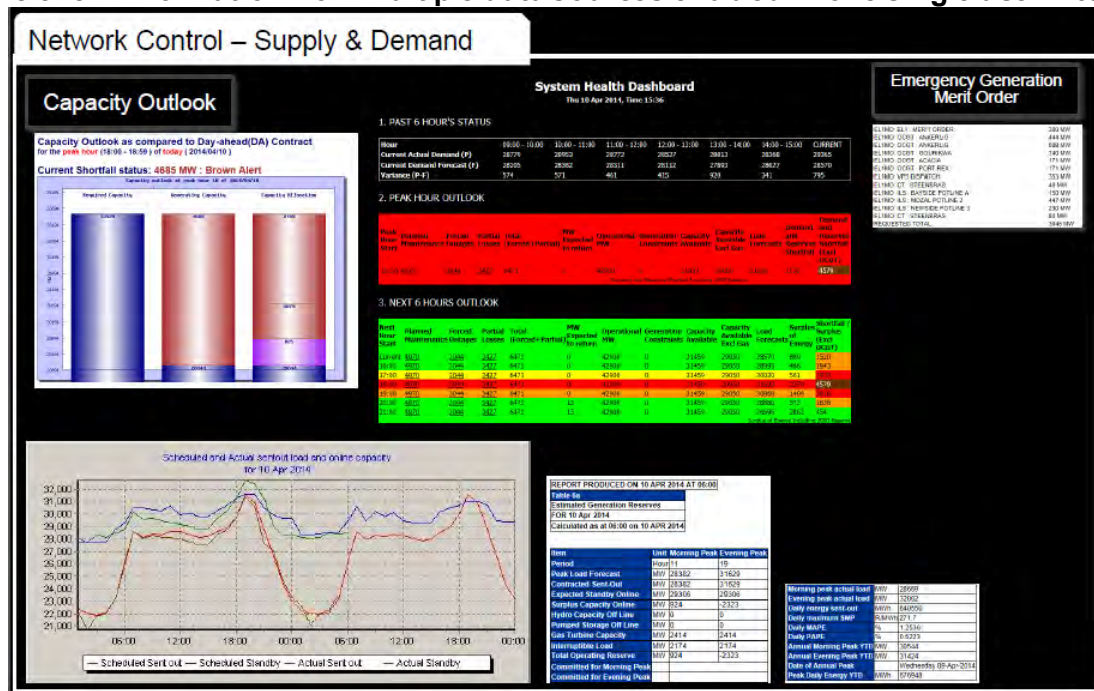
systems (Figure 5–8). An identified minor challenge was the reliability and availability of such external system data sources – especially since the utility would not have control over these.

Figure 5–7: Real-time information availability in Prototype portal



Figure 5–7 demonstrates how available and existing key plant technical information could be enabled very efficiently and rapidly into a portal environment. Previously, this information was available (and thus accessible) via **four** different information system sources which each had to be accessed separately to view the information. This is now displayed and made available on one platform, regardless of the source system location or the need to log into systems to access this information.

Figure 5–8: Information from multiple data sources enabled in one single user interface



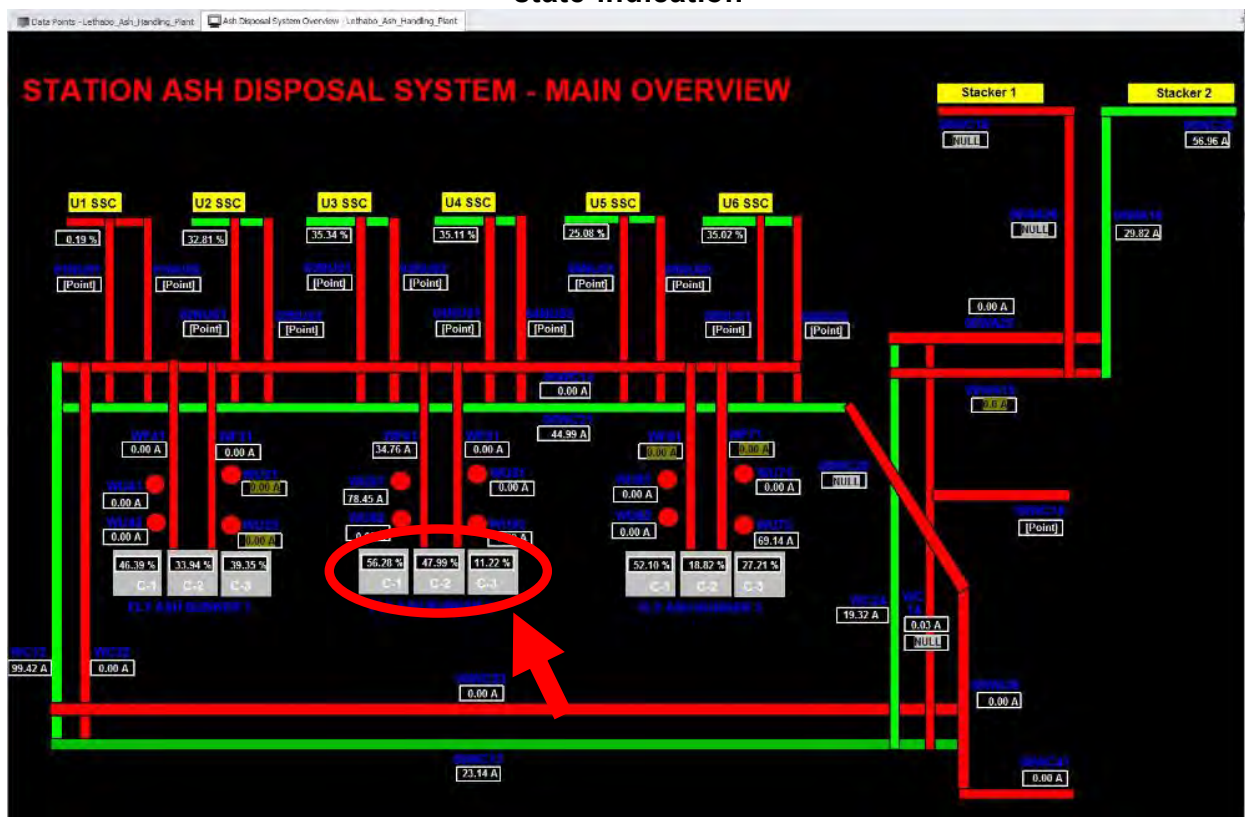
5.7.2 On-line Plant Condition Data Visibility in the Portal Technology

As indicated from the data analysis, the materials handling plant was not configured at all in the advanced analytics engineering simulator nor in the plant historian database. As reported in Chapter 4, the research study had to perform significant amounts of digital data point conversions to enable its use in the engineering simulator.

The engineering simulator also had no visual user interfaces developed on the materials handling plant either, so all the required control system data points had to be identified, configured and enabled into the plant data historian as well as engineering simulator with user interface screens in order to establish the information and data feed to the SharePoint portal technology. The required data integration link to the plant data historian was enabled to make data available for fault analytics and on-line status and fault monitoring.

The reverse engineered Design Base operating envelopes developed as part of the Design Base research scope of work provided the information needed to trigger visual changes to the user interfaces. Operating envelope and control settings could be used to indicate when the plant has shut down or has moved outside of the acceptable operating envelope. Fig. 5–9 shows the outcome of the prototype work on the Ash Handling Plant area.

Figure 5–9: Outcome of plant process visualisation on real–time data with alarming and state indication



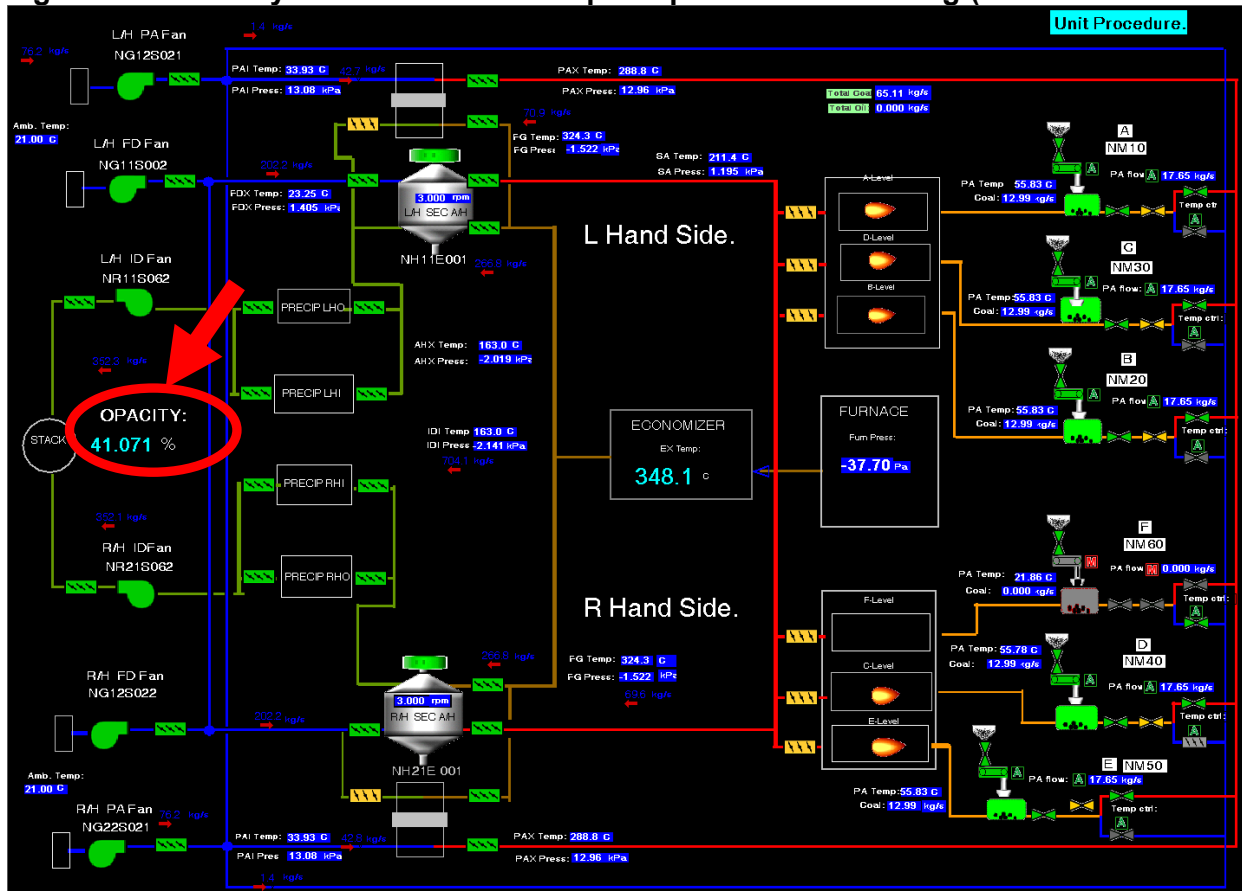
Operating envelope alarms were enabled in this visualisation PoC – for example, should the bunker ash content levels (example circled in red) exceed 75%, the bunker object in the display will change colour from the current grey colour to RED. This will flag the operator to divert ash flow in time to another bunker to prevent load reduction or unit shutdown due to ash bunker over-filling.

In line with the original requirements posed by the Brownfields Plant PSM, this capability provided users with immediate, on-line and continuous feedback of plant status in this area (equipment unavailable/tripped), allowing faster and more informed decision making.

The reverse-engineering work undertaken in Chapter 4 of this research study could, therefore, be effectively used to demonstrate the benefit of making near real-time information available in the SmartPortal.

Fig. 5–10 further demonstrates how real-time plant process parameters of the Brownfields plant air system can be enabled in the SmartPortal. It shows how a key operating parameter (in this case “Opacity”, circled in red in Figure 5–10) can be made visible to technical users for pro-active Design Base parameter management.

Figure 5–10: Air System near real-time plant process monitoring (Brownfields Plant)



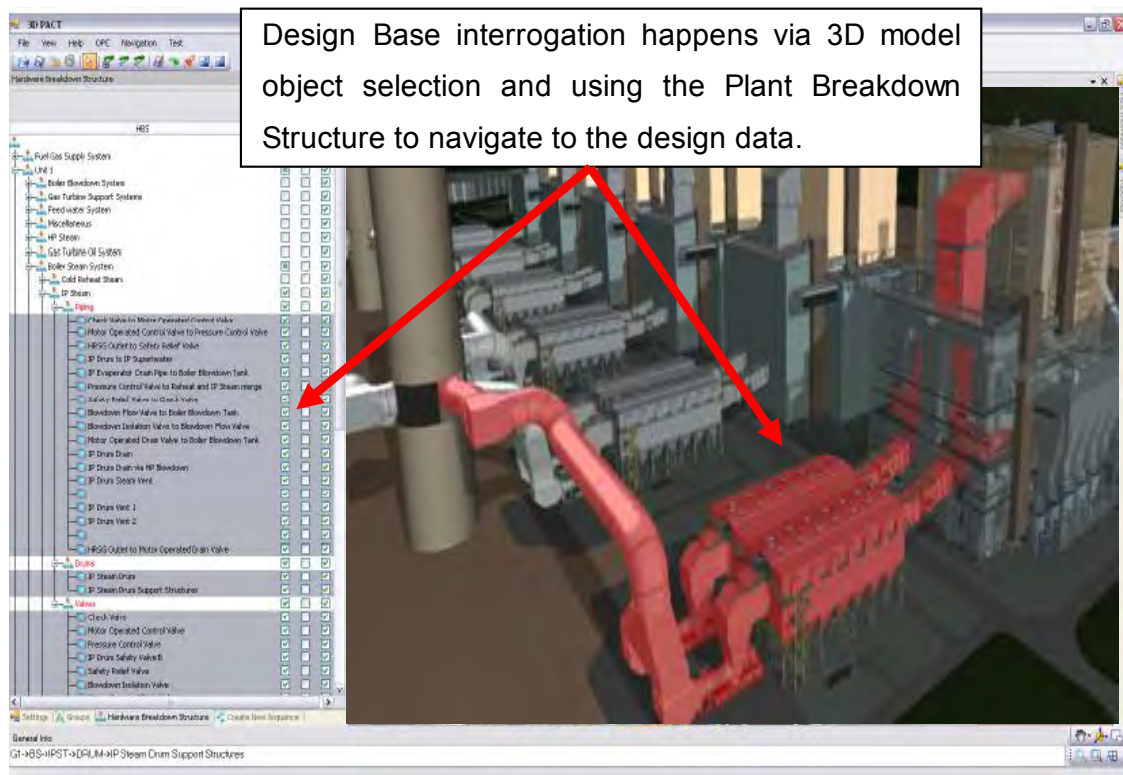
The Opacity level is part of the environmental KPI's for the power station and Power Utility and is measured by external legislative bodies (CAPCO). Poor management of this KPI results in forced load reductions to remain within legislative operating limits and even shut down of the plant if it cannot be contained within the prescribed levels. Although this visual user interface seems complex at first glance, it allows the end-user (operator) to have visibility of all the plant process control points and process values that have an impact on opacity levels.

As a future enhancement, operating envelope constraints (e.g. alarm set-point values on process control points) can be implemented as rule-sets into these user interfaces so that colour changes occur whenever a specific process value moves outside the boundaries of the defined operating envelope. (As was demonstrated with the materials handling plant research scope of work – see Figure 5–9.)

5.7.3 3D Information Delivery Capability Evaluation

The research included evaluation and prototyping of virtual plant simulator technology and 3D-gaming development software technologies in conjunction with conventional 3D CADD model content. The aim was to demonstrate that an interactive virtual plant Design Base environment can be enabled that could be used for training and that would allow an end-user to interact with the 3D model to query Design Base data, content and parameter values (if enabled/available).

Figure 5–11: Visualisation of Design Base Content in 3D interactive plant model



The prototype outcome demonstrated the ease with which modern 3D CADD Models could be used to enable this interactive 3D environment. The prototype further demonstrated the ability to interrogate plant Design Base information using the Plant Breakdown Structure enabled on the left-hand side of the Virtual 3D User Interface (Figure 5–11).

As indicated in the hypothesis, the Brownfields plant was built and constructed at a time when 3D CADD technology was not available or in use by the Utility. The success of the initial 3D CADD visualisation prototype, coupled with an evaluation and research into 3D Laser scanning technology maturity led to a request to extend the research study scope to a small prototype to prove that the same 3D virtual environment capability can be enabled on Brownfield plants using 3D laser point cloud scanning technology.

The initial research strategy to convert 3D laser scanning point cloud data to solid 3D CADD models was shown to not be efficient or cost-effective, and thus not considered a viable solution to create 3D visualisation capability (resulting in a failed research theory and strategy).

The research study then proceeded to evaluate an alternative method by investigating the ability to directly enable 3D point cloud laser scanning data and virtualization capability in the 3D–Pact™ Plant simulation and virtualization software. For this strategy, the researcher collaborated with a 3rd party company (Samahnzi™) and used their technology (3D–Pact™) to prove the viability of the alternative method.

The 3rd party company (Samahnzi™) went on to successfully prove that they could enable virtual reality and user interaction within point-cloud models negating the need for conversion to solid 3D CADD models. Figure 5–12 shows how the interactive 3D simulation technology was enabled using the research study Brownfield Plant's Point cloud data (boiler area).

Figure 5–12: Interactive 3D Visualisation in Simulator Technology using Point Cloud Data



5.7.4 Advanced Analytics in the Portal Technology

The research study conducted a prototype to demonstrate the ease of integration of the 2D advanced analytics Flownex™ capability into the 3D Plant Operating and Engineering Simulator. The research PoC focused on the Flue Gas Desulphurisation plant area of the Greenfields Project power station 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 in CADD format.
- A business need for Operating Staff to be trained on a very complex and intricate plant process technology that has not been implemented in a power generation plant in the Utility before.

Figure 5–13 depicts the outcome of this PoC – demonstrating how the transient process simulation for this plant area (contained in the Flownex™ technology platform) is enabled in the 3D virtual plant platform, allowing the operator to evaluate the impact of plant process setting changes to core and controllable plant process parameters.

Figure 5–13: FGD Advanced Analytical Model enabled in the 3D Plant Simulator

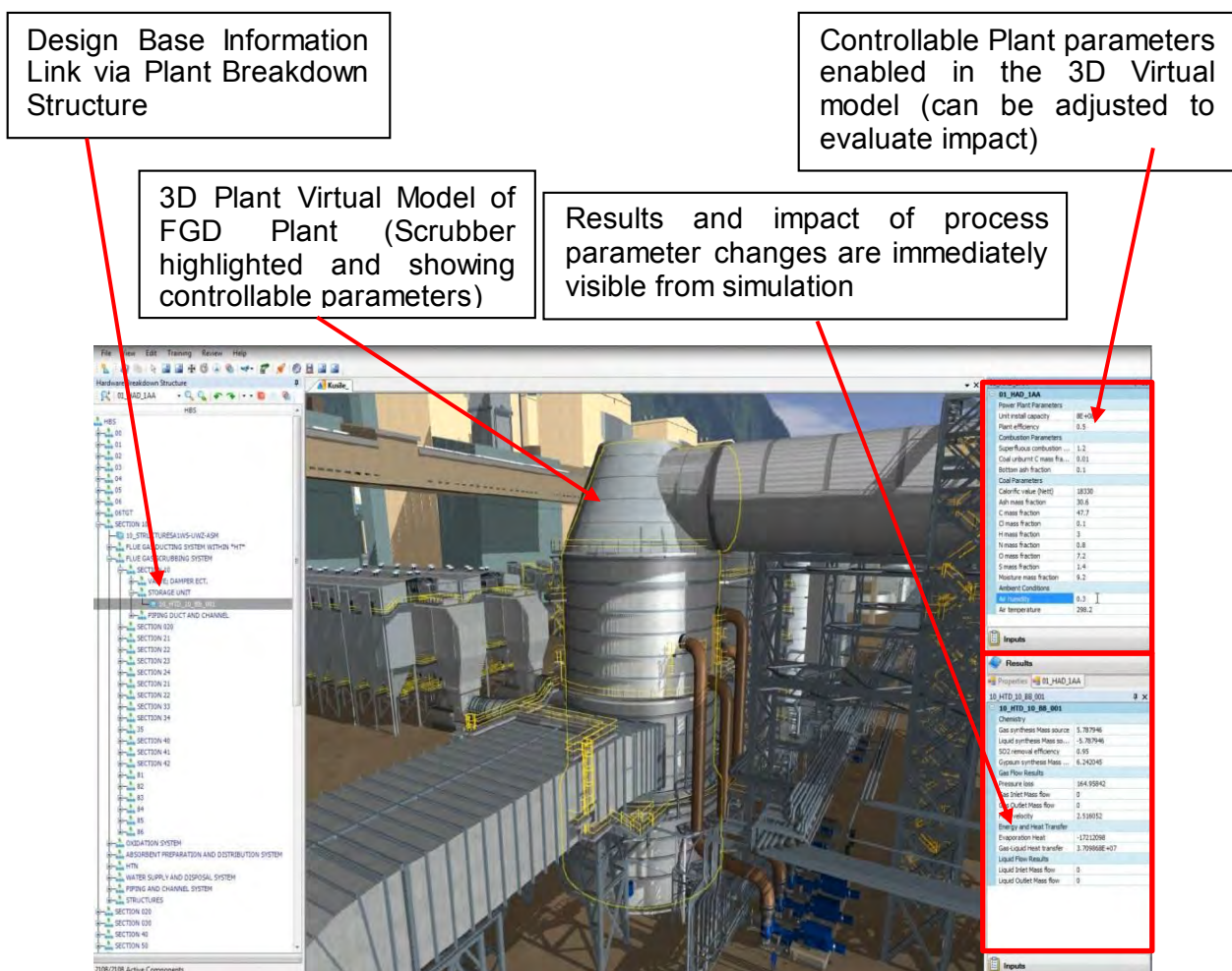


Figure 5–13 demonstrates how the visual 3D interface is used to guide and expose the end user to the Design Base contained in the integrated plant information system (on the left–hand side of the User Interface) via the Plant Breakdown Structure.

This allows the user seamless access to the plant Design Baseline (in a data–centric manner) to evaluate the impact of plant control and parameter changes considered. This link can enable further navigation to documentation, drawings, procedures and other relevant plant information that can affect or influence plant operations and decision making.

Figure 5–13 shows how the user can adjust controllable parameters on the right–hand side of the user interface (that is directly linked to the Flownex™ dynamic process simulator) and immediately see the impact these changes would have on plant performance and outputs.

The outcome demonstrates very effectively how the information delivery capability proposed by the IPI–BIM Framework could be enabled using a common portal–based user interface, and how real–time plant data can be displayed and visualised in the portal technology using the Plant Data Historian technology, negating the need for business users to access C&I SCADA/PLC or complex engineering analytics software technology systems directly.

5.7.5 Simplification of Complex Engineering Information

A key challenge in information delivery is the simplification of sometimes very complex engineering/plant process analytical models to a level where only the information needed to make an operational or business decision is displayed and available for scenario simulation.

This challenge was confirmed during the first pass demonstration of portal capabilities and feedback from more general users which indicated that some engineering information delivery user interfaces are very complex in nature and that they would prefer more simplified and interactive user interfaces.

Engagement with engineering stakeholders also identified concerns around access to engineering simulation and advanced analytics systems by users not trained, or staff not qualified to make changes to plant process simulations and inherent Design Base content.

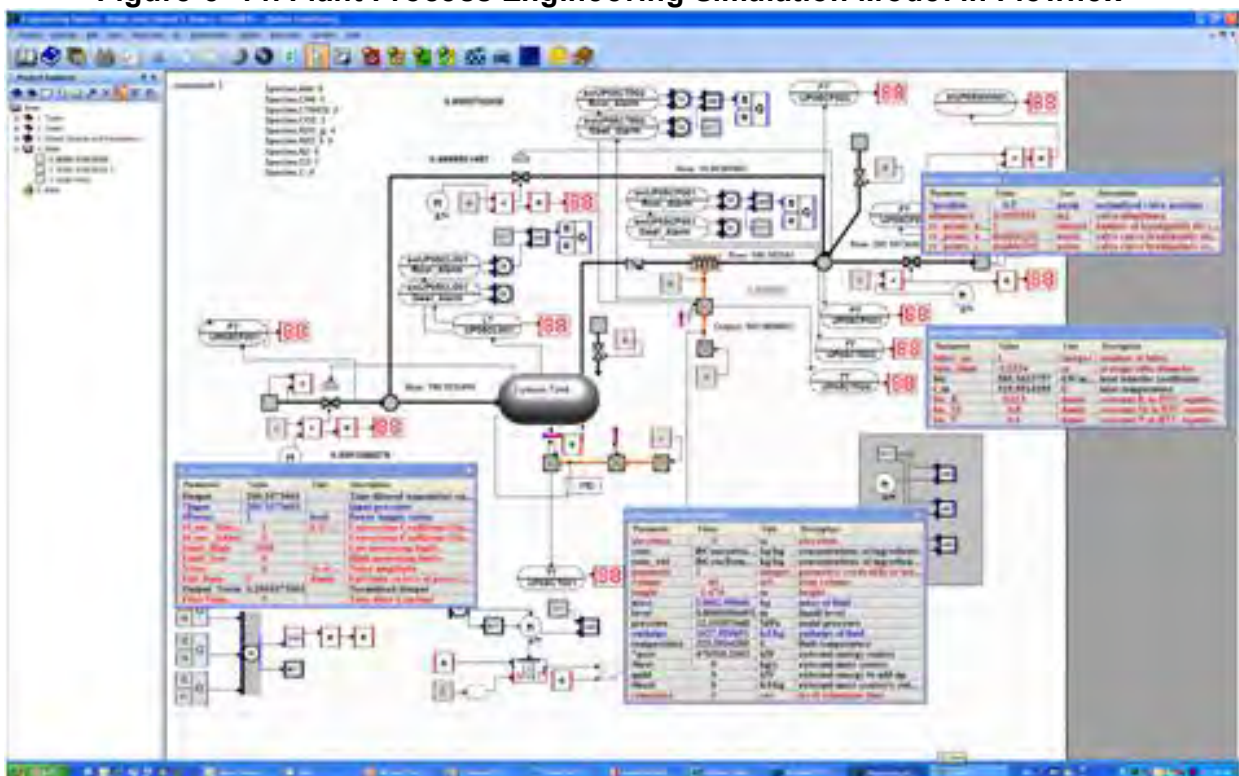
The research study was requested to evaluate whether plant process simulation information delivery could be simplified into easier–to–understand displays, sharing only relevant information needed by the end–user to make the required decision. And to further confirm that simulation activities are possible without compromising the underlying plant process analytical data models.

Further prototyping thus proceeded to demonstrate how a complex plant process model could be simplified for wider use by business/operator users who may not have the skills to build, operate and maintain these complex plant process simulation models in advanced engineering analytics software. Research also had to confirm that this is possible without compromising the process analytical model. It further aimed to demonstrate that within a Portal context, full-on access to the advanced analytics back-end of the source system is not necessarily required.

As a use case, when a plant operator wants to evaluate the impact of making changes to operating envelope parameters, only controllable plant parameters should be available to the operator to make scenario changes. The resultant impact on other plant process parameters should be visible to the Operator in the Portal, but the ability to make changes should not be enabled.

Fig. 5–14 shows a typical high-level process model developed in advanced analytics software (Flownex™) – in this case for boiler feed-water supply control to the boiler. This simulation model would typically be built by a suitably trained and qualified reliability or design engineer who will use the model to simulate and test plant behaviour and potential changes to Design Base criteria.

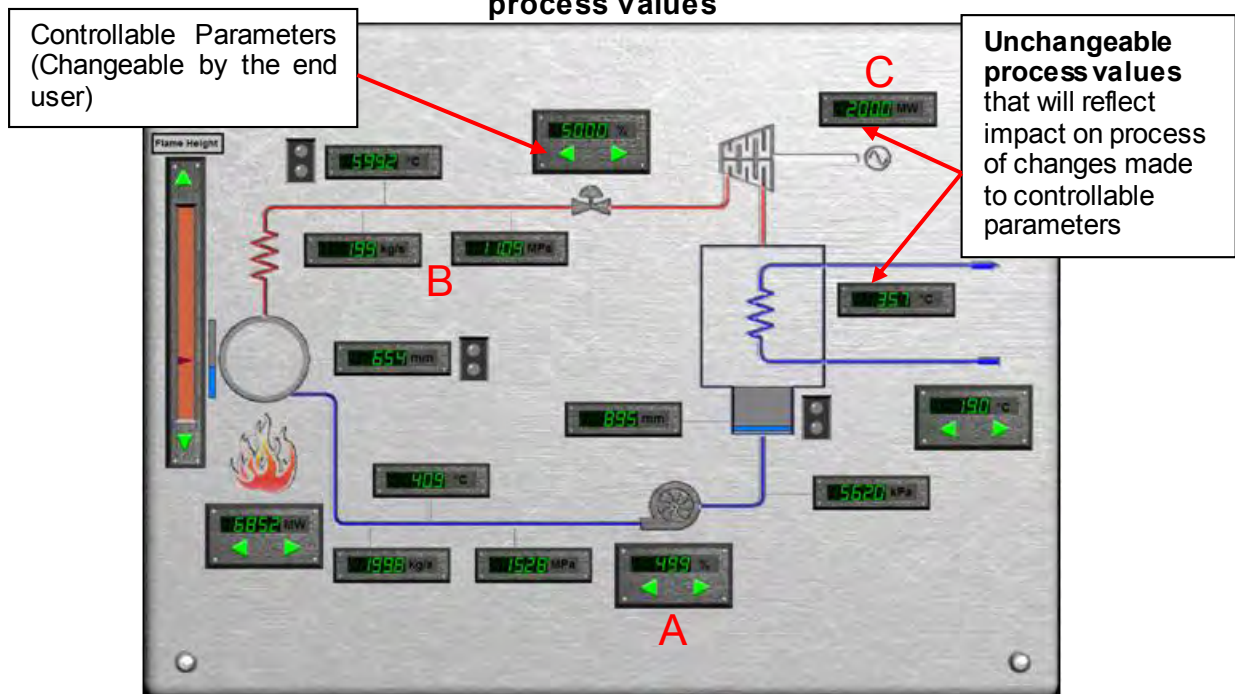
Figure 5–14: Plant Process Engineering Simulation Model in Flownex™



In line with the brief, the research prototype proceeded to simplify this complex process model – using the principle of the use case described.

Figure 5–15 depicts the simplified user interface design, focused on “controllable parameter” items only. In this example “Controllable parameters” are the control value items that have green arrows on the user interface/display where the operator can either move the relevant plant process control value up or down and then evaluate the impact of doing so on other plant process values.

It also enables the operator to evaluate the impact of making **multiple** controllable parameter changes (as would typically happen in a real-life complex process plant environment) and evaluating the impact of these on the plant output.



5.8 Information Delivery and Visualisation Prototype Research Findings

5.8.1 Portal Capability

As indicated, A Proof-of-Concept “Smart Utility” information portal was successfully configured. Figure 5–16 shows the high-level Portal Site taxonomy and Portal capability developed under the research study.

Customizability of the portal technology was also demonstrated, e.g. how the same data/information can be displayed in different formats, based on the needs and requirements of different stakeholders that have an interest in this data/information.

The research on the IPI–BIM element of information delivery capability, and the resulted proof of concept prototype, effectively demonstrated how Design Base content, interactive 3D visualisation capability and advanced analytics capability could be enabled in one common portal-based user interface.

Figure 5–16: SmartPortal Concept PoC enabled in SharePoint System Platform



5.8.2 Plant Analytics and Monitoring in the Portal

The research demonstrated that integrated process plant Design Base criteria like alarm settings and values can be enabled in the portal via the source system to flag operations and business decision makers when the plant is not available (although additional research work scope was required to enable the data points required for the PoC). It supported the view that improved information delivery and earlier remedial response to plant conditions will be of benefit – triggering more timeous response and thus reducing the risk of significant downtime and sometimes even plant shutdowns.

It further enabled visibility of plant information to decision makers without the need for them to access the source plant process control systems (generally contained in high–security environments behind IT Firewall technology on the plant Process IT infrastructure).

The prototype demonstrated how core Design Base content (e.g. the PBS element of the Design Base) becomes the integration lever between plant and business information systems. It demonstrated how it becomes the lever to control visibility of more Design Base information and relevant plant real–time data (thus providing “on demand” data delivery and not overwhelming the operator/user with ALL the information simultaneously).

Performing the PoC on “advanced analytics simplification” demonstrated that the risk of changes made to underlying plant analytical models in the Design Base can be managed and contained. The prototype showed that it is possible to contain the development of simulator capabilities and models to staff trained to do this (i.e. reliability engineers and specialists), while still enabling the simulated results for use by other users of the information (be it for scenario modelling or operator training). This was achieved using the Portal user access control capabilities, as well as enabling only the analytical software system operations needed by the general end–user of the Portal.

5.8.3 3D Visualisation Technology for the Portal

The PoC work confirmed the use–ability of 3D Laser scanning point cloud data for 3D visualisation purposes. Not only are 3D Point–cloud data considered to be extremely “software neutral” (and thus importable in virtually any 3D software technology) but it can also create a more accurate “as built” 3D visual plant model than CADD–based 3D plant models.

Enabling the Brownfields Plant boiler area laser scanning data into a more accessible information delivery platform had further unexpected benefits.

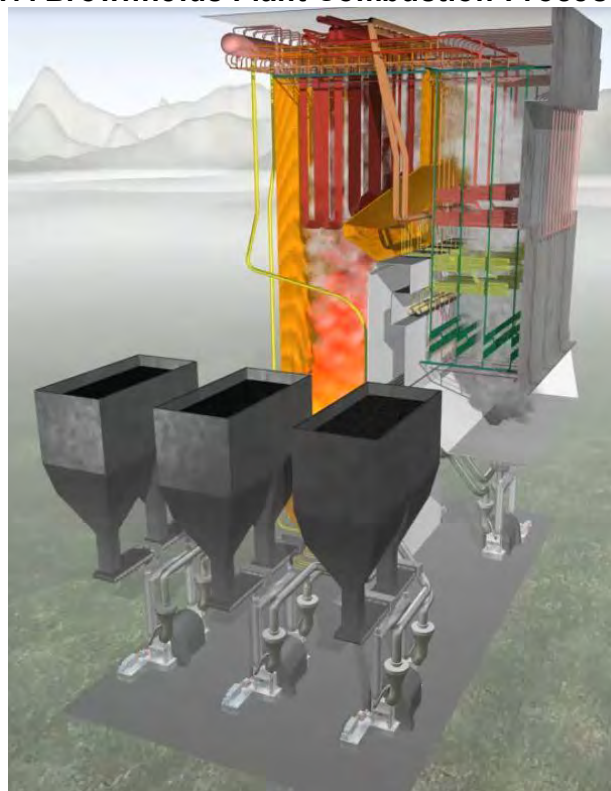
This data has been used to great effect for more cost effective high–pressure pipe replacement work scoping in the boiler plant area and improved planning of electrical/C&I cable replacement scopes of work for the C&I Control System upgrade project.

5.8.4 Portal Value Proposition

The successes achieved with the research prototype, pointed to the opportunity to create a very efficient Plant Operator learning medium created:

- It shows how key plant operational principles can be taught in an integrated, visual and virtual environment. Figure 5–17 demonstrates shows how the 3D models could be used to build process animations enhancing operating understanding of the end–to–end boiler combustion process at the Brownfields Plant.
- Computer–based control mimics could be tied back to simulator technology, allowing users to interact with plant process models to evaluate performance impacts when plant parameters are changed.
- Because of the research study approach to work off confirmed and accurate Design Base information, there is a high level of confidence in information being viewed and the reliability of information displayed in the portal.

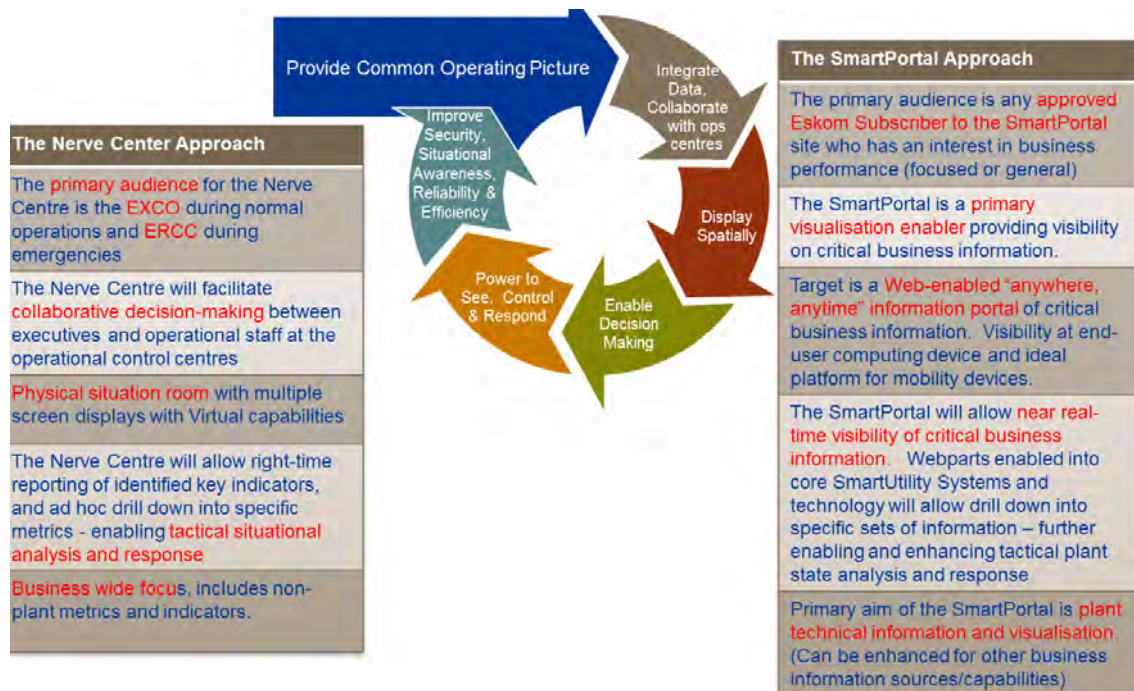
Figure 5–17: Brownfields Plant Combustion Process Animation



5.8.5 Portal versus Nerve Centre Comparison

The IPI–BIM Information Delivery research aspects were concluded by an evaluation of the prototype outcome against the “Nerve Centre” information delivery option (seen as an alternative solution to portal technology by the Power Utility SmartStrategy [Hales, 2013]). Figure 5–18 provides a comparison between Nerve Centre and Portal capabilities.

Figure 5–18: Nerve Centre vs Portal Capabilities Comparison



The biggest challenge with a nerve centre is the small stakeholder/user base it would serve – a challenge to the potential business value and ROI of such an undertaking. Significant investment is usually required for such a centralised operations centre in a physical location.

Due to the extensive cost to enable a location–based “nerve centre” capability, the project was still at Proof–of–Concept/Concept Design phase at research study conclusion; while the SmartPortal prototype was conducted, concluded and demonstrated to business stakeholders in less than 3 weeks. The plant visualisation capability and on–line plant state monitoring of materials handling systems were done in 2 weeks and the capability is available for use at the Brownfields Plant.

It should not be interpreted that the research study question the need to have a nerve centre (The two information delivery capabilities are complementary to each other but with potentially different target audiences). As Value Proposition (ROI) is core to the IPI–BIM, it can, however, be concluded that portal technology will be the preferred option for information delivery in the proposed Framework.

5.9 Conclusion

The research and associated prototype confirmed portal technology as the ideal information delivery platform for the IPI–BIM Framework. By prototyping portal technology and comparing it to nerve centre capability requirements and timeframes to implement, the hypothesis that a SmartPortal information delivery approach is a better value proposition was confirmed (based on the demonstrated capability that a Portal can serve a much wider business user audience and can have more pervasive information delivery capability).

The research demonstrated how very disparate sets of systems and data sources could be integrated into a single–access point information delivery platform available to all users and stakeholders in a large organisation. And it confirmed the need for both static and dynamic (real–time) data to enable effective decision making to business.

The IPI–BIM Data Visualisation research prototype could also successfully demonstrate how real–time plant data can be displayed and visualised in the portal (via plant data historian technology), negating the need for business users to access C&I SCADA and PLC systems directly.

The research demonstrated an optimal information portal delivery design that combines visual (interactive 3D) and conventional 2D hierarchical data display methods. The 3D laser scanning prototype confirmed that similar 3D visualisation capability was a viable option for process plants that does not have a 3D CADD model.

The prototype further demonstrated how core Design Base content (in the case of visualisation – the PBS element of the Design Base) becomes the integration lever between plant and business information systems to expose more Design Base information when needed. It also effectively demonstrated how Design Base content, interactive 3D visualisation capability and advanced analytics capability could be enabled in one common portal–based user interface (Figure 5–13).

Table 5–19 shows typical cost savings achieved by improved operator training methods. The commercialisation of the first Greenfields Project generating unit was executed with minimal trips (8 documented trips due to operator error). The 3D virtual simulator capability developed by the research was deployed on this project for operator training 9 months before the unit was commissioned. This allowed for much better operator training to handle plant commissioning, start–up, alarm and abnormal condition management.

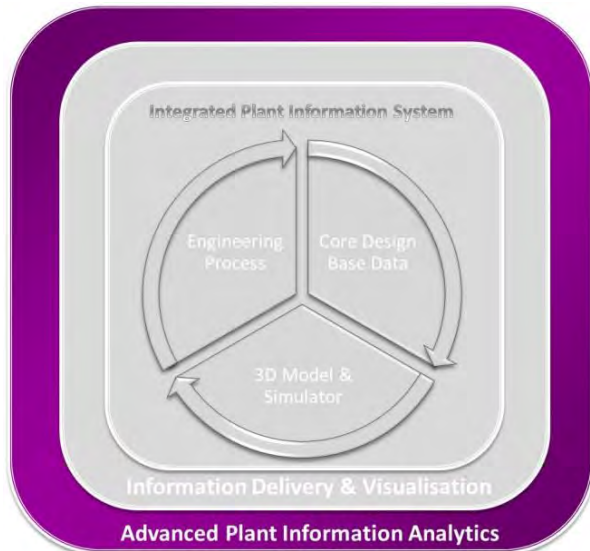
Figure 5–19: Typical Operating Savings

SCENARIO	TYPICAL BENEFIT
Reduced Commissioning Testing and Operator Training intervention time on Project before Faster Handover to Client (800MW Unit)	R5,978,400/day
Better plant alarm and abnormal condition management Scenario training in the Engineering/Operating Simulator – fewer Load losses and trips (8 on Greenfields vs 40 on Return–to–service power station)	R4,493,760/day
Plant load loss risk due to incorrect plant operations Load Loss, 620MW Unit/day Unit Trip, 620 MW Unit, return in 4 hours	R4,493,760/day R748,960/incident

When compared to a previous return–to–service (RTS) project, the trips during commissioning for this RTS plant exceeded 40 for the same time period. This plant did not have the benefit of the virtual plant model and virtual training simulator, nor the benefit of a defined and well–managed Design Base in an integrated plant information management system.

The benefits of using portal technology (as stated in the research literature surveys [Wheeler, 2016]) were demonstrated effectively with the research prototyping. It confirms that portal technology is easily customizable, supports collaboration, consolidates information infrastructure requirements and is very user–friendly and intuitive.

ADVANCED ANALYTICS IN THE IPI–BIM FRAMEWORK



A Study by the Energy Central organisation in global power utilities in 2006 has indicated that significant gaps were identified when it comes to managing the human capital of technical and complex business organisations [Causey, 2006].

The study emphasises the need to address skills losses and having improved automation and control system intelligence to assist with knowledge transfer and managing complex process plants.

An Emerson study confirms that some of the biggest challenges for process plant reliability and control are overwhelmed operators and complex plant operations that demand a new approach to managing plant process and control information more efficiently and predictively [Emerson, 2003]. The challenge of effective alarm management and the mass of control data generated in upset conditions (and the impact it has on the operator) is confirmed by EEMUA research and standards [Mayssat, 2009].

The research study postulated that developing an IPI–BIM Framework that contains Advanced Analytics and Simulation capability as one of its core elements can assist a Power Utility or Process Plant to deal with the challenges identified above.

By using advanced data analytics it should be possible to analyse and compare larger data sets over longer time frames and vastly improve predictive capability very early on during plant upset conditions. The inclusion of advanced analytics and simulation as part of the IPI–BIM framework will also enable plant operating and process control hypothesis testing as a core business improvement capability. Inefficient plant control and other procedures can also be identified and optimised, improving efficiency and reliability of the plant.

Advanced analytics can also enable Design Base capability evaluation beyond the current known Design Basis limits [Parlour, 2007]. This is a capability supported by Lipták's research findings, who believes that process constraints can potentially be modulated to increase production output using advanced simulation and process plant hypothesis testing [Lipták,

2006]. This becomes an attractive and potentially viable option for availability and capacity improvement in process plants where very large design safety margins were introduced (e.g. old process plants with very conservative design approaches).

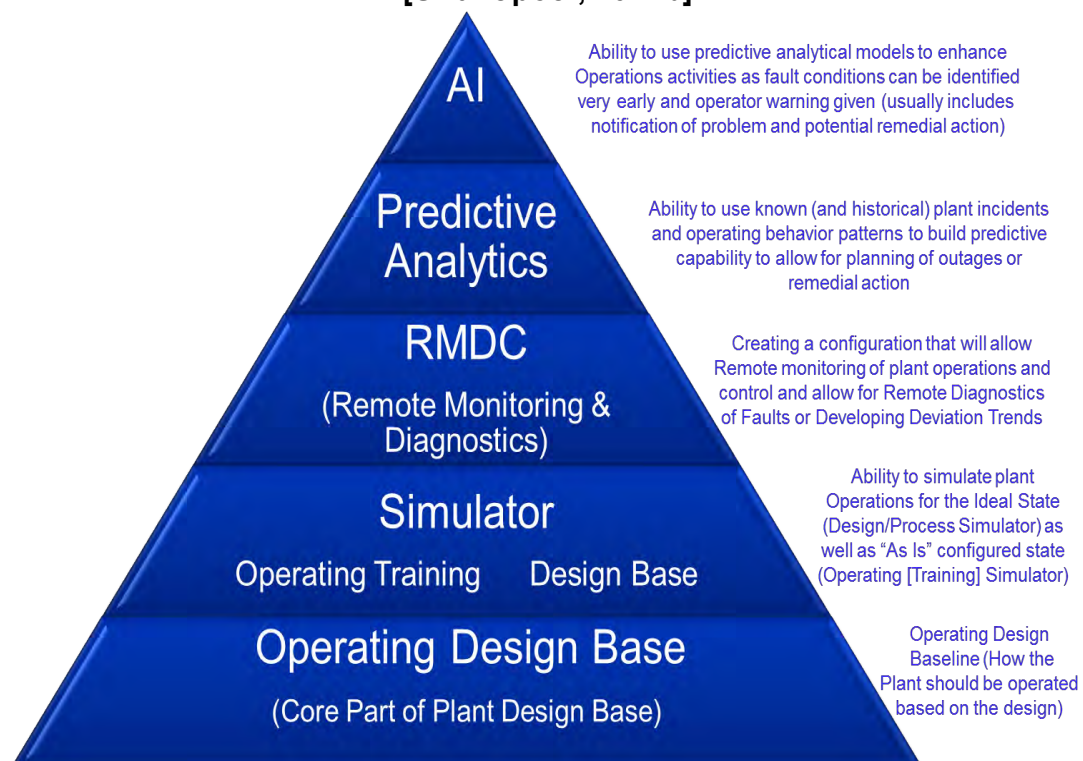
A major benefit of *virtual* simulation and advanced analytics capability is that it allows for simulation of diverse and complex plant process condition changes and evaluating the impact of these changes on a virtual plant environment. This removes the risk of straining the actual process plant to test hypothesised Design Base change models. Crucial to advanced analytics is a thorough validation and verification process to confirm simulation model outcomes.

6.1 Postulated Theories regarding Advanced Analytics

Hypothesis 7: A combination of analytical methods would be required to provide a holistic plant improvement framework.

The research aims to prove that establishing the building blocks for the IPI–BIM Framework will enable the required advanced analytics capability (Figure 6–1). This portion of the research further aims to show how using the required information contained in the Integrated Plant Information System platform will allow the organisation to build, test and refine analytical fault models using the typical Process Optimisation Framework approach [DAMA, www.dama.org].

Figure 6–1: Technology Building Blocks Enabling Advanced Analytics and AI [Swanepoel, 2014b]



Prototyping will be used to demonstrate that the capabilities developed and enabled in previous chapters of this research study can be used to efficiently and correctly define, build and prototype advanced analytical models that will enable more efficient plant asset– and related information management and more extensive predictive diagnostic business capabilities.

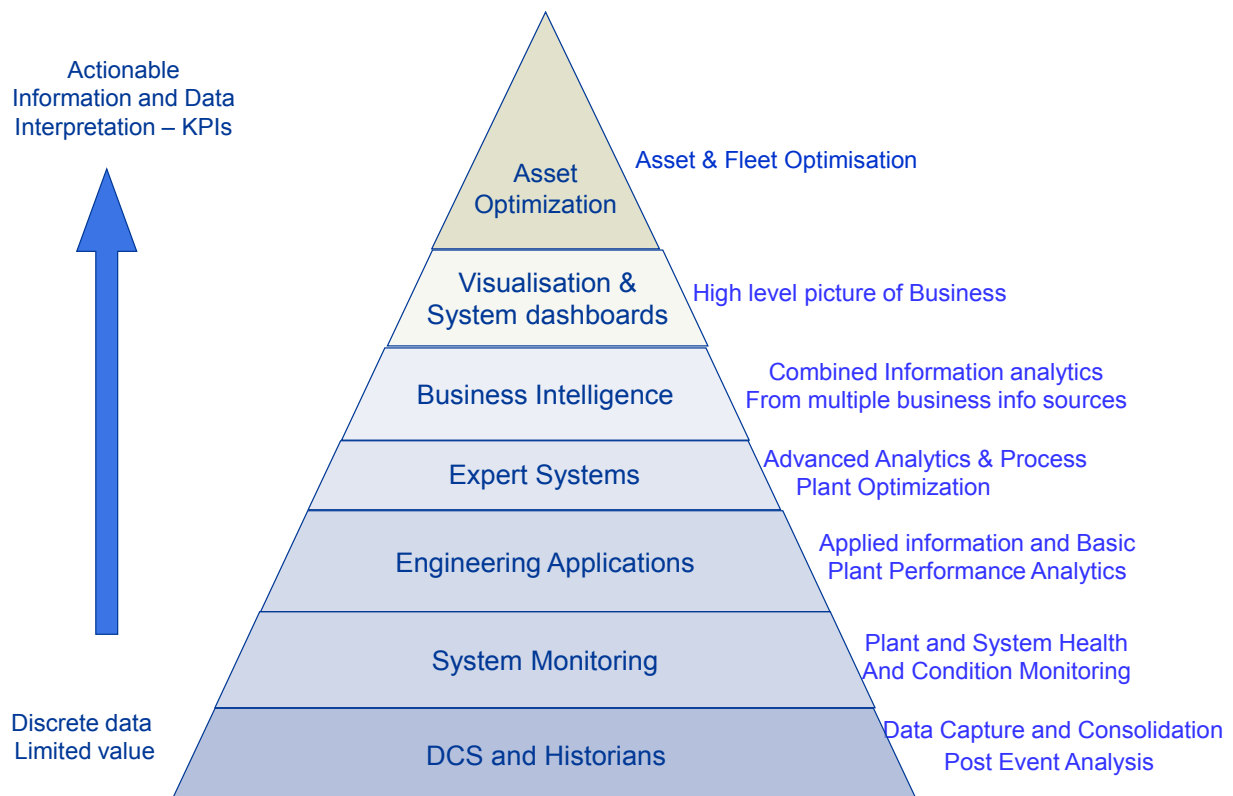
Proving Hypothesis 7 will also support Hypothesis 6: An optimal IPI–BIM implementation methodology will yield a measurable value proposition.

6.2 Advanced Analytics Building Blocks for Asset Management Optimisation

Figure 6–2 shows the logical information building blocks to build a SmartUtility IT/IM infrastructure [Hales, 2013].

It also depicts the phased process of maturing plant process and engineering information in an asset–driven organisation from discrete data to useable and valuable information and knowledge, as well as demonstrating the importance of plant data in the decision–making processes for a complex process plant.

Figure 6–2: Advanced Plant Analytics Information Building Blocks for Asset Management Optimisation [Hales, 2013]

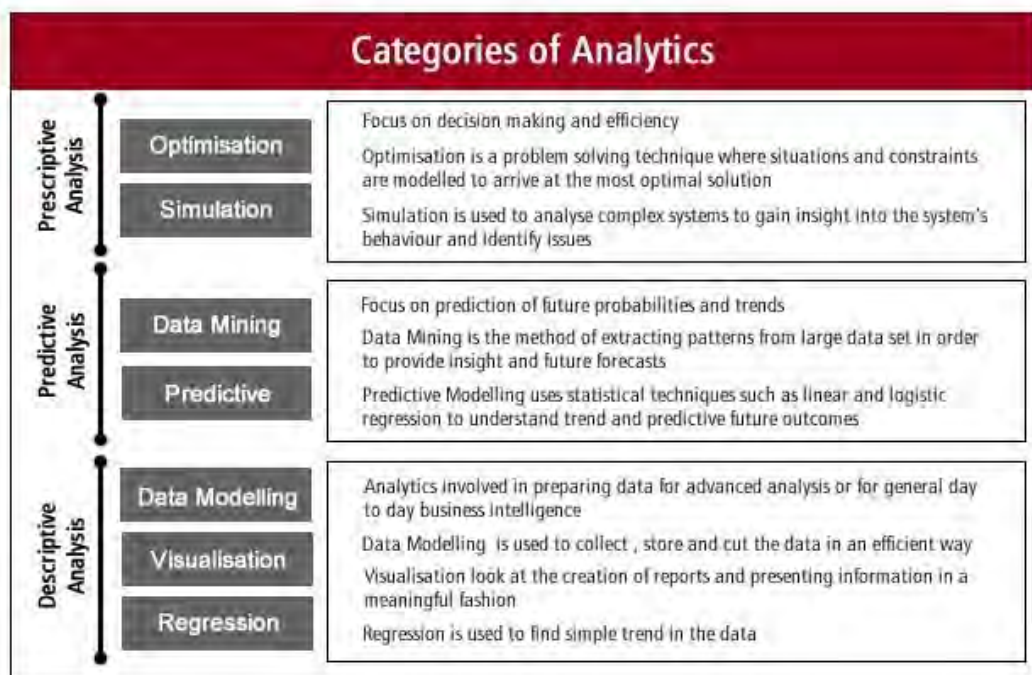


6.3 Research Methodology

The different advanced analytics methods that can be used to manage the scope and outputs of the advanced analytics portion of the research study will be evaluated. As identified and postulated by Lustig in the research literature survey [Lustig et al., 2010], the research has already confirmed that it will require and utilise a number of the listed Descriptive, Predictive and Prescriptive Analytics to develop, test and prove elements of the IPI-BIM Framework and Implementation Methodologies (as stand-alone methods as well as combinations thereof).

Phillips elaborates further on what exactly the different categories of analytics entail (Figure 6–3) [Phillips, 2014]. This confirms the hypothesis posed by the research study that a combination of the analytical methods would most likely yield the optimal value proposition for the business.

Figure 6–3: Advanced Analytics Categories [Phillips, 2014]



6.3.1 Type and Scope of Advanced Analytics Required

Elements from the 3 analytics categories (Descriptive, Predictive and Prescriptive) have already been used to develop, test and prove the IPI-BIM Framework and implementation methodologies proposed.

Predictive analytics were used for the development and classification of core Design Base content, while Prescriptive Analytics methods were used for Design Base reverse engineering and validation/verification of Design Base information.

The research study anticipated that simulation, data mining, predictive analytics, visualisation (and potentially data regression) that forms part of the Prescriptive Analytics methods will be extensively used for advanced analytics of plant performance and control data.

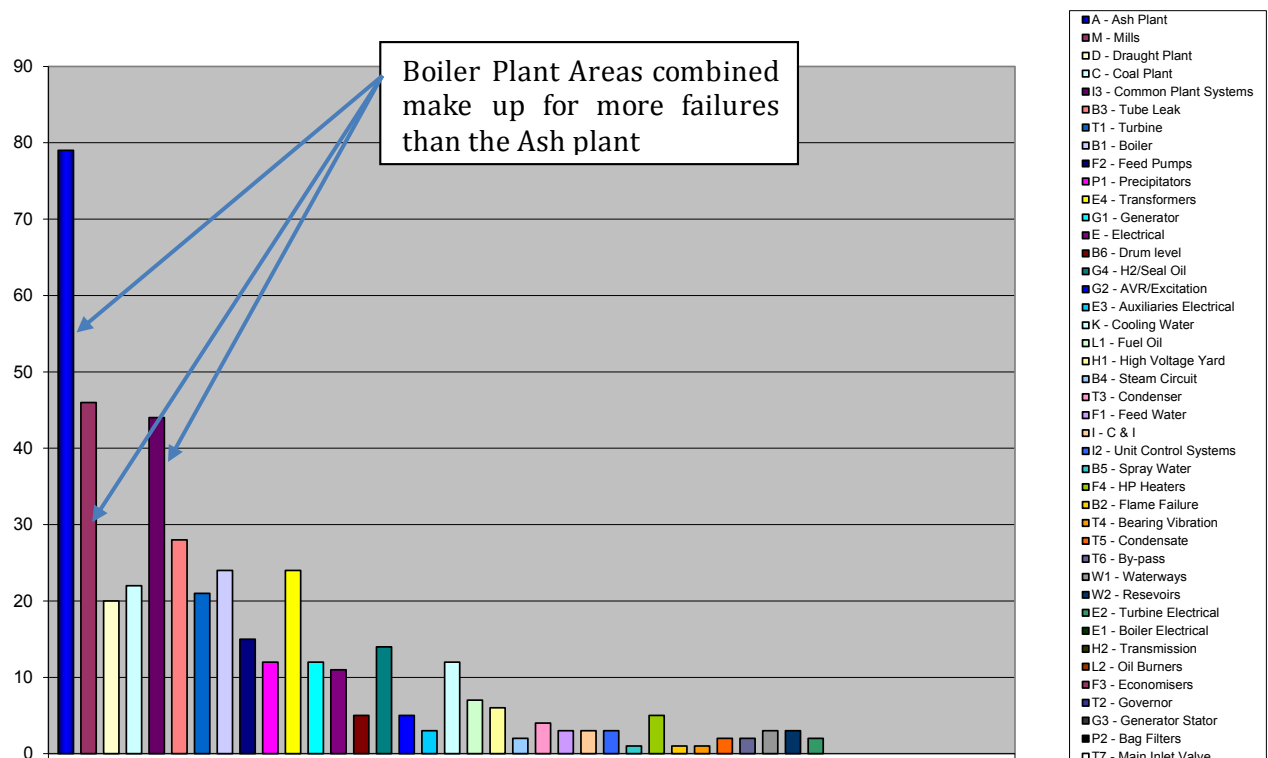
This in part confirms Hypothesis 7 that postulated that a combination of analytical methods is required to provide a holistic plant improvement framework.

6.3.2 Advanced Analytics Prototyping Use Cases

For the Advanced Analytics prototyping research scope, the most problematic plant areas had to be identified to narrow the scope of the prototype and advanced analytical model building. This is in line with the methodology for quantitative algorithm modelling as proposed by Venkatasubramanian in that it will assist in narrowing down the fault diagnostic analytical model choices (especially considering the challenges raised by these researchers regarding some of the analytical modelling methods and choices) [Venkatasubramanian et al., 2002].

The research study utilised the Failure Barrier and IBI Analysis Methodology (considered part of the “Descriptive Analytics” capability suite) to identify the most typical failure modes and barriers that resulted in production downtime (Load Losses and/or Trips) for the research study Brownfields plant. This is depicted in Figure 6–4.

Figure 6–4: Occurrence Analysis to identify Problem Plant Areas [Swanepoel, 2008]



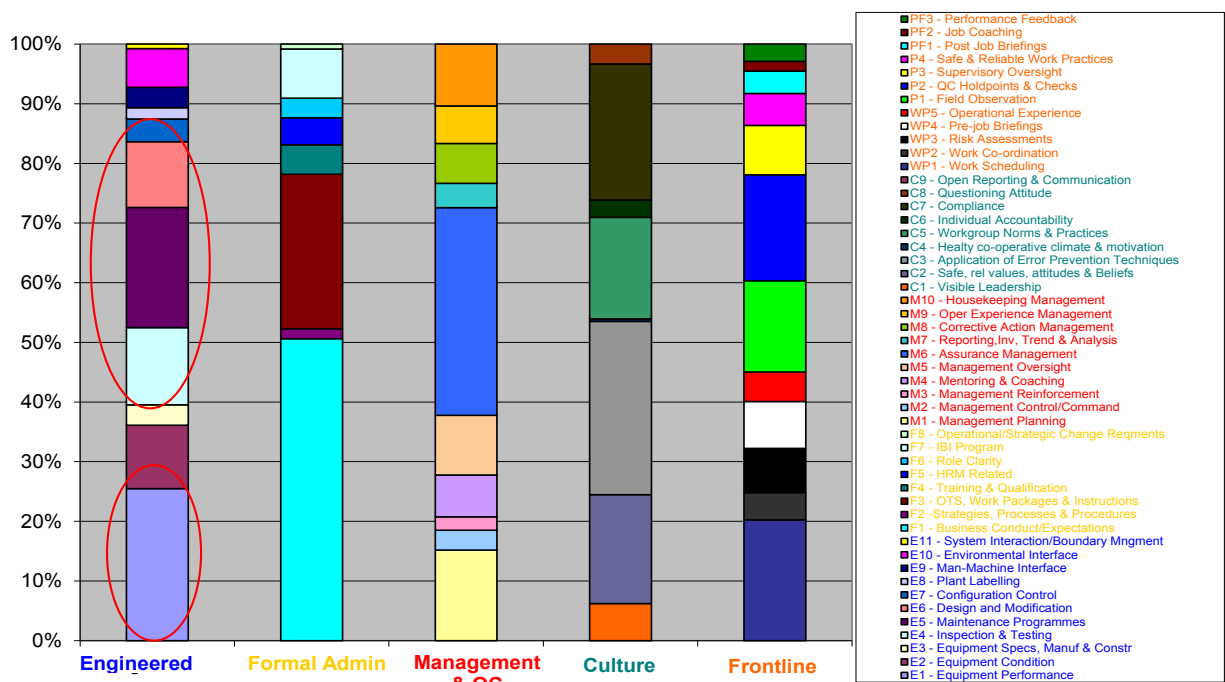
Although the Ash Plant area is the biggest contributor to incidents in the plant, the impact on load losses and trips is less profound as there is generally a backup conveyor belt or system in

place to continue process flow in this plant area. There are also significantly fewer operational data points available for analysis and statistical model building and evaluation.

If the ash plant area is excluded (due to the reasons provided above), the biggest contributing area to incidents would be the boiler plant area (and associated process systems). Being core to the power production process, incidents in these areas will result in significant load losses and even unit trips.

Using this information, it was decided to focus on performing advanced analytical prototyping on the steam–water generation process. The timeframe data captured against the occurrence investigation could be used to source the plant control data relevant to the period of failure from the Plant Data Historian.

Figure 6–5: IBI Analysis of Barrier Failures resulting in Occurrences [Swanepoel, 2008]



Utilising the IBI Failure analysis methodology, the engineering barriers that failed were identified (see Figure 6–5, circled areas). The most notable failure causes in this category being:

- Deteriorating equipment performance.
- Equipment Condition (Ageing and inefficient maintenance strategies).
- Inspection and Testing Activities not executed according to good practice.
- Maintenance Programs not implemented as required.
- Design and modification related issues.

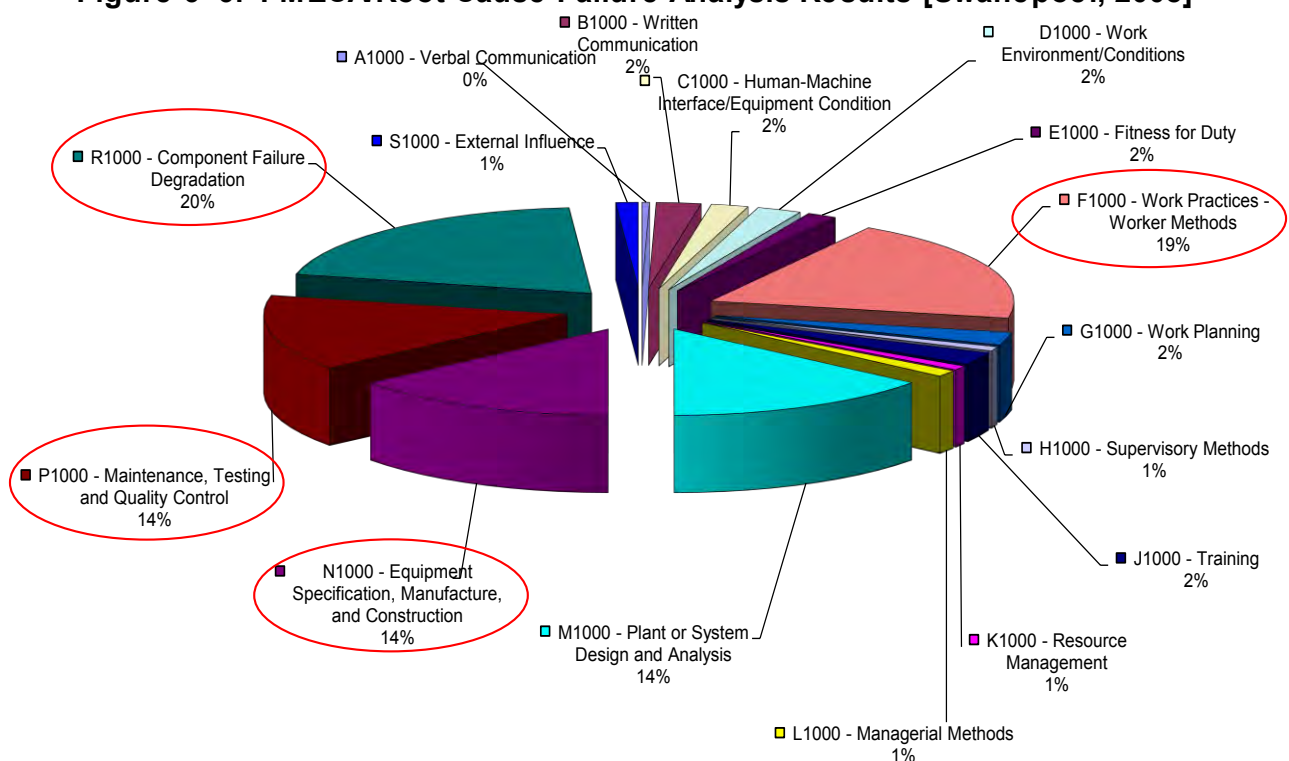
As the research study focus is on engineering elements, the other IBI barriers (“Formal Administration”; “Management and QC”; “Culture” and “Frontline”) were not investigated.

This is in line with the scope of exclusion for this research study (see 1.5). A brief review of the Management and QC Barriers, however, does show a significant “Assurance Management” barrier failure incidence – with evaluation of use cases in this category confirming that it mostly related to post–maintenance quality control not being up to standard.

For validation purposes, an alternative failure analysis methodology was used to confirm that the most problematic plant areas and root causes for the occurrences were indeed correctly identified. The Root cause analytics methodology was deployed on the same data set to test the IBI/Barrier analysis outcome. This allowed for Internal Validation using data triangulation methods – i.e. using the same set of data but with different analytical methods to confirm the data analysis outcomes.

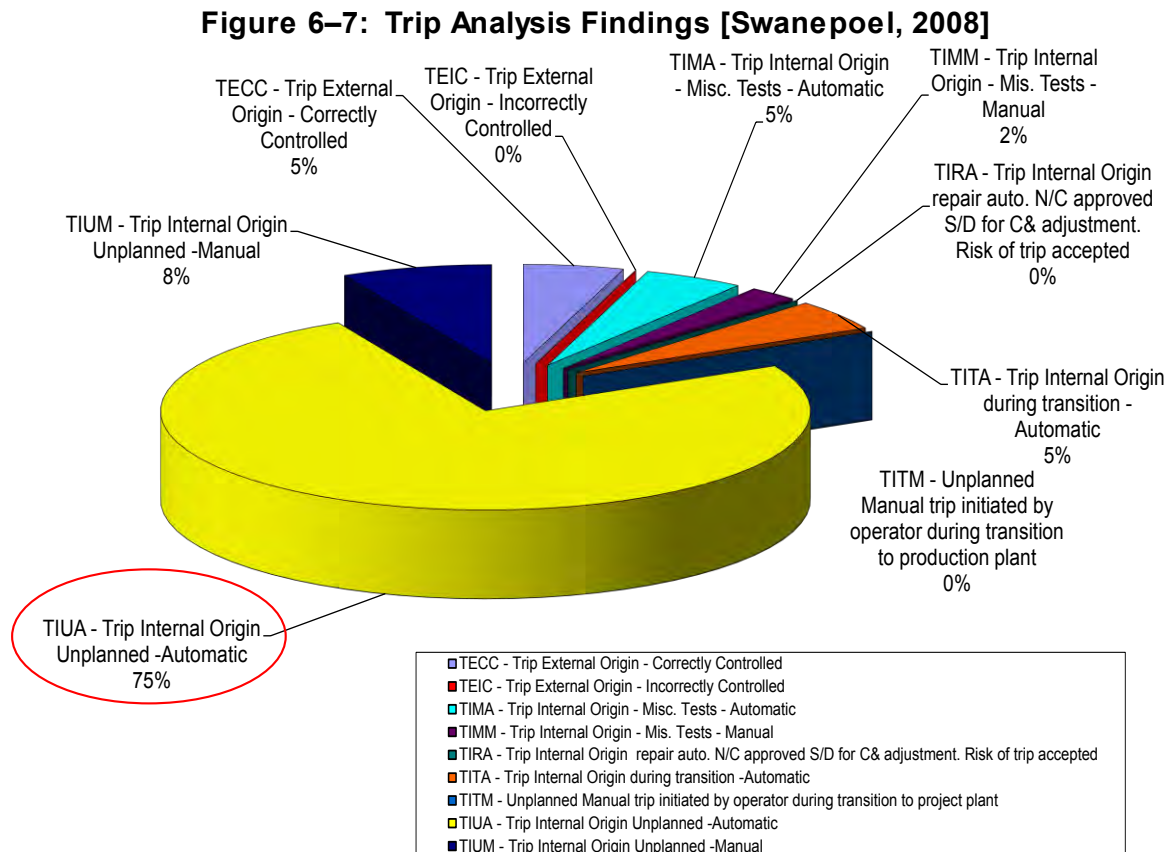
Figure 6–6 shows very similar root cause outcomes when compared to the “IBI Barriers” that failed. This validation confirmed that plant system design issues, operating and maintenance work practices and component failure degradation are the key contributors to equipment failures (and the resultant load losses and trips).

Figure 6–6: FMECA/Root Cause Failure Analysis Results [Swanepoel, 2008]



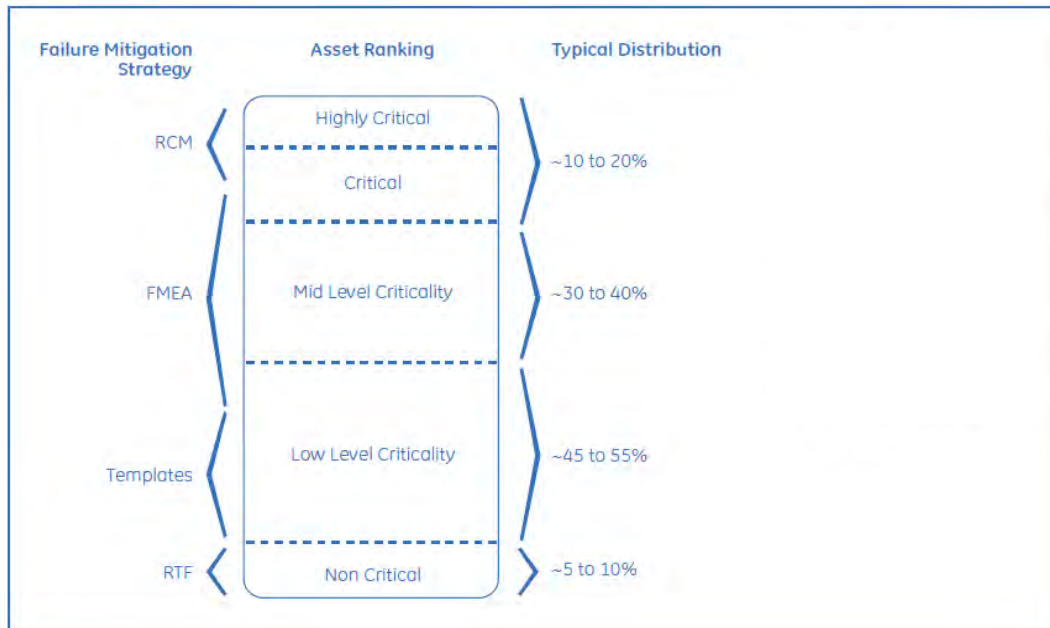
These Root Cause analysis outcomes were also used to assist in fault model building and further advanced analytics analysis work. In addition to identifying occurrence root causes, a specific analysis was conducted on plant trips to determine the most common cause for these. The largest portion of plant trips (75%) is internal, unplanned and triggered by the plant control system. This is classified as the “TIUA” category in Figure 6–7.

When a plant trip incident is assigned to this category it is indicative of a situation where the control system initiated a trip based on process condition anomalies where operator reaction was not timeous to normalise the plant abnormal conditions that resulted in the trip .



The Design Base data enhancement and this failure analysis work conducted in the research study delivered a further unexpected benefit for the Power utility. Optimisation of the Power Utility plant fleet maintenance strategy and work scope was identified as a major opportunity for business improvement and cost optimisation. EPRI, through extensive research, has given some guidance regarding the typical maintenance activity distribution that can be expected at a Utility power plant (Figure 6–8) [Abbott, 2004].

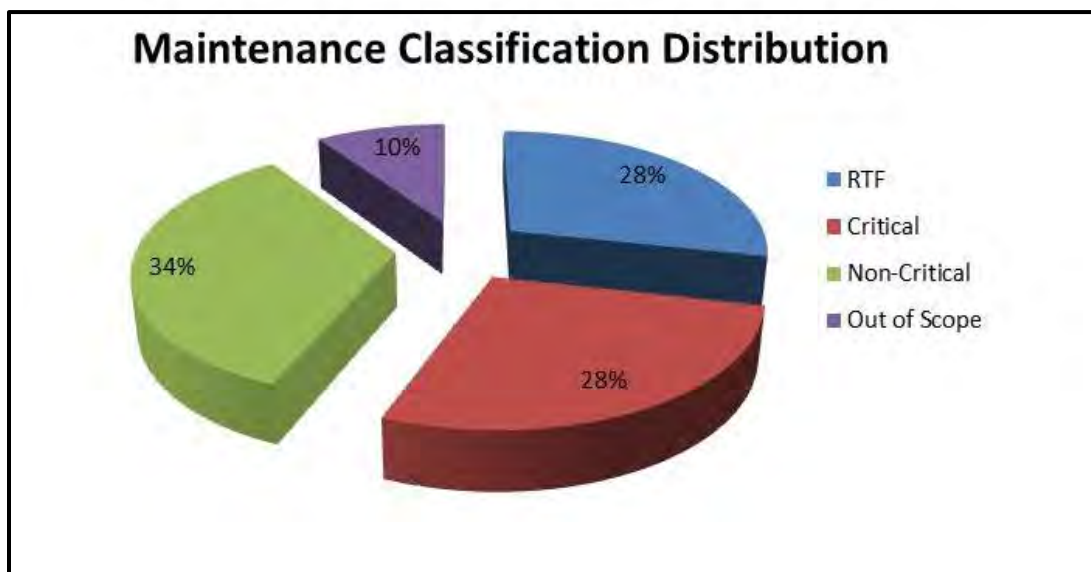
Figure 6–8: EPRI Model for Plant Maintenance (Reliability Base) Optimisation [Abbott, 2004]



A core requirement for maintenance base optimisation is the availability of plant Design Base information in order to do FMEA, classify plant and develop and implement the use of standard maintenance templates for the identified equipment types (and sub–types). Implementation of the EPRI model in conjunction with Design Base information from the Integrated Plant Information System assisted in the identification of significant maintenance optimisation opportunities on the research study’s Brownfield Plant.

Implementation of the Design Base that includes elements of maintenance strategy and work scope definition allowed for significant optimisation of current practices. It resulted in an optimised plant asset criticality distribution close to that recommended by EPRI (Figure 6–9).

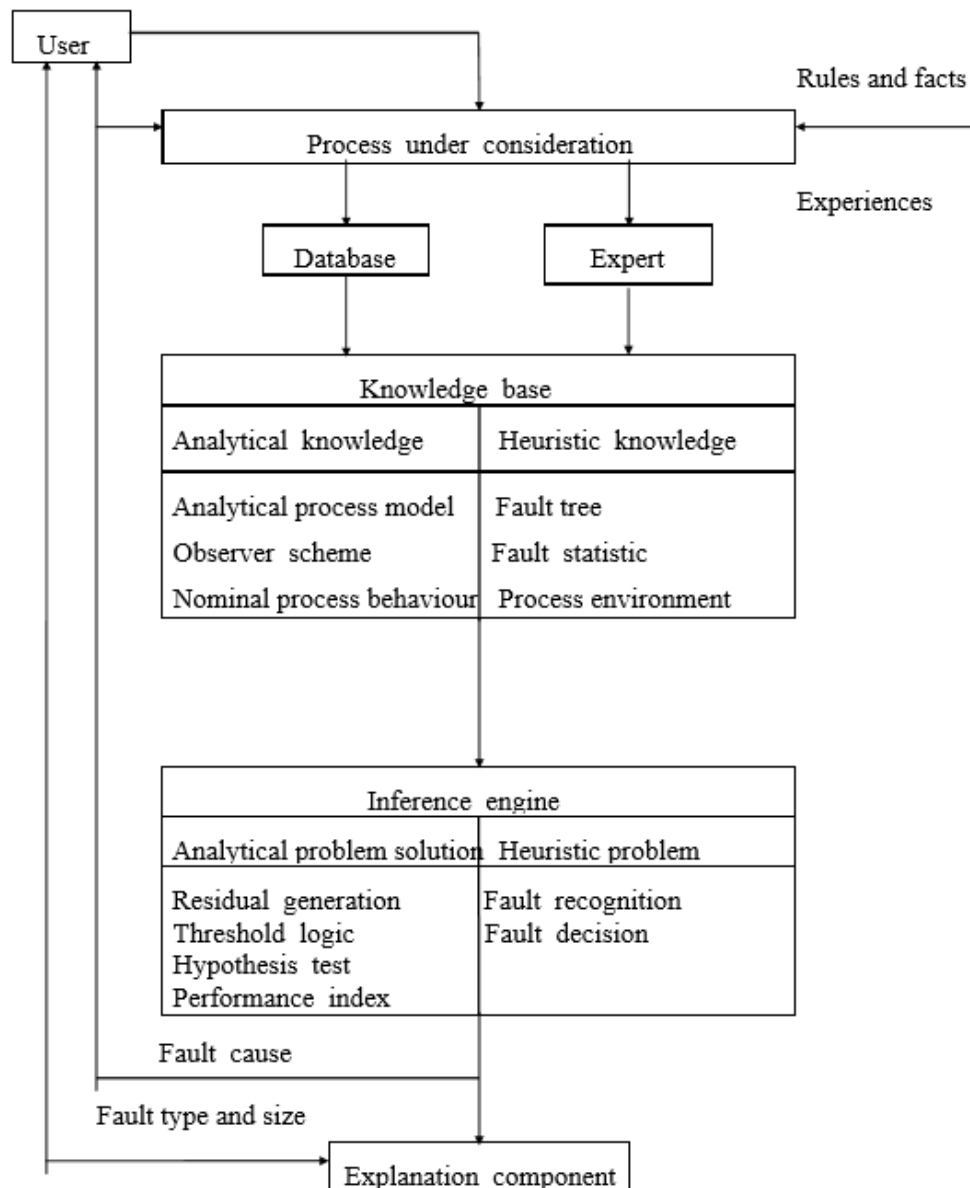
Figure 6–9: Brownfields Plant Maintenance Criticality Distribution [Swanepoel, 2016]



6.3.3 Identifying the Best Research Methodology

From research, it is believed that Angeli most aptly describes the basic research methodology and system elements that make up the advanced analytics models for this portion of the research study (Figure 6–10). His model describes a very holistic approach to defining and building advanced analytical models [Angeli, 2004].

Figure 6–10: Basic structure and elements of an advanced analytics system [Angeli, 2004]



While researching and evaluating past work done on the etaPRO advanced analytics system platform in the Power Utility, the researcher came across the application of Angeli's methodology in the development of plant flue gas monitoring technology trending and analytics on the research study Brownfields Power Plant.

It included the evaluation of the process against expected Design Base and operating philosophy for SO₃ plant management and proceeded to develop the required fault tree using heuristic and analytical data sources.

The required fault diagrams were developed and built into the user interface screens, allowing for “on the fly” fault analysis when an operating condition exceeded the expected Design Base parameters defined in the operating envelope.

The practical use of Angeli’s model on the Brownfields plant led the researcher to hold the view that the proposed system model can also be used to determine whether there are any shortcomings in the current technology stack deployed by the utility to enable advanced analytics.

Angeli’s model elements [Angeli, 2004] can also be used as a research checklist to determine shortcomings and opportunities for future improvement and advancement of work done in this research study. It also offers an opportunity to improve FMECA models for plant equipment and systems in use.

6.3.4 Advanced Analytics System Technology and Validation Methods used

The research analytics was done on the advanced analytics platform (etaPRO™) deployed in the Power Utility. Research required additional analytical model development on this platform, e.g. building PFD level diagrams of controllable parameters and monitoring this over a defined period of time (covered in Chapter 4).

The analytical outcomes were compared to the “ideal” plant Design Base expected performance (modelled into the Rankine cycle analytical model from Design Base content contained in the IPI System platform). This was then used to determine to what extent the operating staff was capable of maintaining plant process operations in line with the (“Ideal”) Operating Design Baseline.

The latter comparison used the operating simulator technology and plant control system software infrastructure as data references. Comparing real-life plant control responses by the operator to what would be expected as the ideal response in the Operating simulator allowed an opportunity for the research study to identify opportunities where operating practices can be improved.

6.4 Scope of Advanced Analytics Research and Prototyping

The research utilised a number of areas to demonstrate the value of creating advanced analytics capability to improve business operations. A typical use-case would be to develop models that can be used to determine if any tell-tale control data patterns emerge in cases of poorly controlled parameters and develop guidelines for the business to improve operations in such cases – allowing the operator to pre-empt and prevent possible failures, load losses or trips in a faster response time.

The operational research was conducted on the research study Brownfields Power Station plant to evaluate how well the controllable parameters are managed against the Design Baseline criteria. This is covered by the three use cases described in 6.4.1 to 6.4.3.

As part of the research, integration of advanced analytics capability into the Operating Simulator of the Greenfields Project was investigated. The purpose of this work was to demonstrate how enabling controllable parameter analytical models into the Operating Simulator will empower the operator to evaluate changes to plant process conditions and be able to train more efficiently on new plant technology. The scope is described in more detail in 6.4.4.

6.4.1 Use Case 1: Plant Rankine Cycle Scenarios – Design Base versus Actual

Identify issues with operating practices that impact efficient operations using Design Base information and advanced data analytics to compare actual performance against ideal/desired conditions.

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

Key plant process parameters (also termed “controllable parameters”) were identified that could be used for comparative purposes in advanced analytics and plant process model/behaviour testing.

The benefit of using controllable parameters is that identifying opportunities to better manage these parameters are within the operator’s control and do not require changes to software or operating control system configurations. Improvement in managing controllable parameters, therefore, yields immediate business improvement benefit without the need for excessive investment to achieve the improvement.

6.4.2 Use Case 2: Evaluate Impact of Design Base Integrity and Changes on Plant Reliability

In this use case, research will investigate the impact of poor engineering change control of Design Base modifications on the plant's reliability and efficiency. The research evaluated scenarios where plant design changes were implemented but the process model was not updated and the impact this has on performance model calculations.

Research also investigated the impact on plant analytical model outcomes in cases where plant ageing and deterioration are not taken into consideration. This was done by considering scenarios like heat exchanger fouling, loss of equipment and component efficiencies due to ageing and deterioration. This could then be used to demonstrate how the loss of key process plant equipment impacts process and plant efficiency.

By evaluating these conditions it will underwrite one of the primary IPI-BIM Framework goals: ***Create a capability that ensures timeous failure identification and prevention as an enabler towards high plant reliability and availability, and thus supporting business improvement initiatives.***

6.4.3 Use Case 3: Evaluate Operational Efficiency of Statutory Plant Tests

Power plants generally operate at very high pressures and temperatures and as such are subjected to a number of statutory/mandatory tests at predefined time intervals. These critical integrity tests are prescribed with a very clear methodology/execution sequence and operational control process requirements.

Failure to control these tests in line with the defined test criteria and operating envelope can cause significant plant damage (as such tests are usually executed very close to asset/component design limits).

This study evaluated key Plant Test methods and expected operational curves, and used advanced data analytics and process models (and expected behaviour/outcome) to determine how efficient the utility is in conducting these statutory/mandatory tests. It also evaluated operational data samples to determine if any notable patterns emerge in cases of poorly controlled test practices.

6.4.4 Evaluate Integration of Advanced Analytics capability into Operating Simulators

The research scope included a prototype that was used to determine the effort and feasibility of enabling advanced analytical models capability into the plant process simulation environment used by Operators (the Operating Simulator environment).

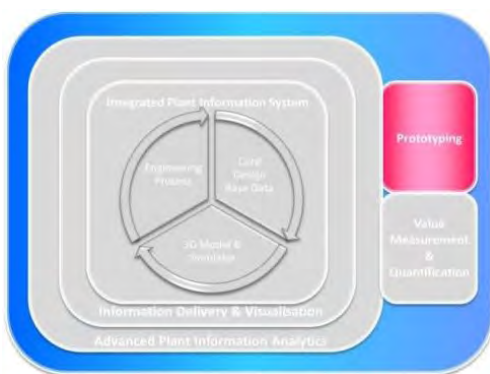
The advanced analytics environment would have significant benefit if it can be deployed in an appropriate and controlled manner for Operator training and skills testing on a Power Plant – especially with very complex plant or advanced fault scenarios.

The research study scope focused prototype work on the Greenfields Project, using a portion of the overall plant process where the utility has had little/no experience in plant optimisation and management before, i.e. the flue gas desulphurisation process that uses wet FGD technology. The Greenfields Project Power Plant will be the first power station in the Power Utility fleet to use this emission control technology.

The scope of the research study entailed development of a high-level Flownex™ model of the FGD process plant and then integrating it on a high level into the PFD level model of the overall Greenfields Power Station process.

Controllable process parameters within the FGD Plant were identified, and these were then integrated into the 3D virtual plant interface. The aim was to demonstrate the ability to expose proven advanced process analytical flow models to the operator in a controlled manner, and allowing them to interact with controllable parameters to evaluate the impact of changes made on overall plant efficiency and process, acting as a very efficient training delivery method.

6.5 Advanced Analytics Prototyping Preparatory Work



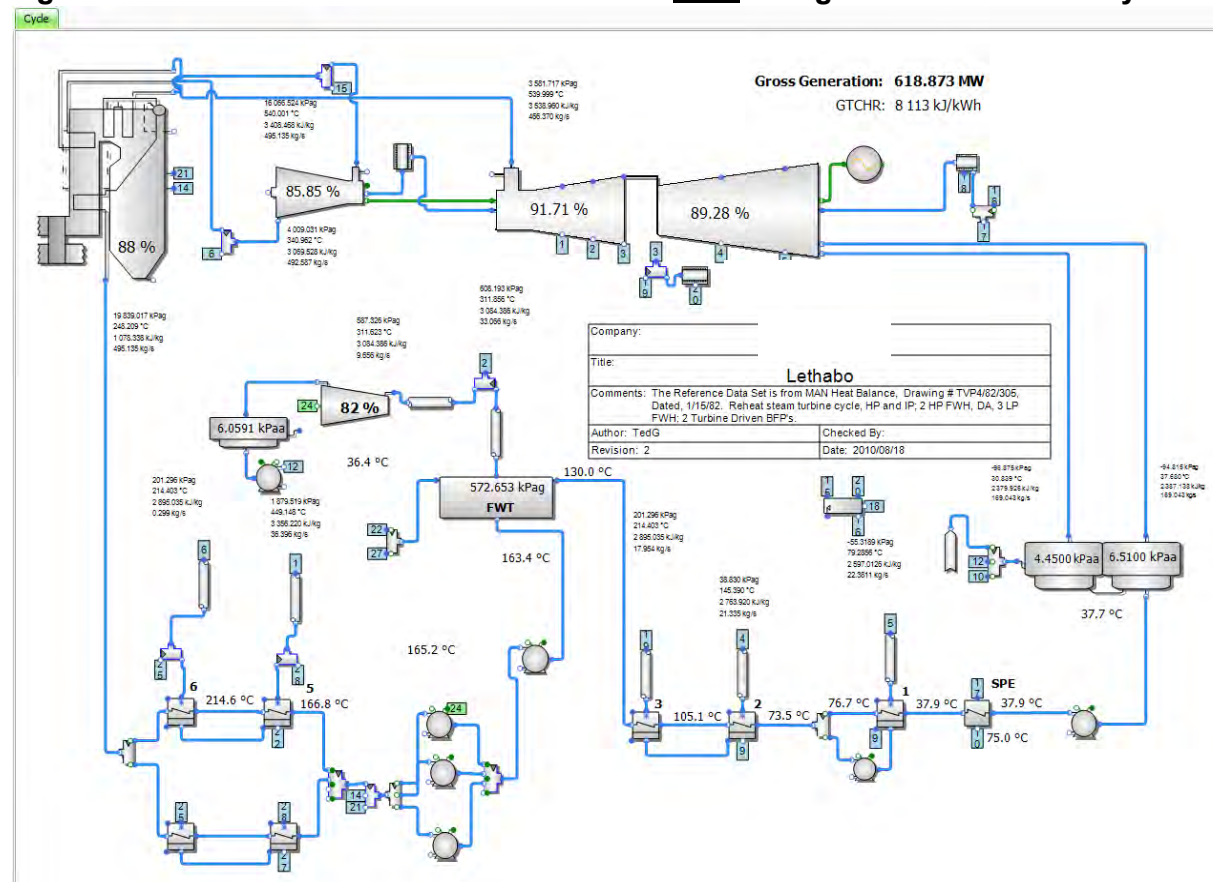
This section covers the preparatory work the research study had to perform to enable the various prototyping activities proposed as part of the operational research. Due to the nature of the research scope, both the Brownfields Power Station and Greenfields Project data sets and Design Base content had to be utilised to demonstrate the feasibility of the intended functionalities proposed.

6.5.1 Creating the Comparative Analytics Baseline

Figure 6–11 depicts the ideal Brownfields Power Plant process (Rankine Cycle) model used by the research study as the comparative baseline (for a single generating unit). This was developed, configured and enabled in the advanced analytics tool simulation module (etaPRO Virtual Plant™).

This plant process model is based on what is deemed the *ideal operating scenario* according to the plant Design Base: all main turbines (HP, IP and LP turbines) are in full operation, together with 2 HP Feedwater Heaters, De-aerator, 3 LP Feedwater Heaters and the steam–turbine driven feed–water pump being in operation.

Figure 6–11: 620 MW Power Generation Unit *ideal* Design Process Efficiency Model



The research study then used this ideal plant model and compared it to the operating simulator configuration of the Brownfields Plant to evaluate how accurate and reflective it is of the actual plant performance behaviour.

A challenge for the plant performance correlation process was the technology capabilities of the Operating Simulator and the Plant Control System. The simulator was much more flexible in its configuration (e.g. the ability to add data points and deduce additional control values from available information) while the actual plant control system had severe limitations for additional

control data capturing points to be created, monitored or even to retrieve additional plant process data.

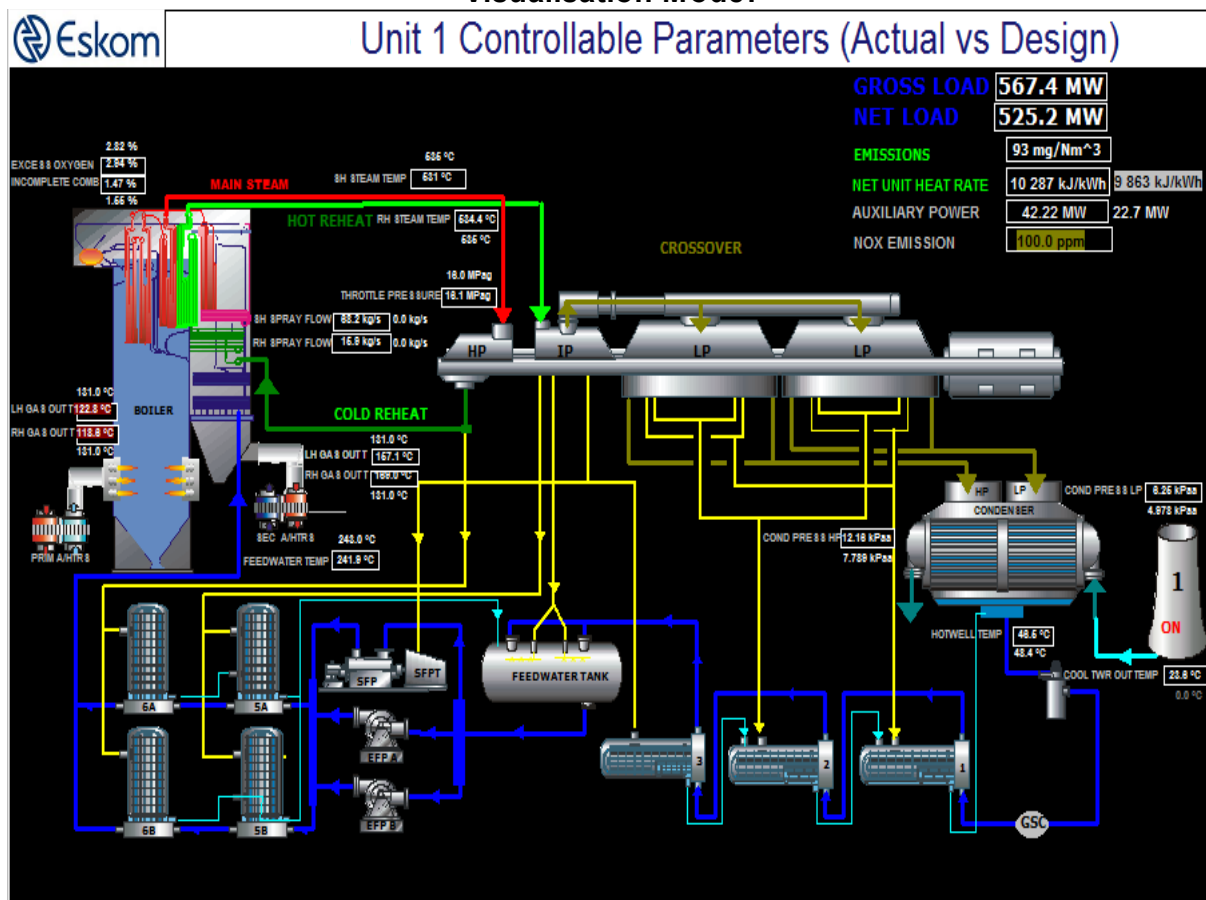
Alarm signals in the control system are also captured in analogue format and stored to a different system (outside of the Plant Data Historian). The analogue signals required conversion to digital format in the engineering simulator before it could be used for comparative purposes.

Despite the challenges, a close correlation was obtained between the Virtual Plant model outcome in the Engineering Simulator platform and the plant process performance behaviour observed in the Operating Simulator.

6.5.2 Identifying the Controllable Parameters

Part of the research scope was to identify controllable parameters and visualise this for Operator control purposes. This visualisation and grouping of controllable parameters for the plant unit are shown in Figure 6–12.

Figure 6–12: 620 MW Power Generating Unit PFD Level Controllable Parameter Visualisation Model

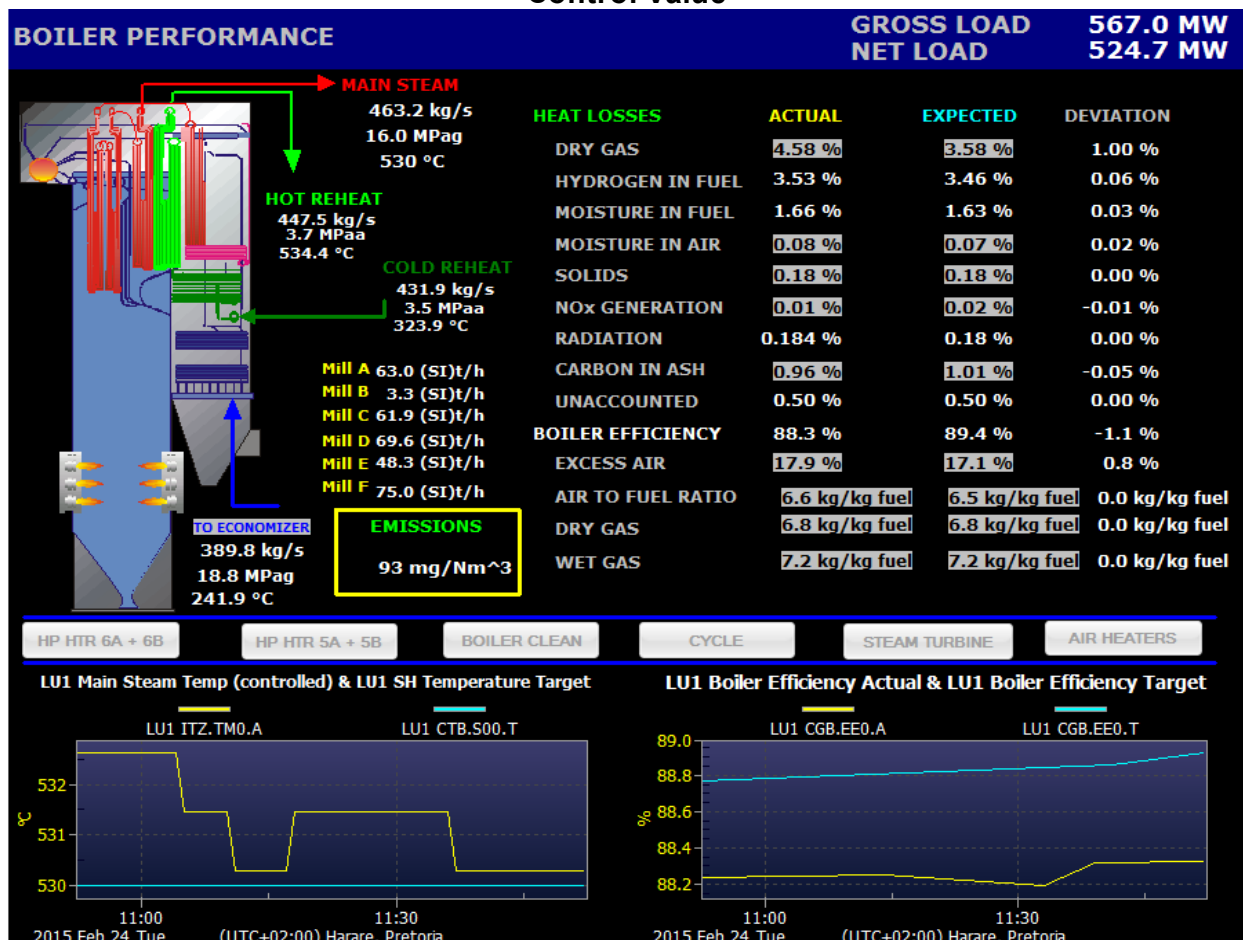


Once identified and defined, these controllable parameters were trended and monitored in an effort to determine patterns where actual plant control is not in line and within the boundaries of the operating Design Base.

The process entailed a continuous evaluation of actual plant process control data (using the Plant Data Historian as the data source) against the plant operating Design Base to identify deviations from Design Base. Figure 6–13 shows an example of how the performance comparison of actual versus Design Base values was done and trended in the boiler system area.

Analysis of controllable parameters was conducted over a period of 30 days per unit to determine how well key parameters are managed in line with the desired Plant Design Base parameters.

Figure 6–13: Boiler Actual Operating Control vs Expected Operating Design Base Control Value



6.5.3 Enabling Advanced Analytics in new Process Plant Technologies on the Operating Simulator Platform

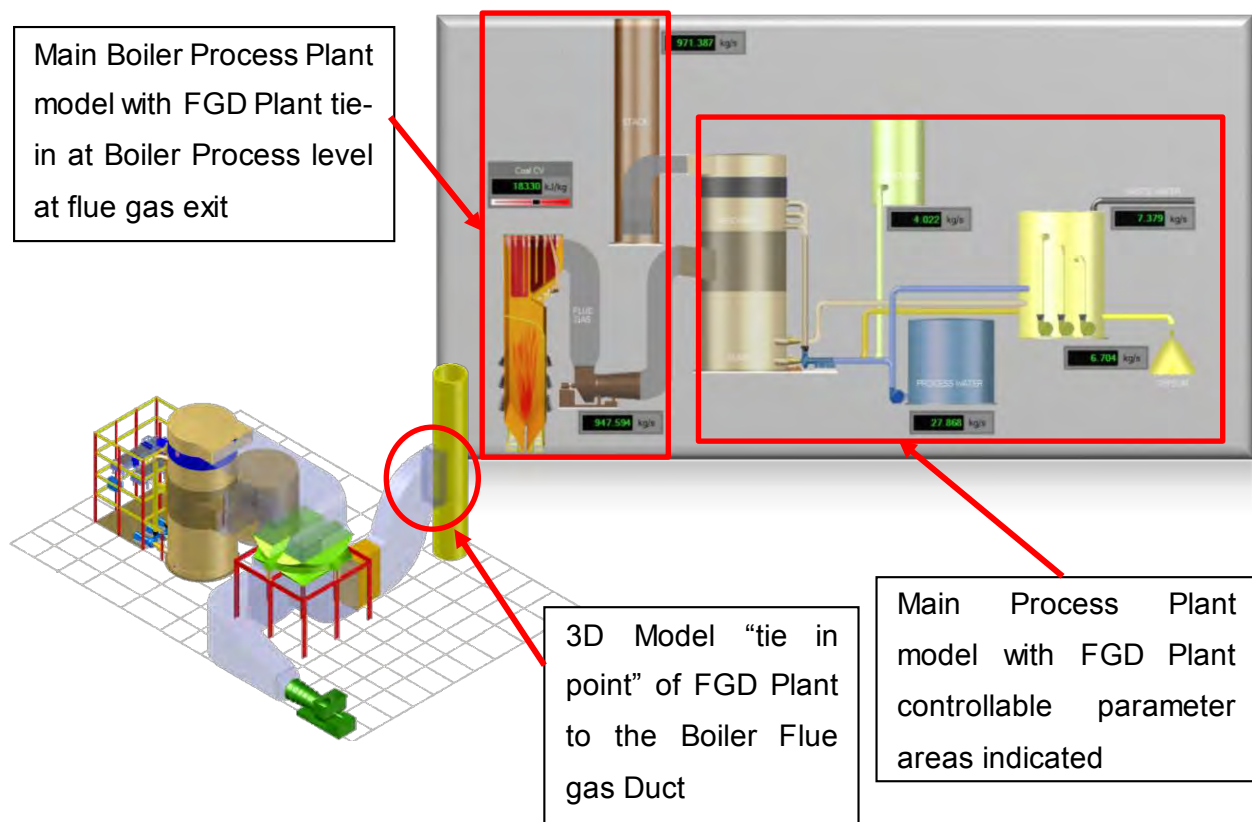
The prototype aimed to demonstrate the value of integrating plant process 2D simulation and analytical capability with the 3D Plant simulator model used for Operating Training on the Greenfields Project.

It was theorised that the prototype can be used to demonstrate to the Power Utility how advanced analytics technology can assist staff in understanding the new FGD Plant Process and related technologies better and to develop operating procedures and methods to manage this new technology capability in the best way.

As indicated, the Greenfields Project will be the first power station in the fleet to use FGD technology for particulate emission control, so little in-house operational knowledge/skills exist for this new plant technology being introduced.

Figure 6–14 depicts the high-level process design model of the Wet FGD plant technology. This process introduces chemicals to treat flue gas and to extract harmful particulates from emissions to the atmosphere. The figure also indicates the FGD Plant design integration point into the boiler exit flue gas ducting of the plant.

Figure 6–14: Layout and high-level visual process model of Wet FGD Plant



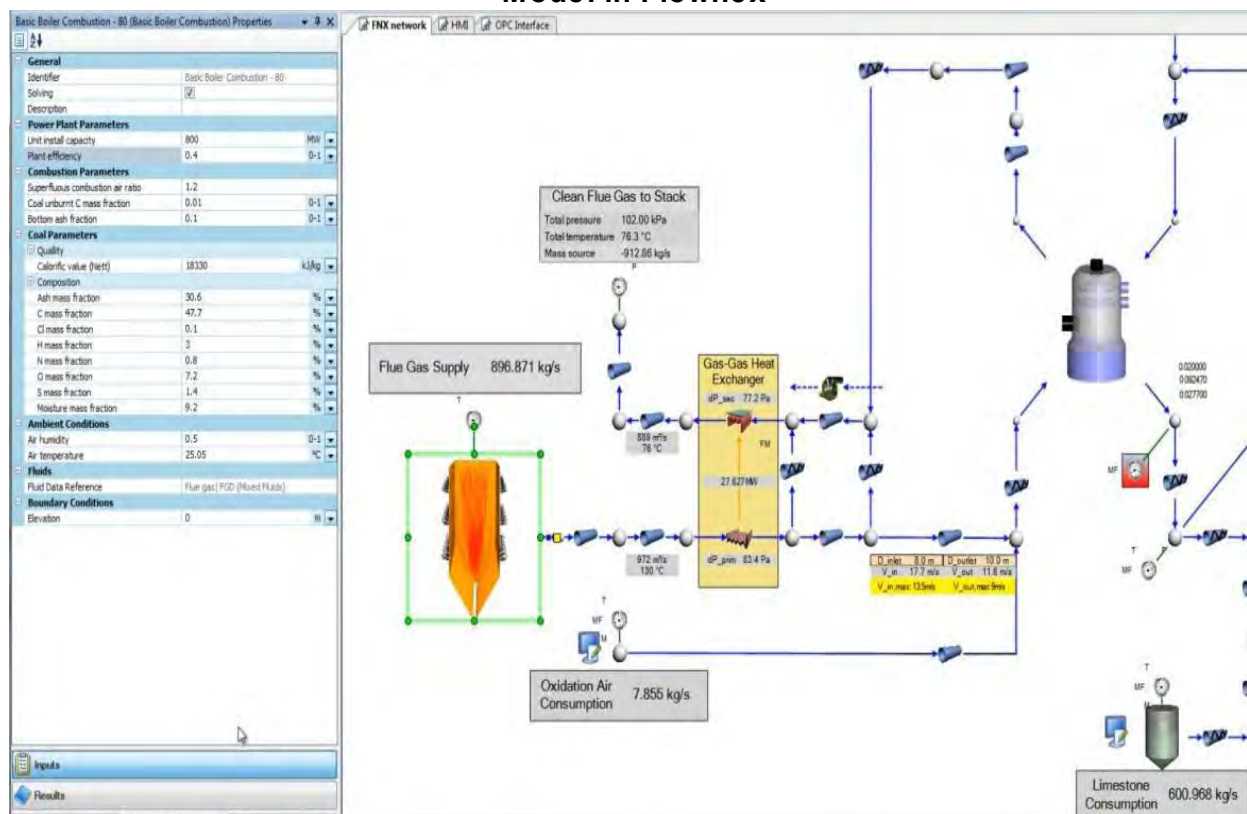
As indicated, the scope of research entailed defining the “controllable parameters” and enabling plant process simulation of changes made to these parameters for the Operating staff. The exposure of operating staff to this advanced analytics simulation would be via the virtual 3D Plant Operator Simulator.

Figure 6–15 shows the User Interface developed in the Flownex process plant simulation software that depicts these controllable parameters within a visual process model.

As this was the first-time technology implementation into the Power Utility fleet, this Flownex process model had to be developed from scratch as part of the research study scope of work. Once developed, this model can be used by Design/Reliability Engineers for advanced analytical simulation and analysis, usually to optimise the plant design or process.

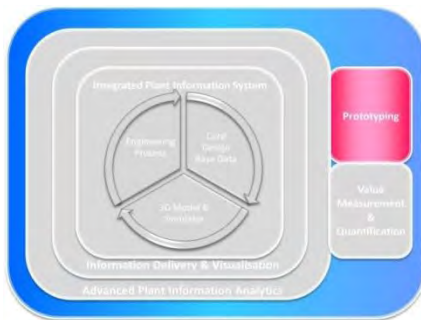
Once validated and verified against the FGD Plant Design Base and operating philosophy, the advanced analytics capability was integrated into the 3D Plant Operating and Engineering Simulator.

Figure 6–15: Controllable parameters enabled on the FGD Plant Process Simulation Model in Flownex



The successful integration of the Process Simulation model into the 3D Operating Simulator prototype was shared in Chapter 5 of this research study (See Figure 5–13).

6.6 Prototyping Results



The section covers the outcome of the various prototypes performed to prove the use cases defined to prove the benefit of introducing advanced analytics as a core element to the IPI-BIM Framework.

6.6.1 Use Case 1 Related: Plant Design Base – Operational Adherence

For the purposes of the research study, Units 1 and 4 of the Brownfields Power Station were selected to compare how well certain key process parameters could be controlled over a period of 30 days. Table 6-1 shows the level of adherence that could be achieved to the required operating controllable parameters.

Table 6–1: Evaluation of Managing Controllable Parameters in line with Design Operating Envelopes

	UNIT 1	UNIT 4
400–600 MW Range	90% Adherence	>98% Adherence
0–400 MW Range	75% Adherence	100% Adherence

Figures 6–16 and 6–17 show the dataset comparison between the two units over 30 days. Graphically, the difficulty of Unit 1 control of feedwater temperature and feed–water flow rates within the prescribed design operating envelopes are quite visible, with the operating values fluctuating significantly outside of the expected operating curve boundaries.

The higher level of operational parameter control within the required operating envelopes on Unit 4 is quite obvious, especially during the plant start–up phase.

Figure 6–16: Boiler Feedwater Temperature Control

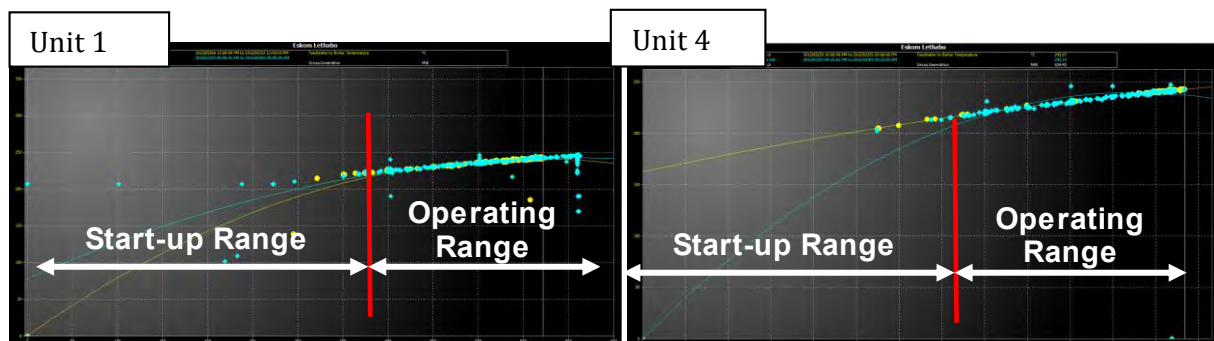
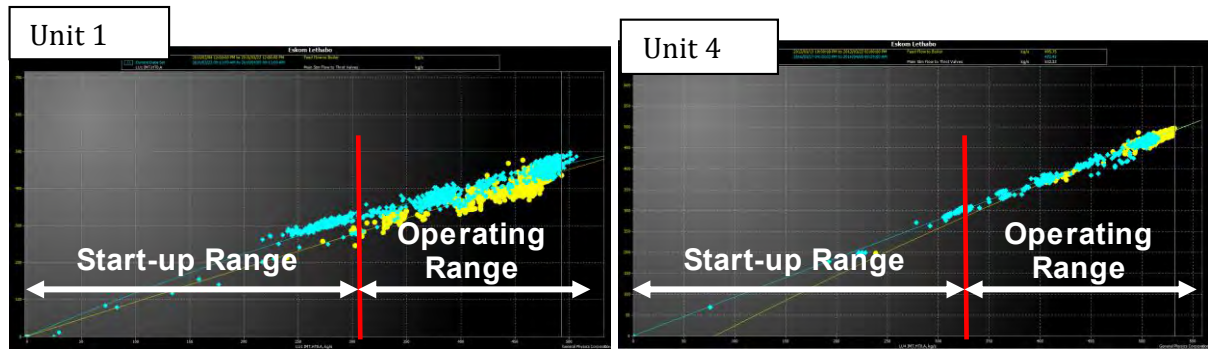


Figure 6–17: Boiler Feedwater Flow Rate Control

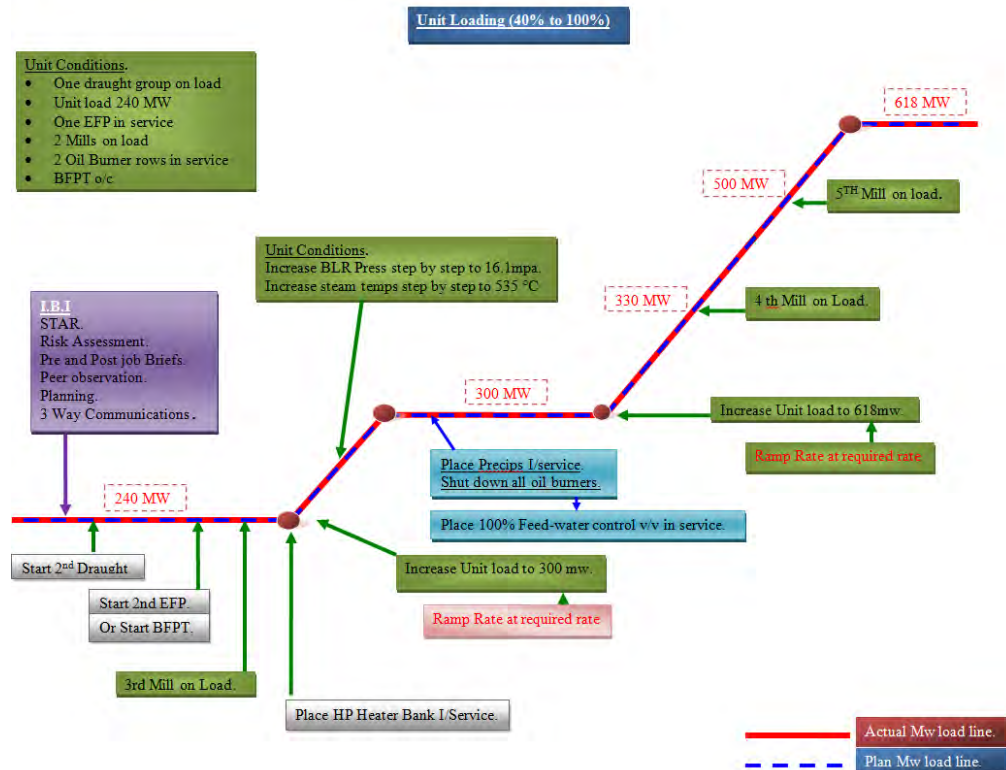


6.6.2 Use Case 1 Related: Operating within Design Base Operating Start-up Curves

Power plants are designed with very specific process loading and ramp rate curves. In order to extend plant life and minimise stress-related damage to plant equipment and components, it is ideal to adhere to these curves as close as possible.

Figure 6–18 shows a typical unit ramp-up operating curve (From 40% to 100% Maximum Continuous Rating [MCR]) developed under the research study for the Brownfields plant. This curve shows the ideal operating process, including meeting very specific plant criteria and “hold points” that have to be met before the boiler light-up can continue.

Figure 6–18: Unit Loading 40–100% MCR Curve – Parameters and criteria monitored



For the purposes of the research, Unit 6 ramp-up data was evaluated to evaluate compliance with loading steps and criteria hold-points. Key parameters evaluated during the ramp-up phase were:

- Excess Oxygen
- Main Steam Temperature Control
- Total Coal Flow Control
- Feedwater Flow Control
- Mean Steam Flow Control through Turbine Throttle Valves
- HP Main Turbine Condenser Pressure control

Evaluation of the data is summarised in Table 6-2 and shows the level of compliance with the operating controllable parameters and suggested plant process focus areas targeted for improvement:

Table 6–2: Evaluation of Adherence to Operating Envelopes

	Problematic Control	Acceptable Control	Desired Control
Excess Oxygen	X		
Main Steam Temperature Control		X	
Total Coal Flow Control		X	
Feedwater Flow Control			X
Main Steam Flow Control through Turbine Throttle Valves			X
Main Turbine HP Condenser Pressure Control			X

Figure 6–19 graphically shows how oxygen control is more problematic during ramp-up with the operator required to regularly intervene to align actual oxygen levels to desired control curve level. In contrast, the HP Condenser pressure was much better controlled and kept in close alignment with the desired control curve.

Figure 6–19: Problematic Oxygen Control vs Desired HP Condenser Pressure Control

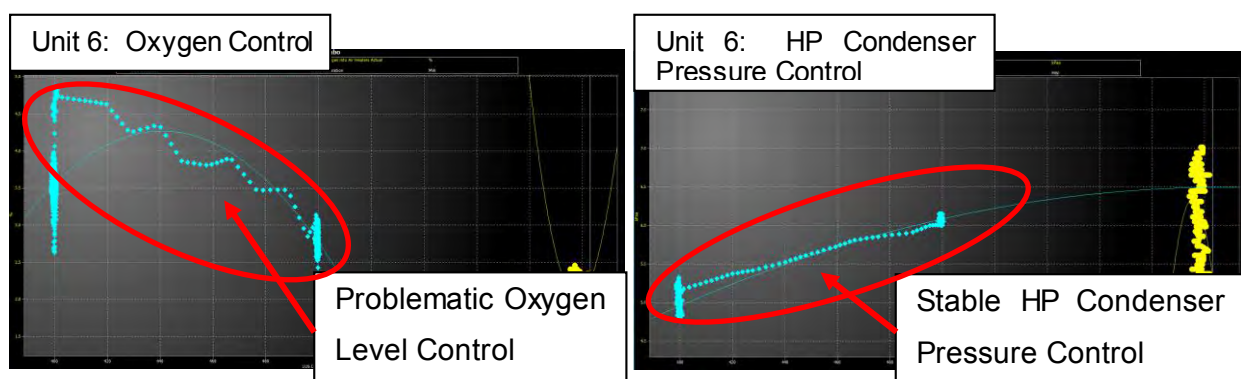
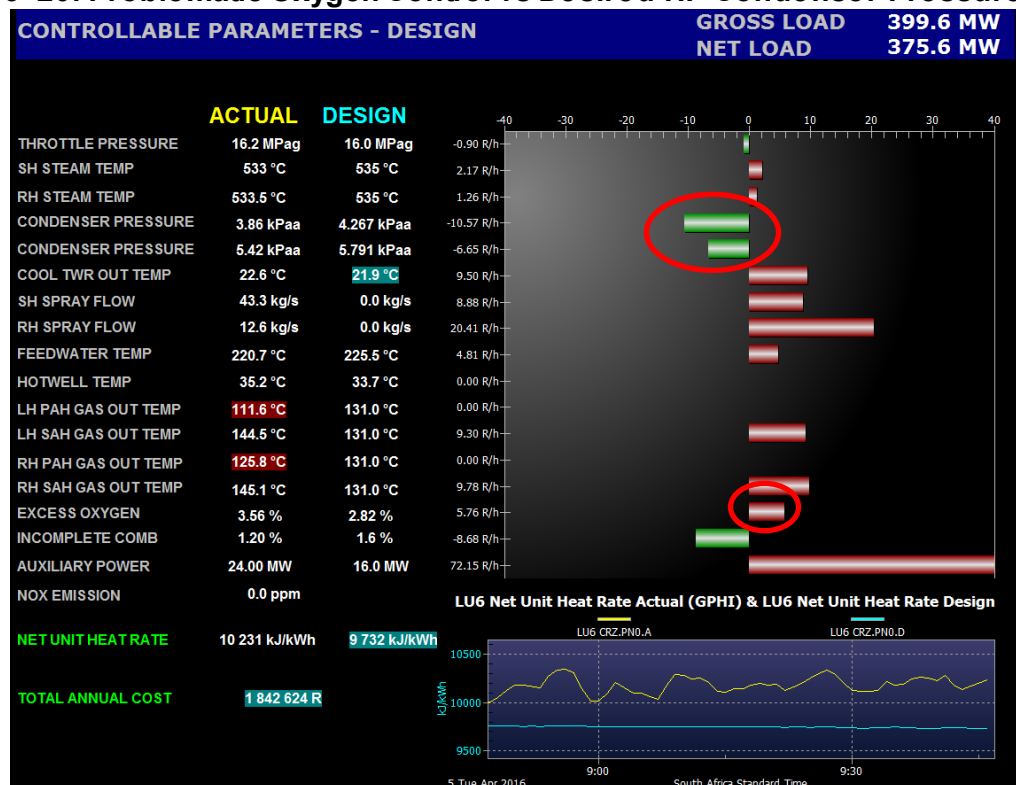


Figure 6–20 indicates the research–developed operator interface screen that provides the operator with a status indication of the controllable parameters and how well they are maintained when compared against design parameters. The problematic oxygen level control is visible (red item circle), as is the good condenser pressure control (green items circled).

Figure 6–20: Problematic Oxygen Control vs Desired HP Condenser Pressure Control



6.6.3 Use Case 2 Related: Impact of Optimal Design Base Deviations/Integrity Challenges

The prototype evaluated the impact of using the two electrically driven feed pumps 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 for normal operations.

Furthermore, the original plant Design Base was the use of steam–driven feed pumps (SFP's) for both normal as well as stand–by duty, but the final implemented design configuration was one steam turbine driven feed pump with two electrically driven feed pumps as a backup in emergencies when this main pump is not available.

The impact of this decision on available output generation and GTCHR is significant – higher fuel consumption for 20 MW less electrical output to the Utility Grid network as can be seen in Table 6–3. In a capacity constrained environment with high primary energy cost (as is currently the case), it would not be ideal to run the EFP's if at all possible due to this impact on output.

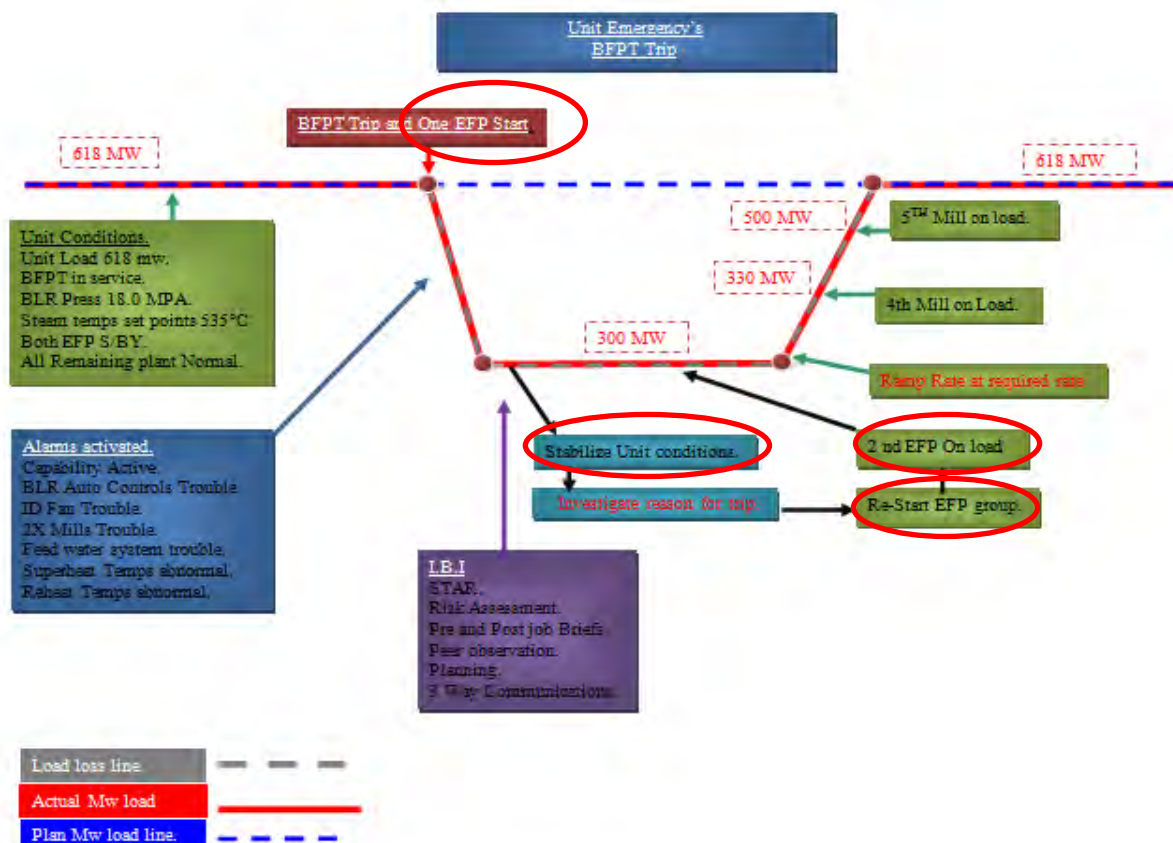
Table 6–3: BFPT vs EFP Feed–water Supply Impact on Generation and Heat Rate

	Gross Generation (MW)	GTCHR (Btu/kWh)
BFPT providing feed–water to Boiler (Ideal Design)	619.384	7,683
EFP's providing feed–water to Boiler	604.309	7,876

Not only did this Design Base decision affect the plant efficiency when the power station is forced to revert to standby equipment (e.g. when the SFP need to be taken offline for maintenance work), but it also affects the control philosophy and the time it takes to return a unit to full load.

The Loading curve (Figure 6–21) shows how the operating philosophy dictates that first one EFP must be put in service, then the plant operations must be stabilised running at this half-load condition before a second EFP can be introduced. This reduces the opportunity to return the unit to full load state faster.

Figure 6–21: Loading Curve to Restore Unit to full load after BFPT Trip



To show the impact on overall plant process efficiency when it operates below the optimal operating Design Base conditions, the research study evaluated the impact of reduced equipment efficiency – e.g. when plant operational issues like condenser fouling and ageing (efficiency loss of components) are brought into the analytical model.

Table 6–4: Evaluation of HP Heater Fouling on Feedwater Temperature and Heat Rate

	Feedwater Temperature (°C)	GTCHR (Btu/kWh)
No Fouling	478.82	7,683
One HP Heater with 40% Fouling	474.11	7,692
2 HP Heaters with 40% Fouling	472.1	7,700

Table 6–4 shows how the boiler efficiency is reduced by the introduction of feedwater at a significantly lower temperature (due to the heaters operating below the designed efficiency due to heater tube fouling). Because of this, more fuel is required for the boiler to generate steam at the required temperature that will maintain the generator output at the desired Design Base MCR Output.

The simulation outcome confirms the importance to maintain plant equipment and systems in optimal condition in order to manage reliability and efficiency. It also demonstrates the importance of considering equipment condition deterioration and plant ageing when building advanced analytical models with which technical performance decisions will be made.

Table 6–5 indicates the analytical outcome when evaluating the impact of losing an HP Feedwater Heater (or entire HP Heater range) out of the overall plant process (the HP heaters are used for boiler feed–water heating). It supports the view that timeous failure prevention is the ultimate means of ensuring consistent plant reliability and availability.

Loss of HP Heaters is deemed significant loss of key equipment in the steam cycle, resulting in much more input fuel required to maintain the MW output to the electrical grid network. Any scenario where fuel supply is constrained to the power station will result in a significant drop in output to the national grid.

Table 6–5: Evaluation of losing HP Heaters in the Process

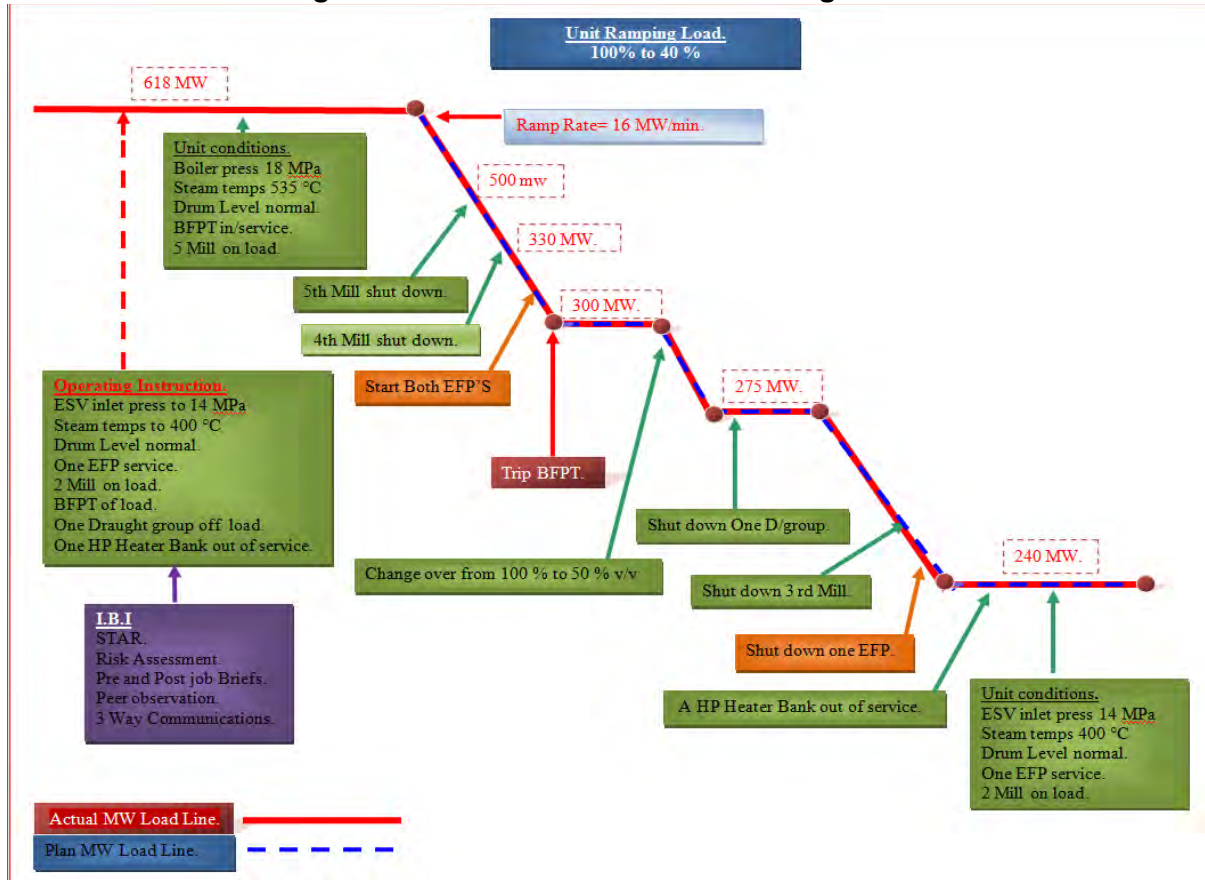
	Feedwater Temperature (°C)	GTCHR (Btu/kWh)
All HP Heaters in Service	478.82	7,683
1 HP Heater Lost	452.741	7,729
2 HP Heaters with 40% Fouling	412.355	7,819
All HP Heaters lost (Back–up heaters not available to put into service)	343.526	7,938

Again, the operating simulator could be used to recreate these anomalies and confirm the advanced analytics findings. Close correlation between actual plant behaviour, response and output was found between the simulator, plant control system data and the virtual plant model in etaPRO.

6.6.4 Emerging Patterns indicating Failure Triggers

Figure 6–22 below show the typical operating curve that has to be followed if there is a need to reduce output from 100% to 40% MCR Load. This curve shows the key parameters that need to be monitored. To prove the hypothesis, a number of operating and control system data sets were sourced for a scenario where the unit had to be de–loaded.

Figure 6–22: 620 MW Unit De–loading curve



These data sets were then evaluated in conjunction with the other plant control data points to determine if there were any emerging patterns where early plant upset triggers can be identified. Table 6–6 depicts the evaluation of the trend patterns evaluated. It confirms that if the plant behaviour patterns are understood, that failure models can be developed off the plant Design Base that can assist the operator to identify risk to plant operations and taking remedial actions earlier.

Table 6–6: Evaluation of early failure warning detection capability

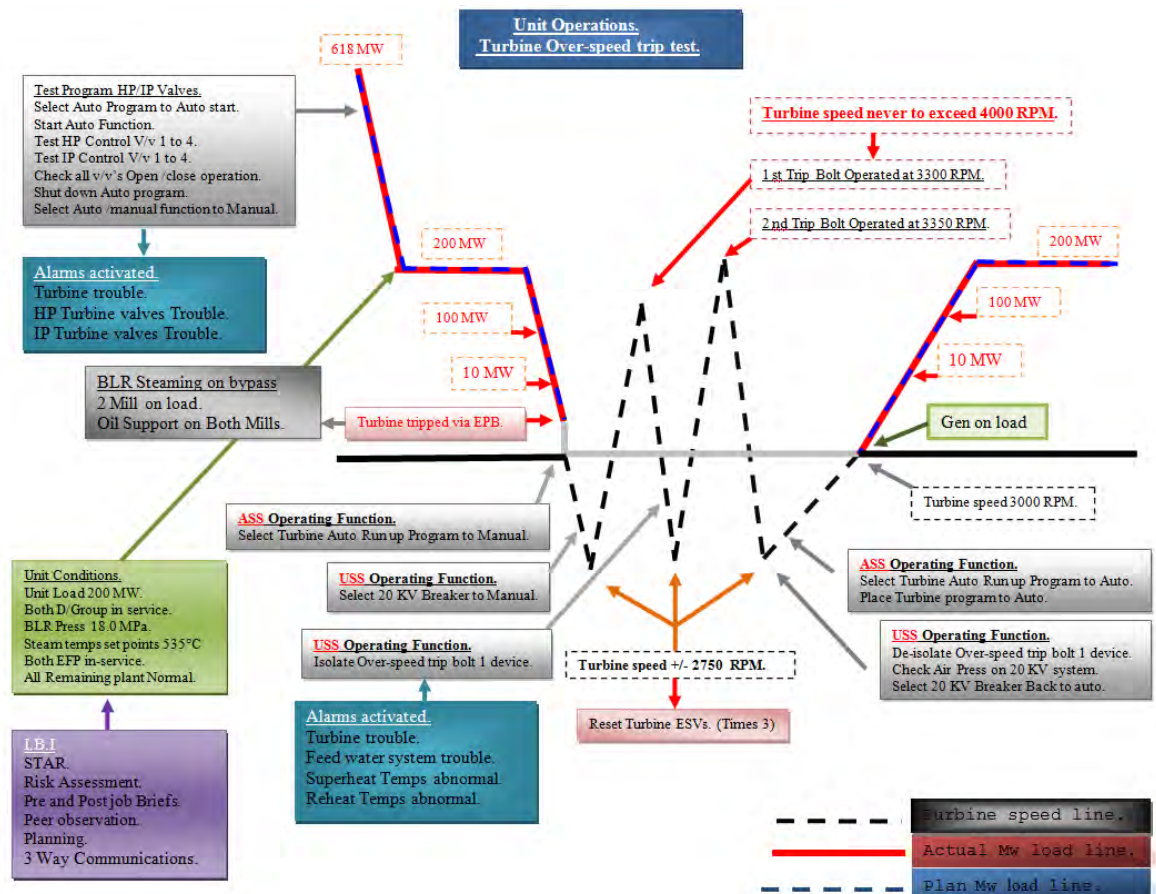
	Data Set 1	Data Set 2	Data Set 3	Data Set 4
Expected Behaviour observed	Yes	Yes	No	Yes
Specific patterns noted	Yes	Yes	Yes	Yes

Development of such failure modules is deemed a research scope of work in its own right and the aim of this research study was not to develop these failure modules. The research succeeded in the aim to demonstrate that trending and evaluation of plant data do indicate the opportunity of earlier predictive failure models to enhance plant reliability and availability as a means to improve business operations.

6.6.5 Use Case 3 Related: Operational Compliance to Design Base Test Conditions

Figure 6–23 depicts the operating curve for one of the statutory tests to be conducted in the Brownfields Plant, i.e. the “Turbine Over–speed Trip Test”. This figure depicts the typical plant behaviour expected during execution of the test, the alarms that should be activated (with an alarm response procedure to support action to be taken when it activates) and the load stabilisation profile expected. Poor control of the curve will result in the Actual MW load line (indicated in red) deviating from the planned load line (indicated in blue).

Figure 6–23: Turbine Over–speed Test ideal plant behaviour curve



Four data sets of instances of over–speed turbine trip testing were evaluated to confirm whether operating adhered to the typically defined test curve. The results are indicated in Table 6–7.

Table 6–7: Evaluation of Test Efficiency according to expected plant behaviour

	Data Set 1	Data Set 2	Data Set 3	Data Set 4
Adherence to overall curve	Yes	No	No	Yes
Adherence to taking control steps at specific operating points	Yes	No	Yes	Yes

In the case of Data Set 2 where the required control steps were not taken (Over-speed Trip bolt 1 device not de-isolated in time), the load output deviated from the expected behaviour, the turbine tripped and eventually had to be shut down as the boiler could not be maintained in bypass mode for an extended period of time.

For Data Set 3, a fault in the control module resulted in the Turbine Auto Run-up Program not automatically kicking in after the test, and the unit had to be returned to full load in manual control mode.

Research data analysis and evaluation confirmed that it is possible for Operations staff to maintain optimal test conditions to minimise damage to plant and equipment during these high-stress conditions. Fault analytics of the cases where this expected outcome was not achieved, allowed for remedial action to be taken, e.g. operator training was enhanced to ensure that the required actions are taken in time.

6.6 Research Findings Summary

6.6.1 Advanced Analytical Methods Used

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 were found to cover all 3 types of analytical techniques – descriptive, predictive and prescriptive [Lustig et al., 2004].

6.6.2 Core Design Base Suitability for Advanced Analytics

The advanced analytics and plant process modelling/simulation portion of the research study confirmed that the identified core Design Base set was sufficient for the research scope of work.

The importance and impact of trusted and reliable plant Design Base data and information were very effectively demonstrated in this research study. This confirms the importance of data reliability validation when it is used for analytical purposes and decision making. Compromised data quality and data capturing capability will have an adverse impact on the outcome and results of plant simulation and analytical performance models.

The core Design Base data-set could be successfully used to identify and demonstrate opportunities for business improvement using the integrated plant information system platform and information visualisation capabilities of the IPI-BIM Framework.

The research demonstrated that certain potential failure patterns can be predicted earlier on in the failure lifecycle. It further confirms the statements from other researchers in the literature survey conducted of **the importance to fully understand the plant process and behaviour before attempting to build analytical or simulation models for business improvement.**

6.6.3 Benefits of Advanced Analytics for Plant Operations

Operating staff were exposed to the research findings confirmed that having access to scenario modelling will significantly enhance their ability to improve plant operations. Operator training interactions were significantly enhanced as the consequence of certain actions can be demonstrated much more effectively with the simulations, without the risk of damaging actual plant assets in trying to demonstrate this.

The Greenfields Project will deliver the first coal-fired plant in South Africa with FGD technology enabled. As such, very little information is available on the operations and control of this technology within the larger Rankine process plant model. The FGD Plant analytical model and simulations have been found to be of immense value to both operators as well as engineering staff in the utility, who can use these models to determine the impact of changing plant parameters and control methods on the efficiency of the technology.

By developing a simulation model, a training solution could be delivered to the Greenfields Power Station operating team where they could familiarise themselves with the technology and create scenarios to evaluate the impact of changing plant and process conditions on the FGD process efficiency. Advanced analytics can be used to effectively assess operating practices to identify opportunities to improve plant operating practices.

The developed FGD model can also be used to analyse future designs of this emissions control technology should it be implemented on some of the Utility's Brownfields plants.

In Chapter 5, the advanced analytics capability was successfully enabled into the operating simulator 3D plant model. In order to protect the integrity of the plant process model, only allowable operating parameters were made available for operating and engineering staff to evaluate changes in operating conditions and the resultant impact on desulphurization efficiency.

The information integration was extended to Design Base elements in the Integrated Plant Information System platform allowing an operator to interrogate the Design Base via the 3D model to obtain more information on plant components to assist with decision making.

6.6.4 Effects of Ageing Plant and Deteriorating Plant Conditions on Analytics of Plant Performance

The research demonstrated how ageing of plant and deteriorating plant conditions have a significant impact on reliability and availability, and how these aspects should be considered in the development of failure analytical models. The negative impact of these conditions on plant output (MW), as well as process manufacturing input costs, was demonstrated, underlining the importance of good maintenance strategies to maintain the plant in the best possible condition.

The research demonstrated the ability to use advanced analytical models and simulations to assist the operator in monitoring and controlling test conditions within the boundaries of the Design Base. The research outcomes were used to enhance the operator simulator-based training.

The research demonstrated that potential failure patterns can be predicted earlier on in the process and confirmed the finding (and recommendations) from other researchers who indicated that it is *mission critical* to fully understand the plant process before attempting to build analytical or simulation models.

6.6.5 Advanced Analytics as a Core Element to SmartUtility Strategy Execution

By understanding the requirements for analysing large plant control data sets and honing in on the controllable parameters during failure analytics, the research demonstrated the significant potential value of modelling failure behaviour patterns and identifying early failure triggers in the failure event sequence.

Failure model development is deemed a specialist research study scope in its own right. Developing the full failure model set for a power station would be a significant research study undertaking and an ideal candidate for a future doctorate level research.

By demonstrating the benefits and value of advanced analytics to the Power Utility in an operational and practical manner, its importance as a critical and key engineering capability in the SmartUtility Strategy execution plan was confirmed [Hales, 2013].

6.7 Conclusion

Using the principles of Angeli's model [Angeli, 2004], the research study proceeded to demonstrate with Predictive and Prescriptive Analytics methods how advanced analytics software, process simulation and fault models can be used to:

- Measure efficiency of current operating practices against Operating Design Base.
- Demonstrate that improved early warning failure detection is possible using big data analytics and methodology to analyse plant operating and control data.
- Measure efficiency of operations during upset and test conditions of the process plant.

The Advanced Analytics have provided significant insight to reliability engineers to understand the impact that aspects like an ageing plant, deteriorating plant conditions and Design Base modifications can have on plant availability, reliability and associated operating curves and control parameters. The advanced analytics were also successfully enabled in the 3D information delivery and visualisation platform (Chapter 5).

Advanced Analytics could be used to effectively assess operating practices to identify opportunities to improve plant operating practices. The analytical models developed in the Advanced Analytics tool (etaPRO™) proved that it is possible to create a sustainable, well documented and controlled platform to confirm the validity of reverse engineered Design Base data (using validation data triangulation methods and 3-way system validation).

By identifying these plant control areas of improvement, the research study collaborated with the site simulator operator training group to address these issues. This has resulted in the prevention of at least two load loss incidents due to incorrect oxygen level control and timeous correction by the operator of the plant condition (Table 6–8).

Increased focus on plant health conditions and better operating of the plant has increased the station efficiency from 74.6% to 84.6% over the past 3 years.

Table 6–8: Preventing Load Losses with improved Operator Training

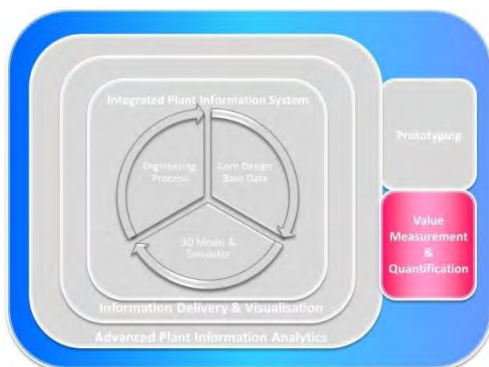
PRODUCTION OUTPUT LOSS PREVENTED	COST BENEFIT
Load Loss due to incorrect plant operations, 620MW Unit	R4,493,760/day
Unit Trip due to incorrect plant operations, 620 MW Unit, return in 4 hours	R748,960

Enablement of visualisation and simulation capability on new technology also enabled the Utility to improve its training program for Operator staff. The FGD Plant analytical model and simulations have been found to be of immense value to both operators as well as engineering staff in the utility, who can use these models to determine the impact of changing plant parameters and control methods on the efficiency of the technology.

Research outcomes delivered are in use on the Greenfields Project for training purposes and allow for design options evaluation and scenario simulations that improve design efficiency and quality of the design end-product delivered.

A major value contribution of the research study was the long-term business benefit of having the fundamental FGD Plant process design developed in the advanced analytics simulation system. Due to environmental legislative requirements, the Power Utility will be required to replace or **introduce more emission control technology on all the power stations in its fleet, and this process technology and design analytical model developed by the research can be used to perform the basic design for proposed FGD plants at these Brownfields Power Station Plants.**

THE IPI–BIM FRAMEWORK VALUE PROPOSITION



Research shows that improved information management of the operating Design Base; integration of this information asset with plant process control data and using it for daily operations have significant savings from a productivity and economic benefit point of view [Emerson, 2003].

Chevron shares the view that the value proposition can be found in improved asset management, design and construction capability. [Watson, 2010] Further value is added by enabling safer operations practices and improvements in plant reliability and efficiency.

Emerson reports the savings achievable by implementation of an integrated information management system and combining it with improved plant control and process monitoring and advanced analytics capability. Their reported savings are based on feedback received from clients who implemented their IPI System technology and quantified the return on investment [Emerson, 2003].

7.1 Value Proposition Hypothesis

Hypothesis 9: The IPI–BIM framework will provide a significant enough value proposition to be a viable implementation, either in portions or as a holistic framework.

Given the reported cost saving opportunities identified by the research literature survey, it was hypothesised that the IPI–BIM Framework and Implementation Methods proposed by the research study could yield the same and even more benefit. Contrary to other business improvement models, the value proposition model forms part of the overall IPI–BIM model.

The research strategy aimed to demonstrate that the value proposition of the IPI–BIM Framework and implementation approaches lies with business drivers that will define and quantify the value that can be realised implementing the IPI–BIM. Typical business drivers and factors are described in 7.3.

7.2 Value Proposition Model Development

7.2.1 Basis of the Value Proposition Model

The research theorised that a business–driver related cost model would be the most accurate means of defining the value proposition of the IPI–BIM Framework and implementation approaches. By using actual scenarios from the two plants forming part of the research study to determine the impact of not having the required plant information available for decision making, and quantifying the cost impact of these scenarios, will add credibility to the accuracy of the cost calculations made.

Typical scenarios considered in the development of the Value Proposition Model was the IPI–BIM Framework benefits of improved and optimised operator training and inspection activities, better safety training and job safety analysis, optimised outage planning and improved efficiencies in construction and commissioning activities.

To prove the value proposition, a value measurement framework was devised by the research study – developed in a spreadsheet format with the required calculation formulae. The spreadsheet contains a more detailed definition of the benefit (business driver) area, assumptions made (or scenario used), the formulas used, the actual calculation and finally the reasoning behind the value contribution (if it had to be defined in more detail).

7.2.2 Core Principles in Defining the Value Proposition Model

The IPI–BIM cost model introduced common adjustable variables and a “cost saving probability factor”. A massive (and potentially unrealistic) value proposition is possible if the “worst case scenario” for each proposed scenario is considered and used. By implementing a probability factor, the benefit value (or “saving”) can be detuned to more realistic values.

For the purposes of calculation and consistency, a 15–year costing lifecycle was considered. This is the typical average timeframe for an information system to be in production before enhancement, significant upgrades or migration to a new technology platform would be considered.

The cost benefits calculated included an indicator whether it could be deemed a “once off cost–benefit” or something that can be annualized.

Certain benefits were calculated as something that can be achieved across the entire Power Utility power station fleet, in which case calculated values were averaged by dividing the benefit by the number of power plants operational in the fleet (i.e. 27 power stations).

The research evaluated information from within the Power Utility to quantify such benefits. For O&M Asset lifecycle cost saving scenarios, the Brownfields plant operational capacity, costs, failure history and resource value calculations were used. The research evaluated actual scenarios that occurred at the Brownfields Plant or were documented in plants of similar size and construction in the Power Utility fleet.

For EPC Cycle/commissioning related cost savings, the Greenfields Plant operational capacity and construction cost history were used. Actual cost and impact scenarios from the Power Utility new asset creation construction program were utilised for cost definition and quantification.

7.2.3 Standardisation Elements within the Value Proposition Model

Standardised costing and value measurement criteria had to be defined to correctly calculate the production availability value and to retain consistency across the fleet (if the cost calculation sheet is to be used within the utility for business case purposes).

For stakeholder and business case purposes the value proposition calculations were assigned to high level “savings areas” directly aligned to the business drivers listed in 7.4.

Once calculated, the potential saving was aligned and allocated to the high-level business driver areas. It should be noted, however, that the MSExcel spreadsheet generated is adjustable and allows for expansion and inclusion of multiple power stations or more business driver areas if needed.

By creating an adjustable formulae input, the Value-proposition model can cater for specific process plant cost inputs and unique plant history, environmental and socio-economic conditions, making its application relevant beyond just power plant environments.

7.3 Production Cost Input Impact on the Value Proposition Model

Cost savings were initially quantified against the research study brownfields 3,600MW Plant business case. The business case created in 2005 was validated in 2008/9 after 3 years of IPI System Platform use in a production environment to evaluate the benefits realisation of the Project undertaken. At the time, the cost of production was around R100/MWh.

After considering the notable production cost increases reported by the Utility over the past 3 years (Table 7–3), it became clear that the model had to be adjusted to 2015/6 production cost values to give a true picture of potential cost savings.

The Utility projection for the next 5 years indicates that average production cost will continue to increase significantly, further supporting an upward adjustment of production cost values in the Value Proposition Model calculations. Based on the volatility of this input value, the IPI–BIM value proposition model also proceeded to define Production input cost as a common adjustable variable.

7.4 Value Proposition Model – Business Drivers

The Value Proposition Model drivers were aligned to the research study outputs as far as possible (as the primary aim was to prove the value proposition of the IPI–BIM Framework). The cost saving calculations and scenarios were grouped and summarised in line with the following business drivers:

7.4.1 Regulatory Compliance and Risk Management

The Value Model considered the impact of non–adherence to regulations and other legal requirements for both Greenfields Projects and Brownfields Plant.

7.4.2 Safety and Health of Staff, Contractors and the Public

The significant short to long term impact of disabling injuries or health issues on staff, contractors, and the general public makes it an imperative to design, construct, operate and maintain the plant in a manner that minimises any negative impact on people over the asset lifetime. In addition to the direct cost of DI's and fatalities, the negative media coverage associated with such events significantly impacts the organisation's brand and investor perceptions – thus something to be prevented as far as possible.

7.4.3 Safety and Health of Staff, Contractors Operational Efficiency and Cost Management

The Value Proposition Model will consider the benefits of improving and optimising operations as well as operator training utilising the various elements delivered under the IPI–BIM Framework and prototypes. Poor Design Base management practices create issues with statutory/regulatory compliance and impact the safe management of plant operations.

7.4.4 Environmental Management and Compliance

Increased focus on environmental compliance requires a focus on maintenance, operating and plant design practices that will ensure plant operations within the required environmental legislation and limits. The Utility over the past few years has had considerable load losses because of an inability to operate plants within the environmental limits imposed by CAPCO.

7.4.5 Inventory and Supply Chain Management

The Value Model evaluated business improvement scope in Inventory and Procurement Management practices. For the Brownfields Plant, it covered the ongoing spares inventory management scenarios, while the impact of constraints in construction material supply and the potential savings if construction materials on Greenfields Projects were quantified. Issues like construction wastage were also considered.

7.4.6 Technical Performance (Plant Reliability and Availability)

The Value Model referenced business improvement opportunities regarding plant availability and reliability extensively. Poor management of Design Base aspects like the plant operating and maintenance baselines will create significant cost impacts if not addressed or managed. There is significant value for the business to have plant assets that are more reliable and available.

7.4.7 ICT and Infrastructure Cost Savings

Most complex production plants require significant ICT and related infrastructure to manage the data generated and to control/operate the plant. Improvements in ICT and infrastructure lends itself to significant cost saving opportunities if a more consolidated, standardised and integrated infrastructure can be created to manage all the data and information needed to make decisions on the plant and utility fleet.

7.4.8 Engineering Capability and Productivity

The Value model considered criteria in both the Greenfields and Brownfields plant scenarios. During the Greenfields phase, more design engineering capability is required and the impact of inefficiencies in the design and Design Base change control process result in significant project delay and design cost increases. For Brownfields plants the cost of poor engineering practice will show in increased equipment failure rates while the lack of the required Design Base information will significantly impact the productivity and decisions making capabilities of system engineers.

7.4.9 Maintenance Efficiency and Cost Containment

The Value Proposition Model considered scenarios where the use of improved plant information data and Design Base content can improve maintenance strategy, practices, and procedures. As the Greenfields project is still under construction, the Brownfields Plant failure history and costing were used to do the required quantification and calculations.

7.4.10 Construction and Commissioning Efficiency

Commissioning Effectiveness and Efficiency aspects in both Greenfields and Brownfields scenarios were evaluated, as commissioning of the plant occurs regularly on a Brownfields plant as it is taken in and out of service and/or undergoes extensive repairs (outages and shutdowns). For the Greenfields plant, the value contribution of optimising the extensive process of plant commissioning in the correct sequence and preparation of plant and information/data for handover to the Owner/Operator client was considered.

7.4.11 Knowledge and Human Capital Management

A number of researchers list the impact of not managing available human capital and skills in the best manner. The Value Proposition Model considered a number of scenarios to evaluate the impact of this.

7.4.12 Non–Monetary Value Proposition

Although the drive was to quantify monetary value, there are considerations around company brand management, legal/statutory compliance, public perception, environmental issues and risk management impacts that can also support the value proposition of the IPI–BIM Framework.

Although not quantified or listed in extensive detail in the Value Proposition Model, the impact of these issues as business improvement drivers should not be under–estimated or excluded from business cases justifying the implementation of the IPI–BIM Framework.

7.5 Cost Model Inputs

This portion of the chapter discusses some of the key cost model inputs where changes to the utility business environment had a significant impact on how it was used.

7.5.1 Power Utility Production–Related Costs

Tables 7–1 and 7–2 demonstrate the major impact power generation input production cost increases have had on the Power Utility over the past eight years. Table 7–1 indicates the cost impact of plant capacity loss scenarios in 2008.

Table 7–1: Typical Cost of Scenarios (2008)

Scenario	Typical Cost
Unit Trip (and able to return within 4 hours of the trip)	R240,000/incident
Load Loss due to issues where return is not possible within 4 hours (return within a day)	R1,290,000/day

The significant impact of increases in the input production cost becomes very evident when the same business case scenarios are calculated using 2015/16 production costs (Table 7–2).

Table 7–2: Adjusted Typical Cost of Scenarios (2015/6 Cost Reflectiveness)

Scenario	Typical Cost
Unit Trip (and able to return within 4 hours of the trip)	R724,800/incident
Load Loss due to issues where return is not possible within 4 hours (return within a day)	R3,973,200/day
Construction Downtime (plant unavailability due to delayed commissioning of plant)	R48,000,000/day

Note: A 5% CPI/inflationary adjustment per year was done to indicate 2015/6 cost

The Power Utility anticipates that these average Production Costs will increase even further (as taken from the Eskom 2014 Annual Report) reflected in Table 7–3.

Table 7–3: Average Production Costs (Historical and 5–Year Projection) [Eskom, 2013/4]

Production Cost (R/MWh)	2013 Actual	2014 Actual	2015 Proj	2015/ 2016	2016/ 2017	2017/ 2018	2018/ 2019	2019/ 2020
Coal	218	243	267	302	318	354	370	403
Nuclear	33	90	38	46	51	59	70	62
OCGT	2,652	2,917	3,813	2,458	3,049	3,235	3,567	3,835
IPP	836	898	1,555	1,698	2006	2223	2,271	2,414
Import	270	352	352	384	330	350	371	393
Overall Average	249	286	322	362	394	415	453	489

Due to the excessively high cost of OCGT and IPP production, it will not be considered in the cost calculations nor used to define the average production cost. Given that Coal production makes up more than 80% of production capability, the 2015/6 cost of coal production (i.e. R302.00/MWh) will be used for calculation.

Only in cases where scenarios evaluated were known to result in maximum/emergency generation due to plant unavailability, will the cost of emergency generation be used in the spreadsheet for calculating the full scenario cost in the Value Proposition cost model. Where lost production capability resulted in the use of OCGT/IPP, the average cost of the two technology capabilities will be used (i.e. R2,078.00/MWh).

7.5.2 Other Cost Elements

For human resource cost assignments, the average cost to the company for engineering staff (“Engineering Charge–Out Rates”) was used considering an engineering staff range from T9 to P18 in the HR TASK Grading schema.

The decision to limit the TASK grading range was based on the fact that this range covers the typical grading level for engineering resources involved in **actual** engineering work outputs – very seldom would executive level resources or staff at lower levels than T9 be used for engineering related activities.

Cost, production output losses and event duration data (e.g. plant downtime duration) were sourced from the Brownfields Power Plant (3,600MW) to demonstrate actual cost savings achievable in a real production environment.

Such costing information was compared to the typical information provided for both proven as well as potential cost savings areas as indicated by the research and literature survey in this phase. This was subsequently compared to history, data, and information from within the Utility to determine the level of correlation and to confirm similar challenges and experiences.

7.5.3 Probability Factor

As previously indicated, a probability factor was introduced into the Value Proposition cost calculation model. By implementing a probability factor for scenario calculations, the value (or “saving”) can be detuned to more realistic values. The Factor assignment and decision–making criteria are indicated in Table 7–4.

Table 7–4: Probability Factor Definition

Probability Factor	Factor Used if it	Factor
High	Has occurred regularly and often across the fleet	0.9
Medium– High	Has occurred, but with less frequency across the fleet	0.8
Medium	Has occurred, but only on certain plants/units	0.7
Low–Medium	Occurs randomly and not considered a regular scenario	0.5
Low	Occurs seldom, not likely to occur often, or not occurred yet	0.3

7.5.4 Industry Cost Saving Benefits – Relevance Considerations

Although the literature survey evaluated and listed research findings and cost saving/benefit conclusions from very varied business industries, the commonality of maintenance, engineering and operations practices and approaches makes the data relevant and useable within the Utility environment.

Similarly, application of the Value Proposition Model to a different industry/process technology may require only minor adjustment, e.g. the calculation and use of different production cost input values and/or the implementation of a reduced “probability (or applicability) factor” to downgrade the potential “value” of the cost saving.

7.5.5 Use Cases to Support Value Proposition Calculations

Development of the calculation framework considered and evaluated cost savings options directly related to the overall IPI–BIM Framework Model deliverables. This ensures relevance of this research study and the value proposition it proposed to business.

Using this research study and the various prototypes undertaken to prove the IPI–BIM Framework elements, demonstrated the practical use of the deliverables achieved to assist in quantifying the real as well as potential cost savings in the high–level business areas identified.

This was enhanced with additional information and cost benefits achieved using actual scenarios where improved plant information and Design Base management resulted in cost savings and improved operations in the Greenfields Project and Brownfields Plants.

7.6 Value Proposition Model Development Outcome

A value measurement framework was developed in a spreadsheet format with the required calculation formulae. The value proposition calculations were assigned to high level “savings areas” directly aligned to the business drivers listed in 7.4. Table 7–5 indicates all the value model use cases identified, and not all of these scenarios may be achievable in one single plant.

Table 7–5: Overall Full Value Proposition – All Drivers linked to IPI BIM Model Elements

Potential Cost Savings (15 Year Lifecycle)		
Construction and Commissioning Efficiency	R	483 719 472.40
Construction/Commissioning Cost Containment	R	269 705 573.36
Engineering Capability and Productivity	R	1 106 905 951.80
Environmental Management and Compliance	R	189 129 312.00
ICT & Infrastructure Cost Savings	R	188 117 135.12
Inventory & Supply Chain Management	R	99 188 332.00
Knowledge and Human Capital Management	R	432 365 768.97
Maintenance Efficiency and Cost Containment	R	624 217 168.80
Operational Efficiency and Cost Management	R	612 002 208.27
Regulatory Compliance & Risk Management	R	1 485 000.00
Safety & Health	R	19 849 532.40
Technical Performance (Plant Reliability & Availability)	R	1 590 912 705.60

Cost Benefit	15–Year Lifecycle	Annualised (2016 base)
Straight Calculation	R8,801,553,031.83	R586,770,202.12
Probability Calculation (Detuned)	R5,619,698,160.72	R374,646,544.05

The summarised table does demonstrate, however, that there is a significant benefit in implementing the IPI–BIM Framework and implementation approaches. It also confirms its value in all business–driver areas of an engineering–intensive industry like Power Generation. Many of these savings can further be consistently realised in a plant **across its entire life–cycle**, providing a significant value proposition to the business.

The fully detailed Cost–Benefit Calculation Framework (developed in MicroSoft Excel format) is available on request from the researcher.

7.7 Applying the Value Proposition Model to prove IPI–BIM Framework Value

To practically demonstrate the use of the Value Proposition Model, the research documented actual use cases from IPI–BIM Framework implementation activities that showcase the value of this Framework as an enabler to business improvement.

7.7.1 Plant Load Loss Prevention Value Contribution

Table 7–6 demonstrates the typical cost of plant incidents on the research study Brownfields Power Station that could be prevented by the capabilities developed and enabled by the IPI–BIM Framework.

Table 7–6: Typical Cost of Incidents in the Power Utility

SCENARIO	TYPICAL BENEFIT
Unit Trip (Improved operator training and response enabling return to full operational capability within 4 hours of the trip)	R724,800/incident
Prevention of a Load Loss where return is not possible within 4 hours (return to full operational capability within a day)	R3,973,200/day
Disabling Injury Cost* due to improved training and safety awareness	R176,000/incident
Fatality Cost*	R1,800,000/incident
Construction Downtime (due to delayed commissioning of plant)	R48,000,000/day
*Note: Direct Cost of the Safety incident and does not cover long-term payments (disability benefits paid to the person affected).	

The IPI-BIM outcomes of improved and integrated Design Base management, improved engineering knowledge management and increased plant reliability and availability improvement using advanced analytics and simulation create the most compelling case for implementing the IPI-BIM.

7.7.2 Typical Value Proposition Elements – Engineering Productivity and Risk Management

Table 7–7 shows typical cost savings achieved by improved engineering productivity and better engineering risk management with better plant modification control.

Table 7–7: Typical Engineering Productivity and Risk Savings

SCENARIO	TYPICAL BENEFIT
Better plant modifications and designs. Increased engineering staff productivity. Less engineering system/software infrastructure maintenance and support	R1,524,000 per plant per year
Plant load loss risk due to unauthorised modifications to plant	R960,000 per plant per year

Implementation of proven and efficient plant process simulation technology, and coupling it with the relevant and correct Design Base information was shown to yield the following business benefits:

- Ability to simulate fast plant process transient operating conditions.
- Improved ability to conduct occurrence (incident) investigations – the ability to “re–create” the failure/trip sequence in the plant.
- Better evaluation of alternative plant modification scenarios and management of plant changes.
- Verification of control system designs – against actual engineering design and control philosophy.
- Improved ability to identify, simulate and analyse plant/process optimisation scenarios.
- Simulate the impact of changing plant conditions on reliability and availability.

- Faster design time – more efficient, productive and at lower engineering resource cost.
- Access to key Engineering Design Data/Info in an integrated Plant Information System environment.

7.7.3 Typical Value Proposition Elements – Operator Training Improvement

Using the research study outcomes, it could be demonstrated that operators and maintenance staff can be trained more effectively on plant identification and system fault-finding.

- Key plant operational principles could be demonstrated and simulated in line with the Design Base of the plant in operator training sessions (creating understanding for the Operator WHY there are defined operating envelopes and limits).
- Operator Training Modules are now directly based on plant systems, their Design Base information and any information pertinent to the operations of the plant.
- Integration with operating and engineering simulators familiarised trainees with computer based control mimics, which would form the foundation of the **actual** plant control system mimic design and layout.
- The virtual operator simulation capabilities enabled help to build confidence levels for new operating staff to deal with unknown process plant technologies and more complex process plant operations – increasing complexity can be built progressively into the 3D Virtual Plant and Operator Training.
- The capability created also improved the assessment and competency declaration of personnel i.t.o. Plant Safety Regulations and High Voltage Plant Operations.
- Operators could be trained and operating inspection and commissioning routes developed during the plant construction phase which resulted in very efficient commissioning and commercialisation of the plant units into production.
- Operability and maintainability issues could also be addressed more effectively during EPC design review cycle and not during commissioning when very little could be done to rectify such issues.
- Implementation of a 3D virtual training environment also created the capability of training operators to perform work in restricted plant areas (e.g. Hazardous Areas) without exposing the trainees to the safety risks until they can prove competency in passing the operating procedures contained within this simulator.

Table 7–8 shows typical cost savings achieved by improved operator training methods.

Table 7–8: Typical Operating Savings

SCENARIO	TYPICAL BENEFIT
Reduced Commissioning Testing and Operator Training intervention time on Project before Faster Handover to Client (800MW Unit)	R5,978,400/day
Better plant alarm and abnormal condition management Scenario training in the Engineering/Operating Simulator – fewer Load losses and trips	R4,493,760/day
Plant load loss risk due to incorrect plant operations Load Loss, 620MW Unit/day Unit Trip, 620 MW Unit, return in 4 hours	R4,493,760/day R748,960/incident

7.7.4 Typical Value Proposition Elements – Maintenance Practices

Table 7–9 shows typical cost savings achieved by improved maintenance practices and planning.

Table 7–9: Typical Maintenance Practices Savings

SCENARIO	TYPICAL BENEFIT
Improved management of scaffolding cost during major outages	R320,000/year
Lost production opportunity due to inefficient outage activity and project planning (delayed start–up of 2 days)	R8,958,528/yr/incident
Generator failure due to a breach in clean conditions during an outage (typical cost of a 620 MW generator rotor/stator rewind)	R68,000,000

The following were typical actual scenarios evaluated:

- Deployment of Design Base and maintenance base information in a 3D visual environment improve understanding of task and safety requirements and allows for better maintenance procedure planning.
- Maintenance strategies and the associated maintenance work task lists can be optimised using Design Base information. 3D virtual plant environments can be used to confirm correct work sequence and assist with optimal maintenance layout area planning and assignment.
- Improved job safety analysis. The 3D virtual plant simulator was demonstrated to have use for training maintenance staff in certain operations like overhead crane maneuvering and lifting large objects.
- By exposing maintenance and planning staff to 3D models with dimensional measurement capability, allowed them to plan scaffolding sizing requirements as well as determining maintainability of the plant (e.g. whether there is sufficient space for maintenance activities like removing large casings and rotor internals).

7.7.5 Typical Value Proposition Elements – Reliability/Availability Improvements

Table 7–10 shows typical cost savings achieved with the introduction of better failure analytics and identifying plant hotspots. It shows how better analysis and planning for boiler tube replacements can reduce outage time and enable a faster return to service.

It also demonstrates the significant impact that high pressure (HP) pipe failures can have on plant reliability. A number of cases were identified where replica testing indicate deterioration of pipe health that necessitates replacement planning. Being able to plan for this in time prevents the extended 6–9 month downtime if there is no spare HP piping available.

Table 7–10: Typical Reliability/Availability Savings

SCENARIO	TYPICAL BENEFIT
Reduced unplanned outages on the boiler due to tube leaks – a boiler tube leak usually results in at least 2–3 days downtime on the unit to allow for time to have the damaged tubes replaced and the required NDT testing to be done.	R13,437,792/incident
Reduced unplanned outages on the boiler due to an unforeseen high–pressure pipework failure can result in at least 4 weeks downtime on the unit to allow for time to have the pipe replaced. If there is no spare HP pipe available, this can result in as much as 6–9 months downtime. Load Loss, 620MW Unit/day (Spare Pipe) Load Loss, 620MW Unit/day (No Spare Pipe)	R125,419,392/incident R752,516,352/incident*

**This excludes the cost of the pipe now required on emergency order which comes at a major premium)*

7.7.6 Typical Value Proposition Elements – Construction/Project Execution Efficiency

The typical benefits and savings achieved using IPI–BIM Framework elements to improve construction and project execution efficiencies are shown in Table 7–11.

Table 7–11: Typical Construction/Project Execution Savings

SCENARIO	TYPICAL BENEFIT
Project Stand Time on an 800MW Unit Impact	R53,903,076/day
Lost production opportunity (Delayed Commissioning)	R5,798,400/day
Faster Assembly time of large and complex equipment and systems in the plant on an 800MW Generating Unit	R5,798,400/day

One of the biggest challenges on a major construction project undertaken (like the Greenfields Project of this research study), is the management of the large volumes of contractors and staff in the same construction space at the same time. In addition to the human space planning aspect, there is also a need to ensure sufficient space planning for large cranes and construction equipment. Not optimising these activities can result in significant project stand time and delayed construction and commissioning activities.

The ability to link construction schedules linked to Design Base 3D plant models and engineering information relevant to the Project enabled better decision making as well as created the opportunity to visualise and optimise construction sequences.

Due to space constraints, it is also crucial to do the optimal equipment lay-down area planning and to optimise dismantling/assembly processes and methods during the construction process. The latter is also relevant to major outage activities on Brownfields plants. Optimization of dismantling and re-assembly processes and methods further enhance construction efficiency.

Implementation of the 3D virtual plant in an optimal information delivery mechanism enabled the optimisation capabilities required in these instances.

7.7.7 Typical Value Proposition Elements – IT Infrastructure

As indicated in Chapter 3 of this research study, a major challenge in the engineering environment was the fact that plant Design Base and related engineering information was contained in a multitude of software system technology platforms.

In many cases, the information was also stored on both the business IT as well as the control network (Operational Technology) side of the plant ICT infrastructure, requiring additional information security measures to be implemented to protect the two environments. This increases the overall infrastructure management requirements and asset lifecycle cost of the ICT investment.

Implementation of a more integrated plant information management system infrastructure as part of the IPI-BIM Framework resulted in measurable ICT cost savings as indicated in Table 7– 12.

Table 7–12: Typical IT Infrastructure Savings

SCENARIO	TYPICAL BENEFIT
Negate the need to support five disparate systems to manage engineering processes and information	R180,000/year
Reduce the reworking of engineering information due to inefficient business processes and resultant loss of information and data integrity	R475,000/year
Productivity time saving achieved, engineering information no longer have to be sourced from multiple repositories and data validation time saving.	R825,000/year
Inefficient knowledge management practices reduced – new staff training much more efficient.	R400,000/year
System Administration, maintenance, and infrastructure management cost reduction	R250,000/year

7.8 Value Proposition Model – Research Findings Summary

A Value Proposition Model was developed as part of the IPI-BIM Framework, and it used actual business use cases and cost saving data to demonstrate how it support business operations in areas such as:

- Operator Plant Training and Competency Assessments.
- Operator Inspections and operating activities throughout the spectrum of start-up, normal running, alarm conditions and shut-down of the plant.
- Hazardous Location Training and Management.
- Safety Training and Job Safety Analysis.
- Maintenance Job Execution (Improved pre-work safety briefings and more efficient maintenance activity execution).
- Outages – Determining and scoping scaffolding requirements, equipment lay-down areas, maintenance/outage sequences, etc.
- Emergency Preparation training (Emergency Scenario Planning and Testing).
- Improved incident and occurrence analysis capability.
- Commissioning and Testing Activities on Plant.
- Constructability analysis.
- Maintainability/Operability analysis.

The spreadsheet developed has been used with success to quantify business improvement benefits realisation. It has also been used to set KPI's for measuring and trending proposed business improvements.

7.9 Conclusion

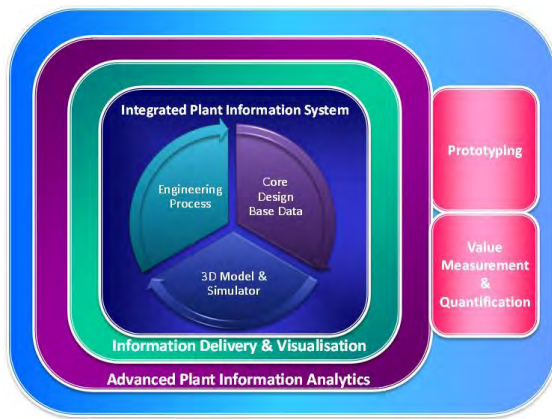
By developing an adjustable cost model with variable inputs, flexibility is provided to other utilities or process plant owners who would like to use this model. A flexible model allows for adjustments (where needed) to reflect their specific plant history, environmental and socio-economic conditions.

The Value Proposition Model (developed in line with identified business drivers) could be used to demonstrate the strategic benefits of the IPI-BIM Framework. It demonstrates the benefit of improved plant Design Base management in an integrated plant information management system platform, supplemented with supporting advanced analytics capability.

The Value Proposition Model summarises and demonstrates the value of:

- Improved Conceptual Development and Scenario analysis.
- Better and faster plant condition and engineering/business decision–making.
- Reduced operating cost for the business.
- Higher Engineering Efficiency and Productivity.
- Improved engineering information and data integrity/quality.
- Improved commissioning and outage efficiency.
- Improved operational efficiency.
- Improved plant and personnel safety.
- Better, more efficient and productive training of Engineering/Technical Staff.
- Increased Maintenance Base optimisation opportunities.
- Reliability and Efficiency Optimisation by improved analysis.
- Simulation and analysis of scenarios and previous incidents to prevent re–occurrence.
- Improved Modification Management in a controlled integrated system environment.
- Scenario analysis of proposed modifications to implement most feasible option.
- Improved Engineering Control and Efficiency.
- Controlling the Design Base and associated Information in ONE central repository with portal information integration capability to access and share information with other systems as needed.
- Consistent, repeatable and auditable engineering processes.
- A portal–based data/information delivery platform for improved Business Intelligence.

OPERATIONALISING THE IPI-BIM FRAMEWORK



Up to this point of the research study, the strategy was a structured and phased approach in developing and enabling the IPI-BIM elements (described in Chapters 3 to 7). It was based on the hypothesis that this would be the most efficient, cost-effective and ultimately viable approach to building such a complex Business Improvement Model and implementation approach.

The phased approach enabled a critical evaluation of each individual element of the IPI-BIM Framework. This was done using the V-Model of Systems Engineering as the research framework and also defined the research approach.

The ability to compare the Design Base content from different power stations and projects enabled the required research data validation. The consistency reported when correlating results between the different plants confirmed the validity of the IPI-BIM Framework and implementation approaches and tools developed under the research study (e.g. the automated data mining tool).

As previous chapters were used to validate the experimental design of the IPI-BIM model and demonstrated the iterative development and validation of the IPI-BIM elements as individual working deliverables, Chapter 8 will focus on demonstrating that the IPI-BIM is implementable as a whole to confirm the Construct Validity. The difference between the IPI-BIM Framework and other widely used business improvement models was discussed in detail in Chapter 2.

8.1 Hypothesis Relevant to IPI-BIM Framework Operationalisation

Hypothesis 8: If all the elements of the IPI-BIM can be proven individually, it can successfully be implemented and proven as a whole.

Hypothesis 10: The IPI-BIM model developed in this thesis can be implemented successfully in a Power Utility environment, and is generic enough to be applicable to any process plant.

8.2 Business Need Considerations during Operationalisation

The ultimate confirmation (and verification) of operational readiness for the IPI–BIM Framework would be the ability to successfully implement all the Framework elements in a Power Utility Plant/Process Plant, and documenting the value proposition achieved from implementing it. A validation of the External Validity of the IPI–BIM Framework would be to test aspects of this model with a process plant specialist audience wider than the Power Utility industry.

For validation purposes, the elements of the IPI–BIM Framework were implemented on the two research study plants, demonstrating its use and applicability to both a Greenfields and Brownfields plant scenario.

It was, however, important to consider the different core business drivers that would prevail in the EPC and OEM Asset Lifecycle phases. These business needs are summarised in Figure 8–1. The IPI–BIM operationalisation followed the implementation strategies outlined in Figure 8–1 to implement the Framework – i.e. taking a revolutionary implementation approach for the Greenfields Project, while a more evolutionary approach was taken for the Brownfields Power Station.

Figure 8–1: Revolutionary vs. Evolutionary Capability Implementation [Swanepoel, 2006]



8.2 Scope and Status of IPI–BIM Framework Validation on Research Study Projects

Table 8–1 provides a summary of the extent to which all the elements of the IPI–BIM Framework were implemented for final validation. Where elements were not implemented (or considered for implementation), the reasons for this were provided in this table.

Table 8–1: Status of IPI–BIM Model Elements Implemented at the Research Study Plants

IPI–BIM MODEL CORE ELEMENT	IPI–BIM MODEL SUB-ELEMENT	GREENFIELDS PROJECT	BROWNFIELDS PLANT
Integrated Plant Information System	Engineering Process – EPC Asset Life Cycle Processes	Being Implemented as part of Utility Wide System implementation.	N/A. Only Management of Change required for plant modification management purposes.
	Engineering Process – O&M Asset Life Cycle	Being Implemented and will enable at the handover of the plant to the Owner/ Operator.	Legacy System Implemented (Project 3 in Chapter 3). Migration of the Design Base to the Utility New IPI system platform in progress.
	Full Design Base	Full Design Base sourcing still in Progress, Plant still in EPC Asset Lifecycle Phase.	40–year old Design Baseline available – full Design Base sourcing would be problematic, the focus is on sourcing and establishing the identified core Design Base.
	Core Design Base	Sourcing in Progress, Plant still in EPC Phase. OEM’s engaged to deliver identified missing core content (e.g. Failure studies)	Yes. Defined, being migrated into the Utility–wide standard IPI System.
	Operating Design Base	Being Defined (Plant still under construction)	Prototype tested. Operating curves and core values sourced. The full set being defined and in the process of validated.
	Maintenance Design Base	Plant Classification in progress in order to confirm Maintenance Strategies. The scope of maintenance work will follow from approved strategy.	Definition, Optimisation and classification completed. Maintenance works scope optimisation in progress.
	Data–Centric Design Base	Partial. Conversion planned of appropriate content being prototyped.	Partial. Prototype testing of automated conversions to data–centric format in progress.
	3D Model	Full 3D CADD Based model enabled in 3D Visualisation and interactive training technology	Boiler Plant Area prototyped: • 3D Laser Scan (Boiler external) • 3D CADD Model (Boiler Internals)

IPI-BIM MODEL CORE ELEMENT	IPI-BIM MODEL SUB-ELEMENT	GREENFIELDS PROJECT	BROWNFIELDS PLANT
	Engineering Simulator	Planned as part of the operating simulator environment and 3D Virtual plant model.	Prototyped, static process plant models in place.
	Operating Simulator	Planned as part of the overall control system supply.	Yes. Prototyped for full integration in IPI-BIM and portal.
	Design Base – Simulator Integration	Prototyped Full integration planned	Planned (potentially part of the C&I upgrade project)
	Plant History	Not available (plant still under construction)	Classified and prototyped (Incidents and Modifications)
Information Delivery and Visualisation	Engineering/Technical Information Classification	Completed (ongoing as plant is still being constructed)	Core Design Base content completed.
	Information Integration (Design Base – simulator – visualisation)	Prototyped – FGD Plant (Flownex – 3D-Pact – IPI System)	Prototyped. (Plant Historian – eta-PRO advanced analytics – Operating Simulator)
	CADD 3D Model	Full 3D CADD model in place and used for virtual plant simulator.	Prototyped – Boiler internal CADD model.
	3D Laser Pointcloud	N/A	Unit 1 Boiler Area scanned and planned for migration into the IPI System platform.
	3D Interactive Simulator	Yes, using 3D CADD Model.	Prototype completed using 3D Laser scan format
	2D Process Data and Simulation to 3D Model Integration	Yes	Planned as a future enhancement when existing plant operating simulator is replaced.
	Portal Technology platforms	Information exchange portal platform in process of being implemented	Information exchange portal planned. Will be implemented in future.
Advanced Plant Information Analytics	Plant Process Model – etaPRO (Design/Static)	Planned	Yes
	Plant Process Model – Flownex (Design/ Transient and Dynamic)	Prototyped (FGD Plant)	Prototyped (Rankine Cycle)
	On-line/continuous Design Base performance monitoring	Planned	In place for the Boiler, Turbine, and critical plant processes
	Operating Simulator	Planned	Yes. C&I control system upgrade
	Design Base Simulator – Static	Planned	Yes. Steam cycle.
	Design Base Simulator – Static (Transient)	Prototyped	Prototyped (Rankine Cycle)

IPI-BIM MODEL CORE ELEMENT	IPI-BIM MODEL SUB-ELEMENT	GREENFIELDS PROJECT	BROWNFIELDS PLANT
Prototyping	SmartPortal Concept	Prototyped with elements from both Brownfields and Greenfields Plant areas.	
	Plant History Analytics	Planned (Plant not commercial yet).	Prototyped. Fault analytics. Plant historian/ Simulator integration prototyped.
	Construction Optimisation	Prototype to be extended in 2016/7 for full use on remaining unit builds	Not relevant – plant in operation.
Value Measurement Quantification	Design and Change Management	Yes	Yes
	Construction Management	Yes	No
	Commissioning Management	Planned	Yes
	Hand-over and Training	Planned	Yes
	Safety	Yes	Yes
	Plant Operations	Planned	Yes
	Plant Maintenance	Planned	Yes

8.3 Operationalisation Results on Research Study Projects

Table 8–1 indicates the extent to which the elements of the IPI–BIM Framework have been implemented (or is in the process of being implemented) on the two research study projects. Full-on deployment of these functionalities is dependent on Power Utility organisational requirements and constraints, e.g. *when* the Utility-wide Integrated Plant Information System deployment to various power stations is scheduled.

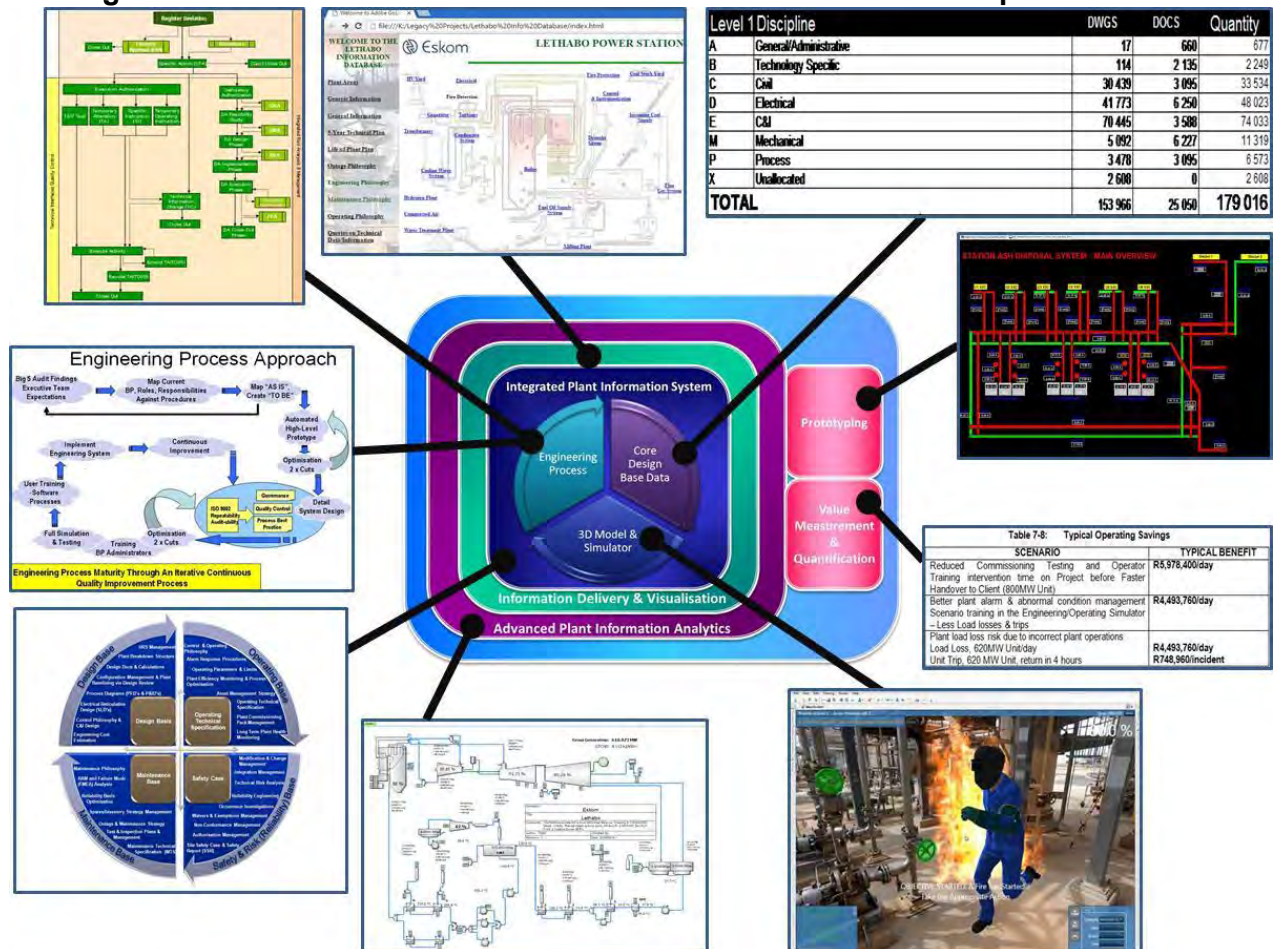
8.3.1 Brownfields Power Station IPI–BIM Framework Implementation

Figure 8–2 depicts the implementation scope of the IPI–BIM Framework at the Brownfields Power Station. It demonstrates how all the aspects of the IPI–BIM Framework were covered while retaining the unique requirements of the O&M environment (different engineering process priorities and process implementation scope, and optimisation approach).

The Brownfields Power Station of the research study was not included in the first roll-out phase of the Utility-wide Integrated Plant Information System platform. Roll-out to this power station was recently brought forward based on the delivery achieved with the research study prototype work, as well as the amount of Design Base preparation and validation work conducted under this research study.

The maturity of the Design Base at this power station was demonstrated to be operationally more ready than any other power station in the Power Utility's Fleet.

Figure 8–2: Brownfields Power Station IPI–BIM Framework Implementation



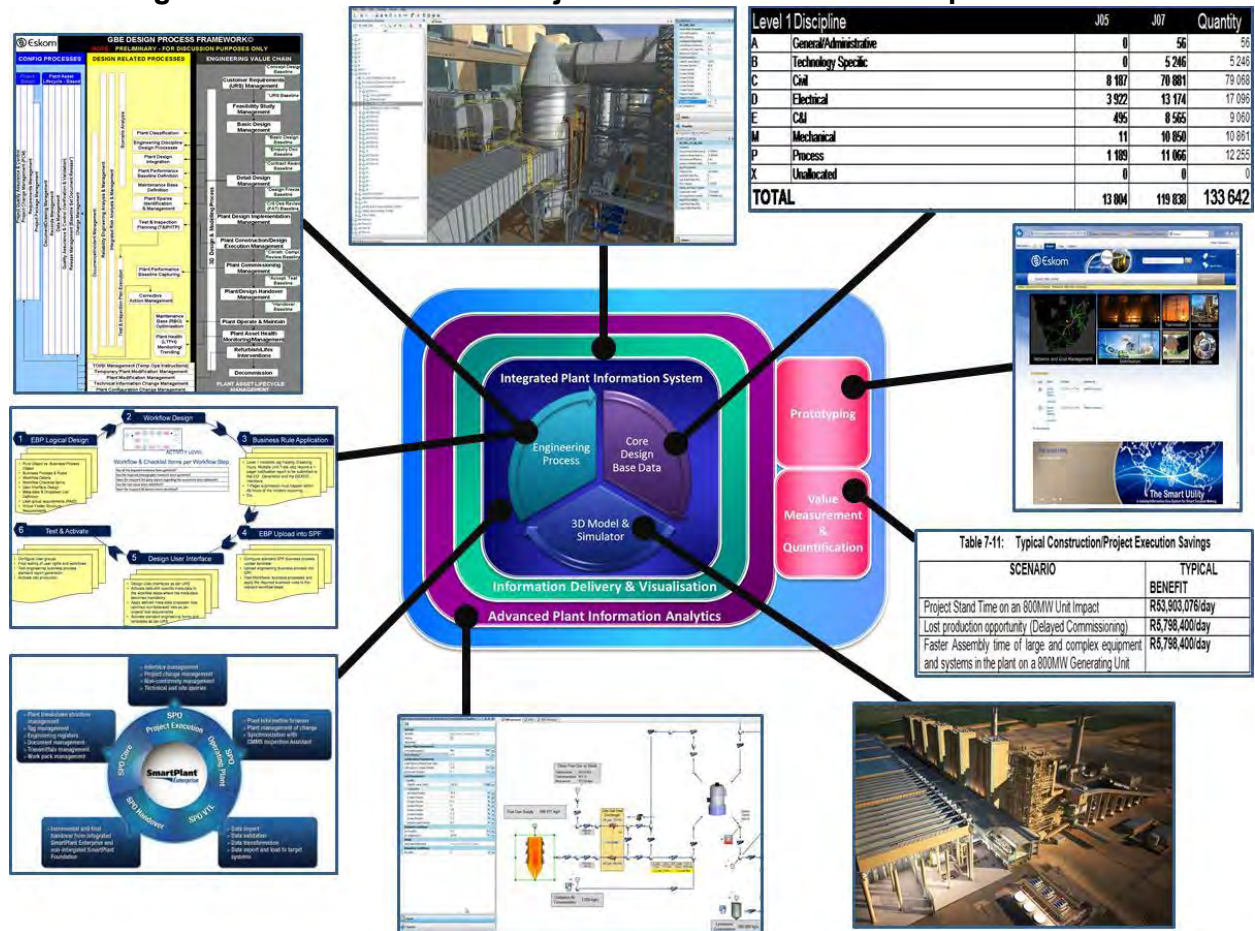
8.3.2 Greenfields Project IPI–BIM Framework Implementation

Figure 8–3 depicts the IPI–BIM Framework implementation aspects implemented on the Greenfields Project that formed part of the research study.

Due to organisational financial constraints, many of the capabilities developed and delivered by the research prototyping in 2012/3 could not be implemented. A number of these capabilities are currently under review for implementation due to the value proposition demonstrated during the research study.

Typical capabilities are improved construction sequencing and more optimised scaffolding and space planning during construction execution. Potential savings in these areas are significant enough to warrant implementation of technology that can approve these processes and activities on the major construction project.

Figure 8–3: Greenfields Project IPI–BIM Framework Implementation



8.4 Actual IPI–BIM Framework Benefits Realisation

Table 8–2 depicts typical cost savings identified and recorded as part of the process of implementing the framework and documenting the value proposition of using the IPI–BIM Framework and implementation approaches. The Greenfields Project reduced construction and commissioning timeline is a combination of numerous initiatives across all aspects of mega-project execution methodology; but the underlying requirement to achieve this is access to Design Base information, integrated with project plans, costing and construction activities.

Table 8–2: Actual IPI–BIM Value Propositions Identified and Documented

SCENARIO	TYPICAL COST
Reduced Construction Time and faster commissioning and handover of the plant into commercial operation. Greenfields Project construction time reduced by 24 months from the original plan – the first unit of the Greenfields Project was commissioned 8 months and 4 days ahead of schedule due to improved cost engineering practices and better activity and engineering work planning and execution.	R5,798M/day

SCENARIO	TYPICAL COST
Access to integrated information also enabled faster and more correct decision making.	
Reduced construction cost and commissioning time by identifying plant Design Base issues and fixing them during design freeze phase and not during construction (missing isolating valve on ACC system, major impact on commissioning of the relevant plant).	R48M/day
Better plant modifications and designs. Increased engineering staff productivity. Less engineering system/software infrastructure maintenance and support	R1,524,000 per year
Reduced Plant load loss risk – prevention of unauthorised modifications to plant due to better Design Base management	R960,000
Plant load loss prevention due to improved plant operations • Load Loss Prevented, 620MW Unit/day • Unit Trip, 620 MW Unit, returned in 4 hours	R4,493,760/day R748,960/incident
Improved planning of scaffolding requirements and reduced scaffolding cost during major outages	R320,000/year
Lost production opportunity due to inefficient outage activity and project planning (prevented delayed start-up of 2 days)	R8,958,528
Use of 3D Virtualisation and Design Base information to enable faster construction assembly and erection of structures	R5,798,400/day

8.5 IPI–BIM Framework External Validity and Relevance

In order to test the relevance of the proposed IPI–BIM Framework, External Validation was required. This was achieved by comparing the Design Base back–fit/establishment efforts on the two research study power stations (that uses the IPI–BIM Framework and implementation methods) against other power stations undertaking the same effort (but not using this Framework).

The researcher had no control over the choice of other power stations, the business model and implementation approaches chosen, resource choices or data quality management methods used and deployed. But all four projects had access to the same potential resource, support and information system platform base, creating a level playing field for comparison purposes.

This allowed for a very independent comparison of how the IPI–BIM structured approach fares against conventional business models and typical Design Base back–fit approaches (Table 8–3).

Table 8–3: External Validation – The use of the IPI–BIM Framework

	USE CASE 1: RESEARCH BROWNFIELDS PLANT	USE CASE 2: BROWNFIELDS PLANT	USE CASE 3: RESEARCH GREENFIELDS PROJECT	USE CASE 4: GREENFIELDS PLANT PROJECT
Design Base Backfit Strategy	IPI–BIM	SDLC (System Design Lifecycle)	IPI–BIM	SDLC (System Design Lifecycle)
Implementation Timeframe (Planned)	12 Months	3 Months	12 Months	12 Months
Implementation Timeframe (Actual)	Currently Underway (anticipated completion 6 months)	48 Months (still ongoing)	9 Months	24 Months (still ongoing, not complete yet)
Number of Project “re–starts”	None	2	None	4
Deployment Timeframe	2 Weeks	8 Weeks	4 Weeks	16 Weeks (still ongoing with issues)
Number of resources	4	24	22	48
Automated Data Mining Used	Yes	No (but subsequently implemented)	Yes	No (Planned for implementation)
Design Base Definition Understood and Identified	Yes	Limited Understanding	Yes	Limited Understanding
Core Design Base Identified	Yes	No	Yes	No
Current Design Base Content Migrated/ Identified for Migration	179,016	84,700	180,068	Unknown
Advanced Analytics Capability	Yes (Integrated and aligned to Design Base)	Yes (Standalone)	Prototyped (planned for implementation)	Limited (Standalone)

From interviews with recipients of the Design Base back–fit deliverable outcomes, key differentiators between Use Cases 1 and 3 and Use Cases 2 and 4 were identified:

- When shown the IPI–BIM Framework in the context of the relevant plant, the immediate response by executives was that it creates an “end state vision” against which the Design Base re–establishment can be tracked and measured for success.
- The IPI–BIM Framework provides a more structured and consistent approach and roadmap that can be used to manage and structure plant information inside information management systems.
- Unclear definition of the Design Base (and differing views by project stakeholders on what makes up the core Design Base) resulted in numerous project re–starts on Use

Cases 2 and 4. Failure to link Design Base artefacts to a structured document classification framework (and not being able to apply consistent IEC assignment rules) creates inconsistency in data sourcing, preparation, and evaluation.

- The automated data mining tool created a major advantage for Design Base artefact identification. It allows for much faster Design Base data preparation, migration mapping, and uploads into the standard plant Design Base management information system (Use Cases 1 and 3).
- On Use Cases 2 and 4, significant engineering time and effort were spent to identify and validate artefacts found and determining its value and relevance for inclusion into the Design Base. Auditing of the document class assignment on these power stations, and the significant error levels observed seriously challenged the perceived business benefit of engineering efforts undertaken.
- If the interaction and dependency between the elements of the IPI–BIM Framework (Design Base Data, PBS, 3D Models and analytics capability) are not explained, understood or considered, it results in additional Design Base back–fit effort and data migration scopes, and unnecessary engineering efforts that do not cover the most valuable (core) Design Base content.
- The unstructured approach and unclear Design Base back–fit scopes in Use Cases 2 and 4 resulted in engineering re–work (data–migration work restarts) and less perceived value for the established Design Base. This typically manifests itself in low engineering user uptake and use of the system solution provided.

8.5 Recognition of IPI–BIM Framework Research Work

A number of capabilities developed by the research study (and which were considered core to the IPI–BIM Framework) were submitted into international engineering competitions for consideration as world–class new innovative capabilities in power plant construction and operation. This is deemed part of the **External Validation** of the IPI–BIM Framework in that such submissions were made to engineering audiences beyond the Power Utility environment (typically covering all process plant industries in a global context).

The innovation and impact of the research study related outputs have been recognised as follows:

- 2008 BE Awards of Excellence: Integrated Engineering Management System for Eskom Lethabo Power Station (Certificate of Achievement recognising the Project as a **Finalist** in the **Innovation in Power Generation Category, as well as one of 3 projects in the world that best demonstrates ROI**³). [Bentley, 2008, p.89]

- 2013 BE Inspired Awards: Kusile Power Station Virtual 3D Plant Simulator for O&M. (**Winner in the 2013 Innovation in Power Generation Category**). [Bentley, 2013, p.131]
- 2013 BE Inspired Awards: Lethabo 3D Laser Scanning Project. (**Honourable Mention in 2013 Innovation in Point–Cloud Processing and Management Category**). [Bentley, 2013, p.123]

8.6 Conclusion

The scope and status of the operationalisation efforts (as indicated in 8.2 and 8.3) confirm that the IPI–BIM Framework can be implemented as a whole or as individual components. This flexibility is deemed a further benefit of the IPI–BIM Framework where the funding for and implementation of the entire framework may not be possible.

Actual cost benefits of implementing the IPI–BIM elements were demonstrated using the Value Proposition Model as basis (defined and discussed in Chapter 7). Documenting actual cost savings further confirms the operational readiness of the proposed Framework.

International recognition of numerous elements of the IPI–BIM Framework confirms it as world–class innovation in the Power Generation and process plant space. It also demonstrates that the research work has value beyond the academic community, with practical and operational implementation in the Power Utility.

Comparing the outcome of Design Base establishment initiatives on the two research power stations to other power stations and projects of similar complexity and plant complexity where the IPI–BIM Framework was not used, provides validation that the Framework has significant potential to improve and optimise business operations.

Although the research was focused in the Power Utility, the international awards recognition further confirms that it offers a viable value proposition for other Power Generation global players and process plant operators in general (as these awards cover all areas of process plant, metal and mining, water resource management, oil and gas industries and numerous other infrastructure areas).

HYPOTHESIS CONFIRMATION AND INTERPRETATION

This chapter summarises the research findings regarding the hypothesis posed and interprets the outcome of the research work and prototyping conducted.

9.1 Interpretation and Evaluation – Hypothesis 1

A sequential approach to developing the BIM and implementation approach will yield the most efficient framework.

Four different approaches to IPI System implementation have been undertaken by the Power Utility over the past 8 years, using varying approaches, methods, and technology configurations. From research, the most cost effective approach was identified to be a RAD Design Base centric approach, with the required engineering business processes and workflows that can support the management and maintenance of these core Design Base elements.

Due to the vastly different business models in the 3 main lines of a Power Utility business (Transmission, Distribution, and Generation), it has proven extremely difficult to build a common enough integrated information system that can address all business needs with one common solution.

Evaluation of the four Project System Implementation methods and strategies confirmed that none of the variations used to date managed to yield an ideal implementation methodology that met all the business requirements (due to very different business models in the Utility Business Divisions).

Leveraging analysis outcomes of these existing business models and system implementation methodologies, the research study developed and delivered a holistic and flexible IPI system framework and implementation method that allows for round-trip management of Design Base elements and the engineering processes required to manage their data content throughout the asset lifecycle.

As a Construct Validation, the full IPI System platform configuration was tested in a stand-alone environment and the UAT was successfully concluded to prove that all processes and functionality were delivered.

The prototyping work demonstrated that it is possible to configure a solution that can meet business needs in both the EPC and O&M cycles of the plant asset lifecycle. *Very careful consideration should, however, be given to the complexity created within system user interfaces when both the EPC and O&M environments are to be covered in one solution.*

This identified complexity resulted in the Power Utility making a conscious decision to split the two asset lifecycle environments in the Utility-wide IPI System platform solution currently being rolled out across the power station fleet and the three new build projects. (The System is split into an EPC/Design environment and an O&M environment).

The testing and validation results from the new implementation methodology developed effectively demonstrated how the structured and templatised approach proposed by the research **significantly reduced business process implementation cycle times** as would be expected by any RAD methodology proposed.

Table 9–1 depicts actual cost savings achieved on the Brownfields Plant of the research study by implementing an integrated plant information management system platform.

Table 9–1: Cost Savings achieved by implementing an IPI System Platform using the new research Implementation Methodology

BUSINESS BENEFIT AREA	BENEFIT
Software Implementation: Reduced time to configure and implement systems (The benefits of reduced implementation time and lower configuration error rates was captured in Chapter 3)	R3.15M
Negate the need to support five disparate systems to manage engineering processes and information	R180,000/year
Reduce the reworking of engineering information due to inefficient business processes and resultant loss of information and data integrity	R475,000/year
Productivity time saving achieved, engineering information no longer have to be sourced from multiple repositories and data validation time saving.	R825,000/year
Inefficient knowledge management practices reduced – new staff training much more efficient.	R400,000/year
System Administration, maintenance, and infrastructure management cost reduction	R250,000/year

9.2 Interpretation and Evaluation – Hypothesis 2

The methodology and approach taken to implement an integrated plant information management system will have a direct impact on Design Base management, system implementation and engineering efficiency.

Research confirmed the hypothesis that system implementation methodology can have a significant impact on implementation timelines and cost as reflected in Table 9–2. It summarises the timelines and resource requirements analysis of previous implementation methodologies deployed by the Power Utility to implement and integrated engineering information system.

Table 9–2: System Implementation Timeline Impact

	PROJECT 1	PROJECT 2	PROJECT 3	PROJECT 4
Implementation Method	RAD	Conventional	RAD	Hybrid – Mostly Conventional, some RAD
Implementation Timeframe (Planned)	6 Months	24 Months	9 Months	6 Months
Implementation Timeline (Actual)	6 Months	3 Years	2 Years	5 Years (Phased)
Deployment Timeframe	4 Weeks	2 Years	8 Weeks (Prototype)	52 Weeks (Still Ongoing)
Team Size	5 Core (System Specialist and 2 Discipline Specialists)	25 Core Team (Various Disciplines)	10 Core Team (Various Disciplines, including Project Office staff)	30 Core Team (Various Disciplines)

As indicated by the “Failed Theory” portion of this study, caution should be exercised when adopting a “phased and as/when required” engineering business process implementation. The prototype IPI system UAT/FAT testing showed that there are peripheral engineering processes required to complete the 6 CORE engineering processes successfully, so a decision to exclude peripheral processes in first pass system implementation may result in incomplete engineering processes where activities have to be completed manually or outside of the IPI System platform.

Exclusion of such engineering business processes in the implementation framework is not ideal and will definitely influence the value proposition of the IPI System platform. Especially if the IPI System platform is to be used as part of the holistic integrated IPI–BIM Framework that contains all elements required to manage the plant Design Base throughout the entire asset lifecycle and if it is intended to act as the primary information provision enabler for advanced analytics capabilities to improve business operations.

9.3 Interpretation and Evaluation – Hypothesis 3

A minimum plant Design Base content is required to enable advanced analytics. This Design Base needs to be managed in a well-designed system and engineering process environment.

The methodology of sourcing the Design Base data proved to be the same regardless of whether it was a Brownfields or Greenfields scenario. The value of using a structured information classification system like the IEC 61355 framework to identify and manage the plant Design Base was proven by the research.

The benefits of using advanced analytics techniques to create an automated IEC Document classification capability was also demonstrated by the research study. A very high level of accuracy could be achieved with the automation IEC data–mining tool, and is deemed an invaluable tool in the process of Design Base validation and verification of documents and drawings in the Power Utility.

The assignment of the classes is generally done by experienced technically qualified staff with expertise on the IEC documentation classification system, **and automation significantly reduced the time spent by these scarce and costly resources to do the Design Base artefact classification.**

Table 9–3 indicates the productivity and cost saving achieved on plants in the Power Utility where the Automated Data–Mining tool developed by the research study, was implemented.

Table 9–3: Actual Productivity Time Saving by introducing Automated Data–Mining

PLANT AREA	DESIGN BASE ARTEFACT VOLUME	BEFORE AUTOMATED IEC DOC CLASS DATA–MINING	AFTER INTRODUCING AUTOMATED IEC DOC CLASS DATA–MINING
Brownfields Power Station (not part of research study)	738,000	9 Months ⁽¹⁾	7 Weeks
Greenfields Project – Data Dumps 1–7	148,000	6 Months ⁽²⁾	8 Weeks
Greenfields Project – Incremental Data Dump 8– 11	29,000	2 Months ⁽³⁾	2 Weeks
Brownfields Project – Information Systems Content	158,000	4 Months ⁽⁴⁾	3 Weeks
Brownfields Project – Design Base Back–Fit Project Contents	654,000	7 Months ⁽⁵⁾	6 Weeks

Notes:

- {1} The automated data mining tool was not available and the assignment was done manually without any clear rule assignment. Review of the work indicated low levels of accuracy and consistency in IEC Document Class Allocation. The automated data mining tool was re-applied on the data-set and was executed in a much shorter time with very high accuracy levels.
- {2} First pass allocation of IEC Document Class Allocation was done manually and was used as “data ruleset” baseline. After the tool was developed, the allocation was automatically assigned to test the accuracy of rules-engine which confirmed the high level of accuracy in a much shorter timeline.
- {3} Given the volumes involved, this is an estimated timeline. More than 60% of artefacts in this data dump from the project were totally new deliverables, so manual assignment would have taken significantly more time to complete.
- {4} The automated data mining tool was not available or optimised yet, so assignment at this project was also done manually. In preparation for migration to the Utility-wide integrated plant information management system being implemented currently, the dataset was re-run via the Data-Mining tool to confirm accuracy.
- {5} The automated data mining tool was not available and the assignment was done manually without any clear rule assignment. A different project team was assigned to this power station, and again reflected low levels of accuracy and consistency in IEC Document Class Allocation. The automated data mining tool was re-applied on the data-set and was executed in a much shorter time with very high accuracy levels.

Research confirmed that a minimum (core) Design Base set of information can indeed be defined and sourced successfully. **By documenting and confirming the core Design Base needed for effective asset management and advanced analytics enablement, the scope of validation and verification could be reduced by up to 66%**

Table 9–4 reflects the difference in artefact volumes between the full Design Base versus the CORE Design Base as proposed by the research study. **The benefit of the reduced Design Base is less engineering time spent on validation and the associated reduced cost involved in executing detailed V&V of such Design Base content.**

Table 9–4: Decrease in Design Base Volumes by defining the CORE Design Base

	4,800 MW GREENFIELDS	3,600 MW BROWNFIELDS POWER PLANT
Full Design Base Artefacts	133,668	179,016
Core Design Base Artefacts	51,115	59,214
% Reduction in Design Base Validation Scope and Effort	61,76%	66,92%
Operating Design Base artefacts (as part of the Core Design Base)	30,606	24,851
% Validation effort reduction focusing on only the Operating Design Base content	40,1%	58,03%

The identified core Design Base content could be successfully sourced from the research study Brownfields and Greenfields power stations. Evaluation of the maturity of core Design Base information and availability confirmed a complete set of information on the Brownfields plant due to the project execution stage that the Greenfields Project was at (concept and detail design phase).

The Brownfields maturity level can, however not be stated to be the norm for the Power Utility. A typical impact on maturity to be considered would be how well other Brownfields plants managed their Design Base with good configuration management practices. In cases where this was not done, the sourcing of such information may be much more problematic and difficult, with much lower Design Base data quality achieved.

The research study has shown the benefit of identifying the core plant Design Base artefacts and managing and controlling the integrity of this Design Base in a controlled and integrated engineering information management system throughout the plant asset lifecycle.

The data quality of the core Design Base is crucial to advanced analytics to achieve trustworthy analysis results on which appropriate technical and business decisions can be made. The information sourced was used successfully in the research study to build advanced analytics models of the plant process.

9.4 Interpretation and Evaluation – Hypothesis 4

The lifecycle age of the process plant where the IPI-BIM is implemented may necessitate the need to perform reverse engineering to establish core Design Base content.

The research confirmed the need to reverse engineer some Design Base content to enable advanced analytics. Research analysis indicated a limited availability of Operating Baselines on the Brownfields Plant. Similarly, for the Greenfields Project some Design Base content was found to be still in the early phases of the EPC Cycle (Concept/Detail design). Some of the Design Base artefacts are also only created (or submitted by the EPC's) towards the end of the EPC cycle (during commissioning and hand-over of the plant to commercial operation).

In cases where the information identified was not available on the Brownfields plant, it was possible to reverse engineer such information using advanced analytics and engineering simulation software and technology as part of the research study. The required data validation between modelled data and the Design Base could be established successfully using 3-way data validation.

Availability of the Operating Simulator environment allowed the research to confirm findings of engineering model outcomes to actual plant behaviour. The use of actual plant control data from the control system, the Operating Simulator and the Engineering Simulator and Advanced Analytics software platform created the ability to introduce a 3-way data validation capability (data triangulation) that could be used successfully to confirm reverse engineered Design Base values and models.

9.5 Interpretation and Evaluation – Hypothesis 5

An optimal information delivery capability needs to be enabled to make information available in the most efficient, productive and clear manner to support decision making.

The research demonstrated how a portal technology platform could be implemented and enabled in the organisation with relative ease and at low implementation cost. The prototype IPI “SmartPortal” demonstrated how sometimes very disparate information system sources could be brought together on one platform to give a much greater level of business visibility and information use. It created a very effective platform from where core business KPI's could be visualised/displayed, monitored and trended.

Significant growth and maturity of information technology and information visualisation capabilities over the past few years have overcome the issues that previously hampered the full implementation of the IPI System information visualisation platform as proposed in the IPI-BIM Framework.

A low-risk constraint identified was that some software vendors created proprietary configurations that affect data extraction capability to trend the plant control information needed for advanced analytics and business performance trending. Increased adoption of open source platforms by Plant Control system vendors and more open/generic data/information exchange platforms are fast minimizing this risk.

Table 9–5 shows typical cost savings achieved by improved information delivery and plant Design Base information visualisation.

Table 9–5: Optimal Information Delivery – Actual Savings

SCENARIO	TYPICAL BENEFIT
Reduced Commissioning Testing and Operator Training intervention time on Project before Faster Handover to Client	Conventional Training Methods: 24 Months Simulator and 3D Virtual Plant enabled training: 15 Months
Better plant alarm and abnormal condition management Scenario training in the Engineering/Operating Simulator – fewer Load losses and trips during unit commissioning for Commercial Operation Release	Greenfields Power Station: 8 RTS Power Station: 40
Plant load loss risk due to incorrect plant operations Load Loss, 620MW Unit/day Unit Trip, 620 MW Unit, return in 4 hours	R4,493,760/day R748,960/incident
Reduced Operational Cost due to more timeous action taken on Ash Handling Plant (prevent cost of ash removal trucking when conveyors are not available)	R19,845M

SCENARIO	TYPICAL BENEFIT
Plant Identification training using 3D visualisation and integrated Design Base information (New Build Operator Training – Actual)	Accurate Plant component identification, 20% faster execution of scheduled operator inspection schedules
Virtual Plant abnormal condition scenario training (New Build Operator Training – Actual)	40% reduction in training schedule timelines
Time is taken to source engineering information and verifying/ validating information in disparate sources.	R660,000
Inefficient knowledge management (timeframes involved to train new staff).	R320,000

The commercialisation of the first Greenfields generating unit was executed with minimal plant trips. The 3D virtual simulator capability developed by the research was deployed on this project for operator training 9 months before the unit was commissioned. **This allowed for much better operator training to handle plant commissioning, start-up, alarm and abnormal condition management reducing the risk of operator induced plant trips.**

The SmartPortal prototype was conducted, concluded and demonstrated to business stakeholders in less than 3 weeks, while the Nerve Center Power Utility project was still at Proof-of-Concept/Concept Design phase at the conclusion of the research study.

The **plant visualisation capability and on-line plant state monitoring of materials handling systems were enabled in 2 weeks** and the capability is available and in use at the research study Brownfields Plant, including its use in plant condition monitoring monthly reports [Maharaj, 2015].

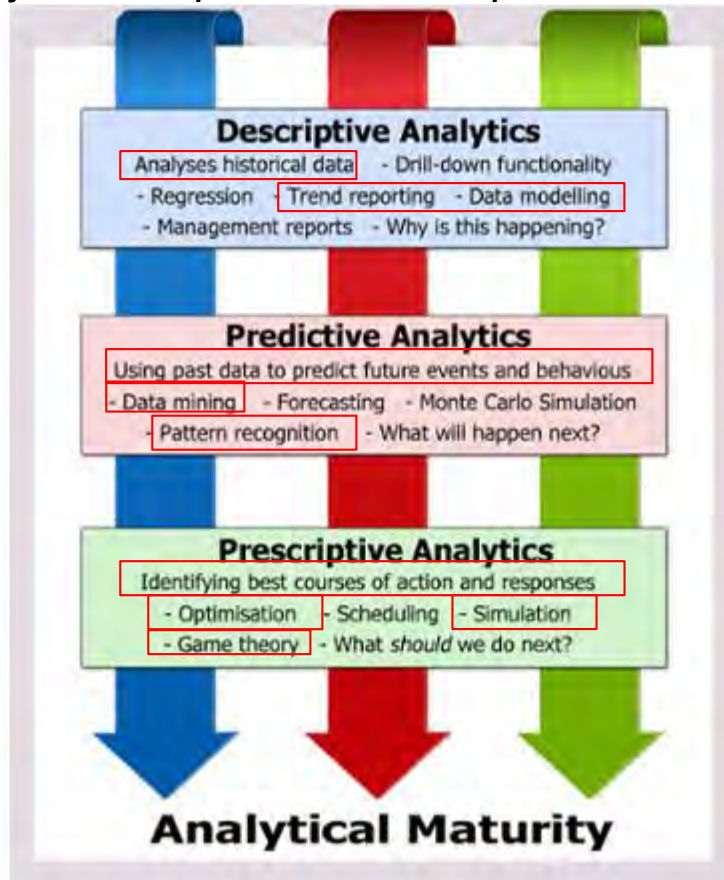
9.6 Interpretation and Evaluation – Hypothesis 6

A combination of analytical methods would be required to provide a holistic plant improvement framework.

The research demonstrated that a combination of Descriptive, Predictive, and Prescriptive Analytics methods was used throughout the IPI-BIM Framework development to achieve the end result.

This confirmed the theory postulated that a combination of analytical methods would be required to provide a holistic plant improvement framework as stated by Lustig in their research study [Lustig et al., 2010]. Figure 9–1 highlights (in red) the analytical methods used in the execution of the research study.

Figure 9–1: Analytics Techniques used in development of the IPI–BIM Framework



The research literature surveys confirmed that advanced analytics have matured significantly over the past few years. The literature surveys performed in the research study, as well as the outcome of the prototype work done confirms that most businesses have access to the required analytical technology capabilities required to drive a more advanced analytical approach in improving their plant and business operations.

Research indicated that identifying and securing access to the critical Design Base information and plant information is key to enabling more advanced analytical capability.

The research prototyping confirmed that sufficient Design Base content and other business/ engineering information was contained in the IPI System platform prototypes to support the intended advanced analytics capability development.

By identifying problematic plant control areas of improvement, the research study collaborated with the site simulator operator training group to address these issues. This has resulted in the prevention of at least two load loss incidents due to incorrect oxygen level control and timeous correction by the operator of the plant condition (Table 9–6).

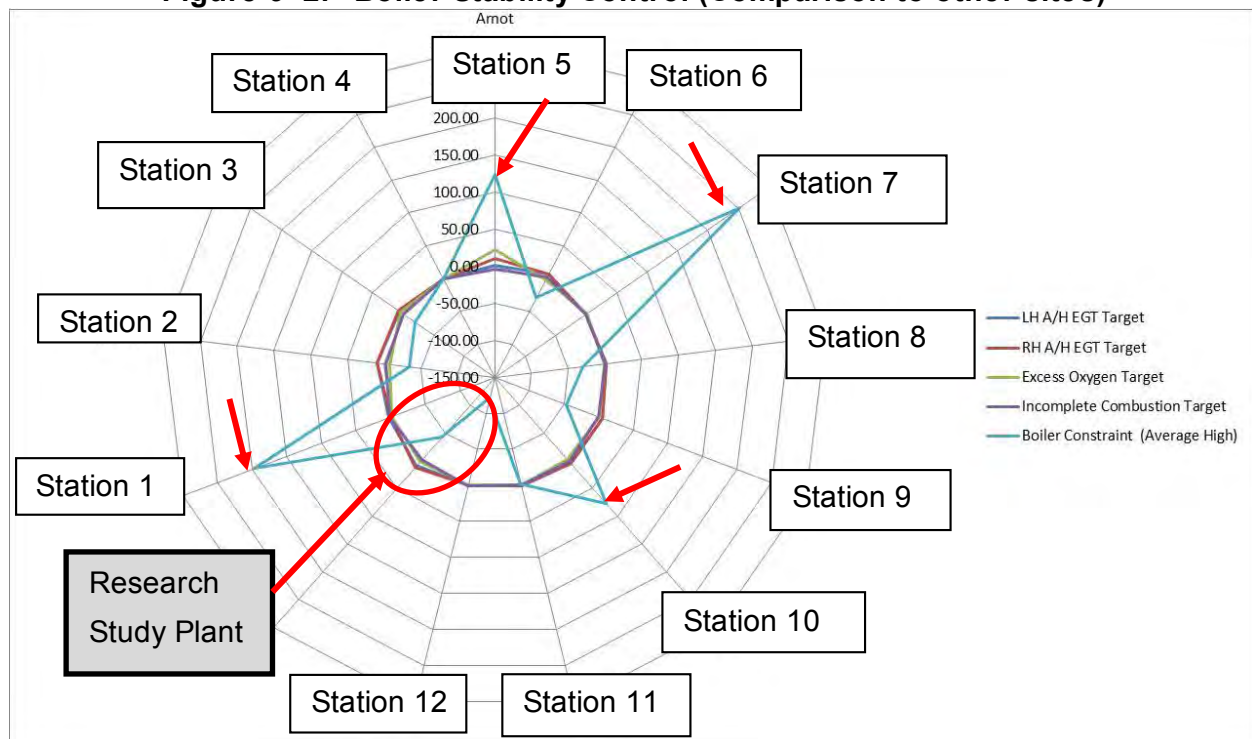
Table 9–6: Typical Actual Savings having Advanced Analytics Capability

SCENARIO	TYPICAL BENEFIT
Prevention of load reduction and load losses by preventing unit shutdown due to inoperative ash conveyors to remove ash from production units (Actual – December 2015)*	R1,497,920 (Production Cost) R19,845M (Operational Expenditure – ash removal trucks)
Load Loss Prevention due to incorrect plant operations, 620MW Unit (Operating baseline control – oxygen combustion level control)	R4,493,760
Training of abnormal condition simulation and operating baseline changes on new technology plant (FGD Plant) – reduction in training timeline.	30% Reduction in training schedule
FGD Plant Process Simulation Model Available for plant process optimisation and optimised operator control	Immediate visibility of the impact of changing operating parameters and the impact it will have on plant output.
20% reduction in the use of Electric Feed Pumps on Brownfields Plant	R10,58M/year

Note: Since the ash handling plant continuous monitoring capability was enabled, there was no need to use trucks for ash removal for 9 months (up to the conclusion of the research study).

Figure 9–2 also shows how increased focus and use of advanced analytics and improved operator training allowed the research study Brownfields Plant to have a much better Boiler Stability Control profile (circled in red) than other power stations in the fleet (Stations 1, 5, 7, 10 indicated with red arrows).

Figure 9–2: Boiler Stability Control (Comparison to other sites)



Increased focus on plant health conditions and better operating at the research study Brownfields Power station has assisted the power station to increase efficiency from 74.6% to 84.6% (deemed significant, as it was achieved over a period of only 3 years).

There are sufficient socio–economic indications that adoption of more advanced analytics for business improvement has become an imperative in an environment where fundamental business models are now challenged and most utilities are contemplating significant changes in the way business is done.

9.7 Interpretation and Evaluation – Hypothesis 7

An optimal IPI-BIM implementation methodology will yield a measurable value proposition.

The Value Proposition Model contents demonstrated the ability of the IPI–BIM Framework to support the various key business drivers identified. A flexible Value Proposition Model was developed in spreadsheet format, and if used correctly can be used to guide IPI–BIM Framework Model and implementation prioritisation (based on the criticality of business driver areas).

The flexibility of the IPI–BIM Platform (implementable in a phased approach) provides the opportunity for the business to first establish the building blocks that make up the IPI–BIM Framework; and as affordability calculations and organisational maturity assessments indicate the readiness for the business to move towards the more advanced analytics and A.I. environment, more elements of the Framework can be implemented.

E.g. if engineering productivity is a major concern, the initial focus would be on the standardisation of engineering business processes, enabling an integrated engineering information system (IPI System Platform) and improving productivity with better availability of plant information to make business decisions.

The research showed that there is significant value in the implementation methods proposed in the IPI–BIM Framework. Table 9–7 depicts typical benefits reported from implementing the templatised methodology proposed in the research study.

Table 9–7: IPI System Implementation Methodology Benefits [Swanepoel, 2008]

BENEFIT AREA	TYPICAL BENEFIT
Speed of roll–out of the IPI system platform to a fleet of process plants.	RAD 30–50% faster than conventional SLDC models
Repeatability in roll–out of IPI system and the configuration methodology.	40% faster system configuration
Re–usability of configuration – suitable for both EPC and	30–40% implementation cost

BENEFIT AREA	TYPICAL BENEFIT
O&M portions of the plant asset lifecycle.	reduction
Ease of customization using system configuration templatised approach – project/plant specific processes.	20–30% implementation cost reduction
Increased internal design capability – configured for the business specific needs and in line with approved process control manuals (PCM's).	40–60% faster engineering uptake
More consistent usage of design tools, higher standardisation across the plant fleet.	30–50% productivity increase using standardised “design seed files” and configurations
Better administrator–level control of software application configurations resulting in reduced IT infrastructure costs.	20–40% reduction in system administrator tasks
Flexible process and system configurations enable better technology uptake by technical/engineering staff.	50–75% faster technology uptake
Improved data quality management and control (data quality and consistency of design deliverables produced).	30–40% improvement

9.8 Interpretation and Evaluation – Hypothesis 8

If all the elements of the IPI-BIM can be proven individually, that it can successfully be implemented as a whole.

Ultimate confirmation of the operational readiness of the IPI-BIM Framework and implementation approach lie in the ability to successfully implement all its elements in a Power Utility Plant/Process Plant and evaluating its success by documenting actual value proposition scenarios achieved by implementing the model.

Figures 9–3 and 9–4 depict the outcome of the IPI-BIM elements as they were deployed as a holistic solution for the research study power stations. These elements are either in the process of being fully implemented (in cases where the research study only conducted a prototype to prove the concept) or were implemented as a final IPI-BIM Framework element at the research study plants.

The value proposition of IPI-BIM Framework implementation is directly coupled to the elements it contains. The more IPI-BIM Framework portions are implemented, the more business value is achieved. Adoption of the holistic approach to integrated plant information management towards business improvement at the two research studies has also allowed them to implement the IPI System platform at a significantly faster and efficient manner than other power stations in the fleet.

Figure 9-3: Brownfields Power Station IPI-BIM Framework Implementation

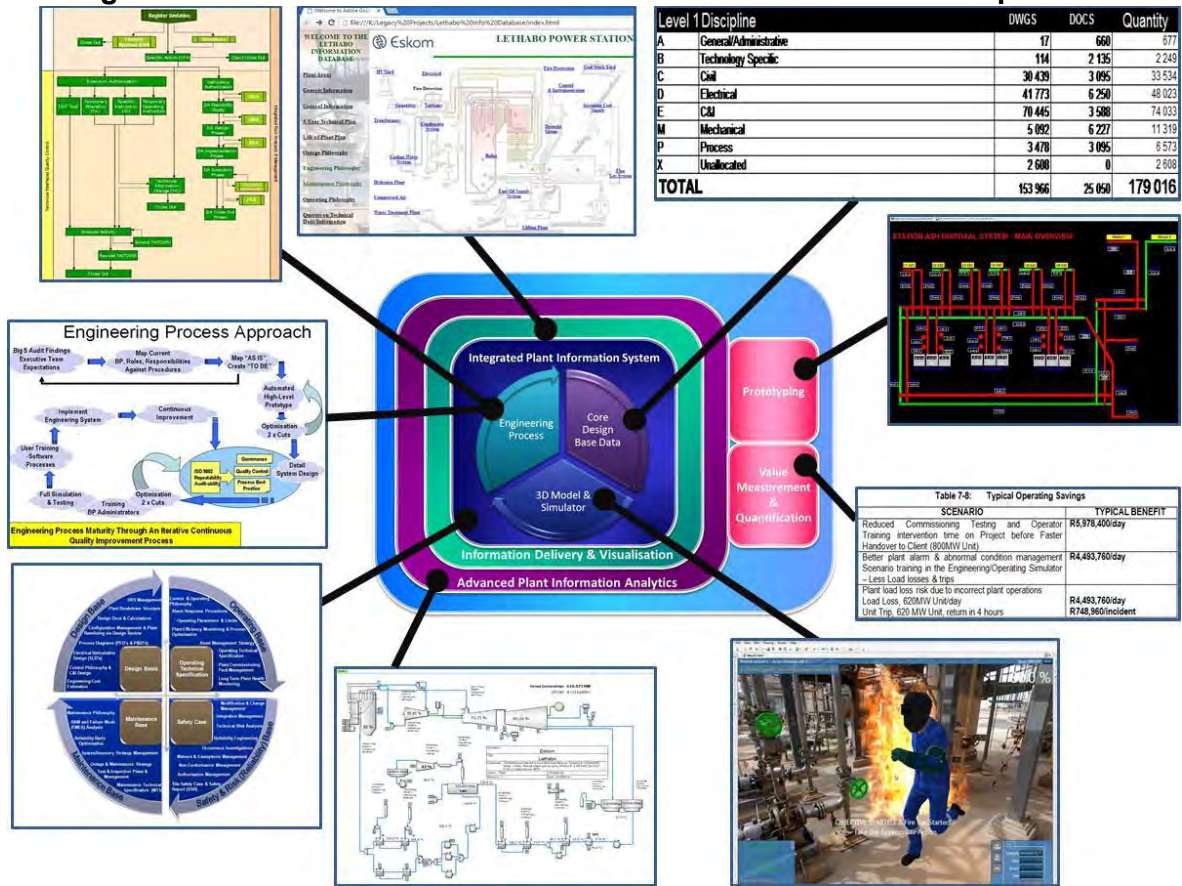
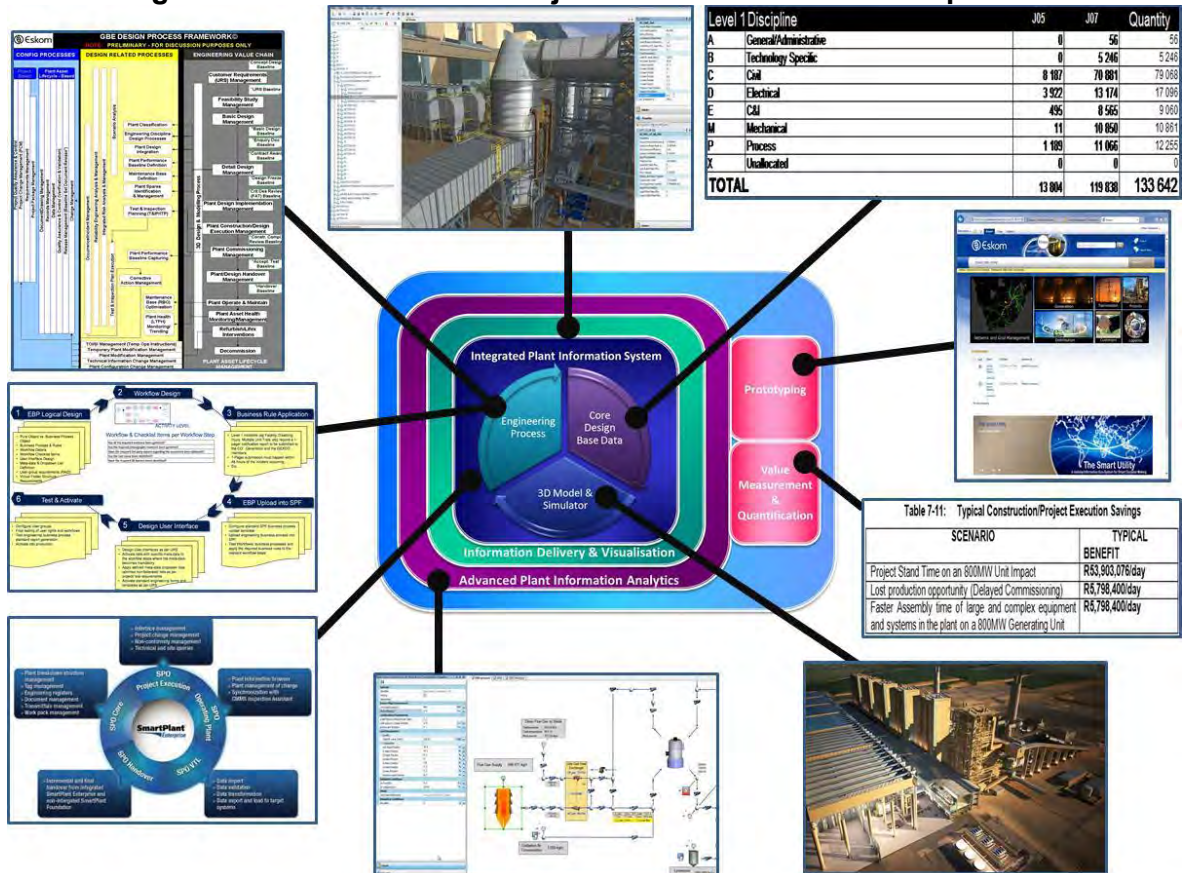


Figure 9-4: Greenfields Project IPI-BIM Framework Implementation



As all IPI-BIM Framework elements could be successfully implemented on the two research study projects, the actual value contributions reported in Chapter 7 were considerable and sufficient enough to support a Power Utility decision to bring implementation roll-out of the Utility-wide Integrated Plant Information Management system platform forward on the research study Brownfields Power Station.

Migration of the core Design Base at the two research study stations is far progressed while the migration progress on the other power stations where the same technology platform is being implemented (of similar size and technology base) are lagging behind. Assignment of standardised document classification is much slower and less consistent as these power stations also did not make use of the automated data-mining capability developed by the research study.

This provided a means of External Validation of the IPI-BIM Framework as a Design Base back-fit approach and efficiency comparison was possible between the research study power stations (that uses the IPI-BIM approach) and other power stations that followed different implementation approaches and methods to execute the Design Base data migration.

9.9 Interpretation and Evaluation – Hypothesis 9

The IPI-BIM framework will provide a significant enough value proposition to be a viable implementation, either in portions or as a holistic framework.

Chapter 7 aptly demonstrated the potential IPI-BIM Framework business value with the introduction of a Value Proposition Model that quantified a wide range of potential beneficial business improvement scenarios in the key business driver areas identified.

Implementing and documenting the value model using actual use cases from both the Brownfields Power Station as well as Greenfields Project demonstrated that such value is indeed achievable and measurable in real financial terms.

Table 9-8 depicts typical cost savings identified and recorded as part of the process of implementing the framework and documenting the value proposition of using the IPI-BIM Framework and implementation approaches.

Table 9–8: IPI System Implementation Methodology Benefits

SCENARIO	TYPICAL COST
Reduced Construction Time and faster commissioning and handover of the plant into commercial operation. Greenfields Project construction time reduced by 24 months from the original plan.	R5,798M/day
Reduced construction cost and commissioning time by identifying plant Design Base issues and fixing them during design freeze phase and not during construction (missing isolating valve on ACC system, major impact on commissioning of the relevant plant).	R48M/day
Better plant modifications and designs. Increased engineering staff productivity. Less engineering system/software infrastructure maintenance and support	R1,524,000 per year
Reduced Plant load loss risk – prevention of unauthorised modifications to plant due to better Design Base management	R960,000
Plant load loss prevention due to improved plant operations Load Loss Prevented, 620MW Unit/day Unit Trip, 620 MW Unit, returned in 4 hours	R4,493,760/day R748,960/incident
Improved planning of scaffolding requirements and reduced scaffolding cost during major outages	R320,000/year
Lost production opportunity due to inefficient outage activity and project planning (prevented delayed start-up of 2 days)	R8,958,528
Use of 3D Virtualisation and Design Base information to enable faster construction assembly and erection of structures	R5,798,400/day

The outcome of the implementation efforts demonstrates individual as well as holistic implement–ability of the IPI–BIM Framework.

9.10 Interpretation and Evaluation – Hypothesis 10

The IPI-BIM model developed in this thesis can be implemented successfully in a Power Utility environment, and is generic enough to be applicable to any process plant.

Operationalisation of the IPI–BIM Framework in both a Greenfields as well as Brownfields power station scenario provided Internal Validation that the model is generic enough to have applicability for the Power Utility environment as comparative data analysis confirmed similar results for the two asset lifecycle scenarios.

Further Internal Validation was achieved by using an unrelated Design Base dataset to confirm data validity in the development of the automated data-mining tool as well as confirming the core Design Base dataset proposed by the research study.

The elements of the IPI-BIM Framework are generic in nature and as such will have applicability and relevance to any process plant. The advanced analytics methods used and the Value Proposition Model are also generic enough in nature to have application to any process plant.

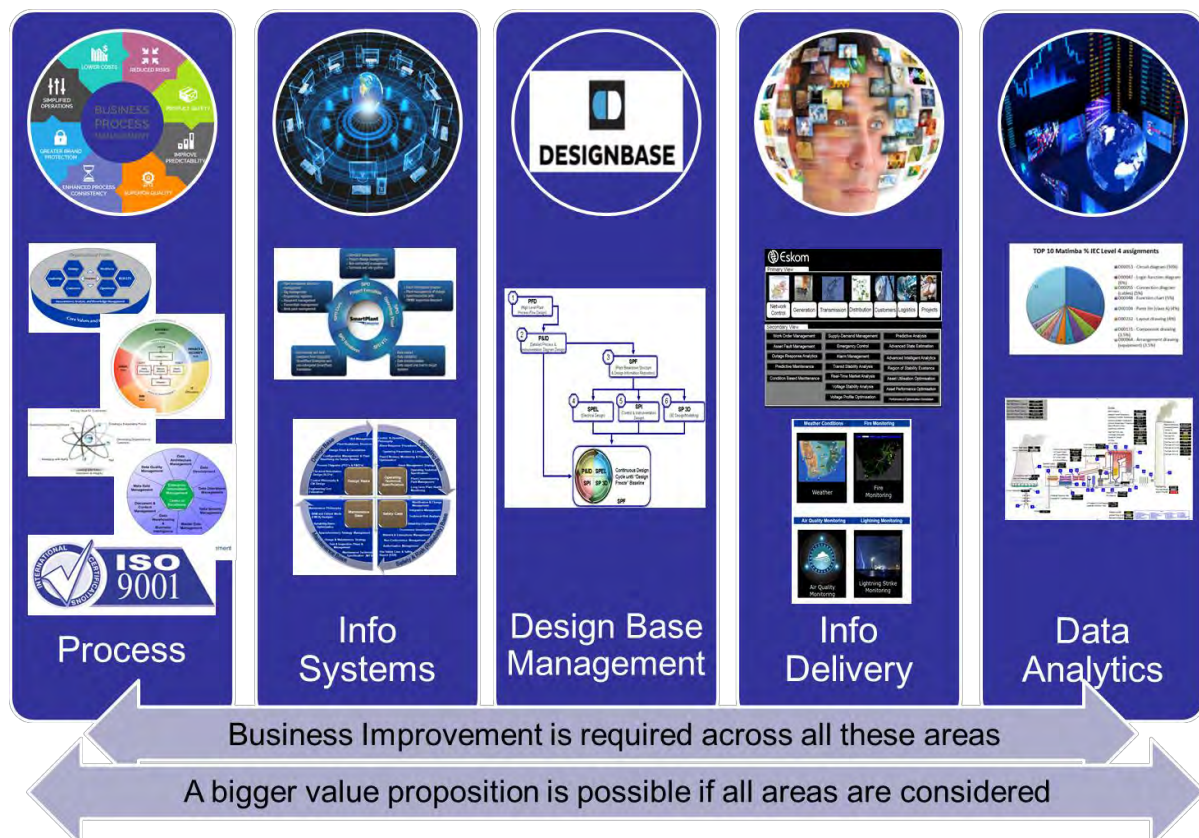
Although the research was focused in the Power Utility, the international awards recognition provides the External Validation that the IPI-BIM Framework offers a value proposition to other Power Generation global players and process plant operators in general (as these international awards cover all areas of process plant, metal and mining, water resource management, Oil and Gas industries and numerous other infrastructure areas).

CONCLUSION

This research study outcome significantly adds to the Engineering Management body of knowledge around business improvement models. It provides an alternative to conventional business improvement models for process and power utility plants.

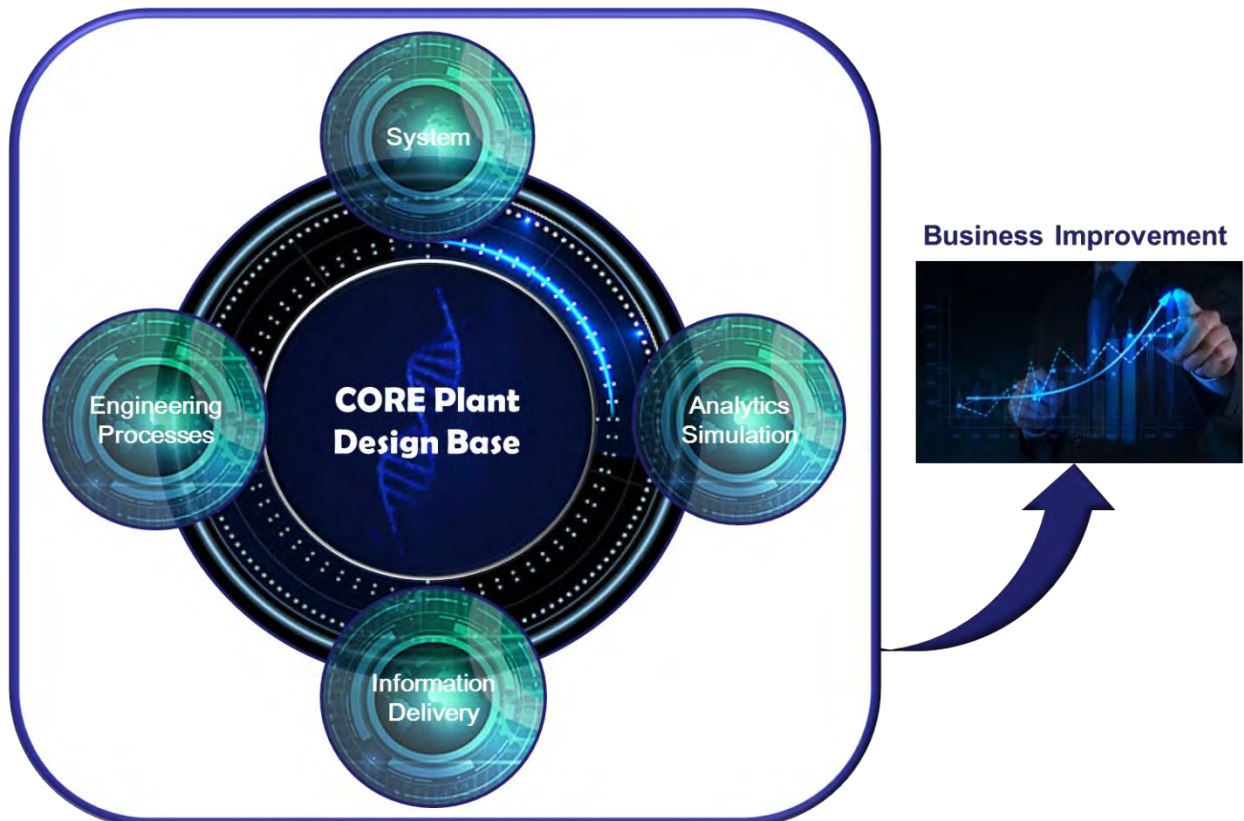
As shown with the research literature surveys, the most popular and used business improvement models focus on business process improvements and not data. And where a number of potential improvement areas are targeted, it is done in a silo approach (Figure 10–1). The silo approach generally manifests itself as separate project and business improvement initiatives within an organisation, and are seldom grouped together to increase the business value and benefits realisation prospects.

Figure 10–1: Existing Silo Approaches to Business Improvement



The research study developed a new business improvement model and implementation approach based on an integrated plant information system platform. Operational research, validation and verification methods in an operational process plant/utility environment were used to prove and confirm its viability and readiness. Validation of its business value was also demonstrated by documenting use cases where it resulted in measurable business improvements and could be equated to real business (monetary) value.

Figure 10–2: A New Integrated Approach to Business Improvement



The research study developed a templatised and standardised Integrated Plant Information (IPI) system implementation methodology covering the information management elements of data content, workflow, process and information integration. The research demonstrated that a balanced focus and understanding of the holistic engineering business process environment is needed when configuring an Integrated Plant Information (IPI) System Platform.

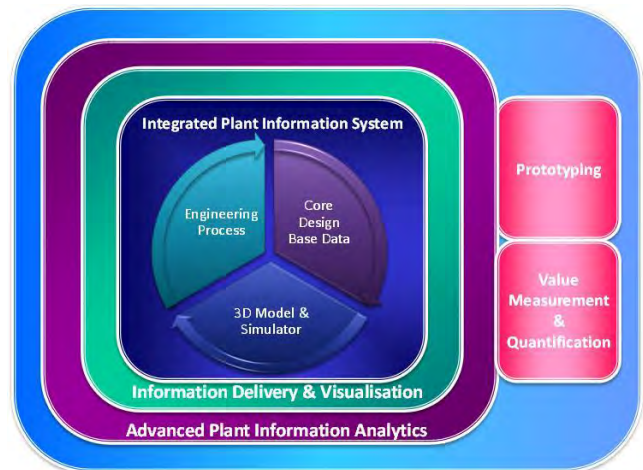
IPI System prototyping confirmed that it is possible to configure a solution that can meet business needs in the EPC and O&M lifecycle portions of the plant asset. Consideration should, however, be given to the complexity created within user interfaces when both environments are to be covered in the same solution.

Actual benefits realisation reported in the research study indicates a very compelling business case to adopt and implement the IPI-BIM Framework. The research demonstrated that the IPI-BIM Framework supports and enables:

- Improved management of the plant asset throughout the entire asset lifecycle.
- Improved capital project expenditure management and control.
- Lower primary energy costs and reduced water usage with better plant control and management of the production asset within Design Base envelopes.
- Higher engineering efficiency and a more integrated fleet management approach due to the availability of information in a single environment.
- Improved engineering information and data integrity (improved validation and verification capabilities).
- Improved commissioning and outage efficiency with smooth engineering project data hand-over during commissioning of the plant.
- Improved operational efficiency and reduced operational cost (achieved with better plant operations management and control of plant within the Design Base operating envelope and expected operating parameters).
- Integration of information from various sources to improve decision making, including a better understanding of risks sometimes not visible when analysing sets of business information in isolation.
- Better and more efficient and productive training of Engineering/Technical Staff in a virtual (3D) environment integrated with advanced simulation capability to do scenario analysis and evaluation.
- Maintenance Base optimisation opportunities and optimised Maintenance Strategies supported by documented standard methods and decisions.
- Opportunities for Reliability and Efficiency Optimisation by better analytics of failure modes, their impact and earlier detection of failures in the plant operations.
- Improved Modification Management (MoC) as all plant and Design Base changes are controlled in an integrated engineering system environment.
- Improved Conceptual/Detail Design Development and Scenario analysis.
- Enabling true Business Integration across the entire Plant Asset Lifecycle.
- Implementation of more repeatable and auditable processes in line with ISO9001 principles.
- Lower IT Lifecycle Cost due to fewer systems being used to achieve the same information output and visibility.

It can, therefore, be concluded that the proposed IPI-BIM is an operationally ready business improvement model proved with operational research and prototyping. ***It is, however, a complex undertaking and the effort required to fully establish this framework should not be under-estimated.***

It should be noted that although the prototyping and proof of concept were done in a power utility environment, the proposed IPI-BIM and implementation approaches are generic enough in nature to be applicable to any process plant environment with minor adaptations for industry specific requirements.



10.1 Further Research Areas

10.1.1 Advanced Analytics

An enhancement opportunity identified by the research study was the ability to make changes to controllable parameters of the FGD process directly from the Plant 3D simulator environment. This can be highly beneficial as it will negate the need for training of operating staff and conventional plant system engineers to understand the complex operations and algorithm management requirements of a tool like Flownex™.

Future opportunities are the development and implementation of more Flownex™ process algorithms and models (based on the plant process design) within this 3D simulator environment. The ideal would be the availability of plant process simulation models at P&ID level.

10.1.2 Reliability Engineering Framework

Although the research reverse engineering focus was on operating Design Base content, it can potentially add value in defining and documenting other portions of the overall Design Base information set as well – e.g. enhancing the Maintenance or Reliability Design Base aspects of the overall Design Base.

Such work is deemed candidates for future research and enhancements to the IPI-BIM capability stack and framework.

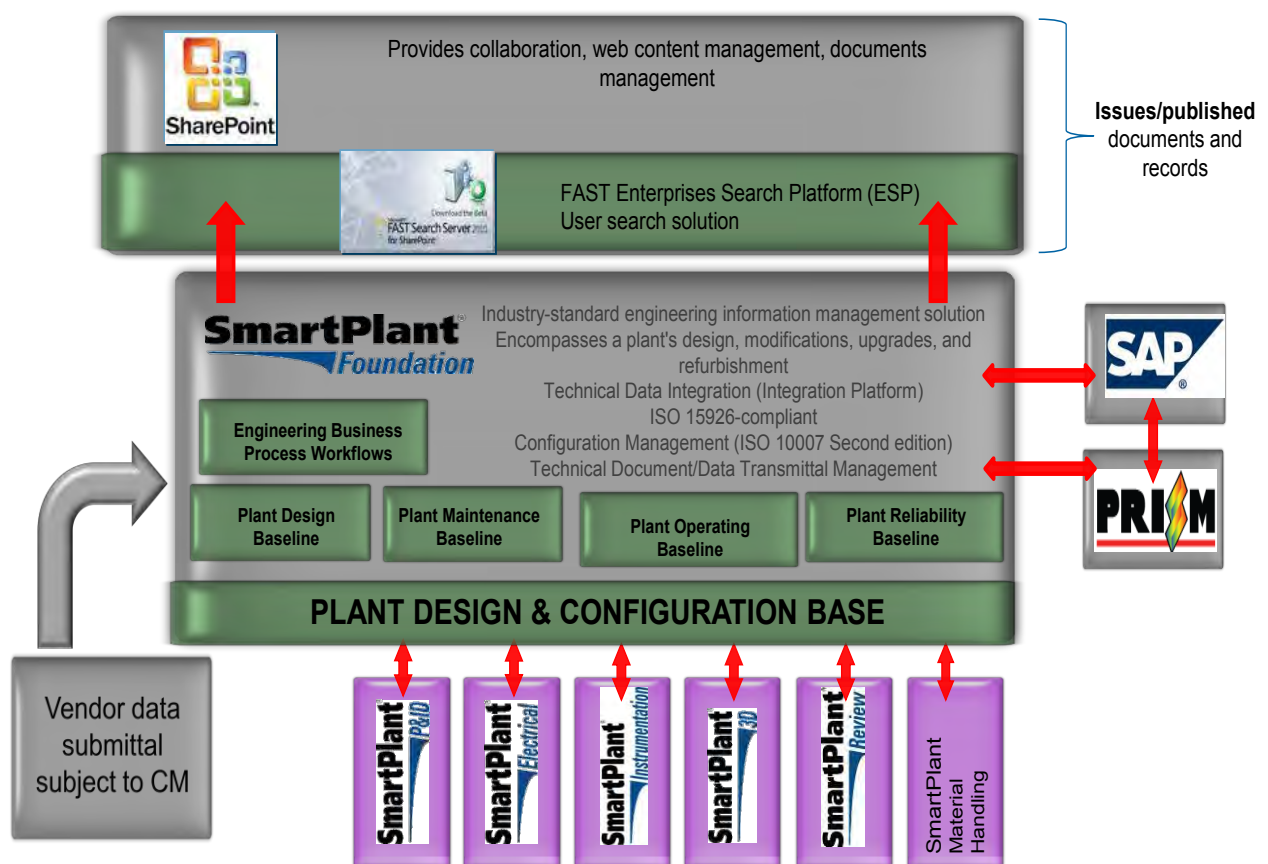
10.1.3 Extension of Information Delivery Capability

The research has demonstrated that an integrated plant information system platform is possible and achievable. In addition, the use of portal technology as a common information delivery platform was also demonstrated. This opens up the opportunity to integrate this platform with other business source information systems in the utility.

In line with the research delimitations, the IPI–BIM Framework was focused on deliverables in the Engineering Management environment. There are obvious benefits of extending the information delivery capability into all business areas.

Figure 10–1 depicts a potential integrated Business Information Delivery Portal/Hub concept. The most likely delivery mechanism would be Portal technology that can bring together all the required business information available into one common, easy to access platform.

Figure 10–3: Potential future integrated Business Information Hub



10.1.4 3D Laser–scanning Technology Advancements

While the 3D laser scanning visualisation collaborative research with Samahnzi™ proved that it was possible to create a virtual reality and user interaction platform within 3D Laser scanned models, a constraint at the time was that the Laser Scanner viewer software technology was restricting data views to a scanner position where the data was captured in the plant. This reduced the flexibility to seamlessly (and fully) navigate the virtual plant Pointcloud model.

Later research literature surveys have confirmed that some 3D laser scanning technology and software providers have managed to integrate point cloud scans into a light enough data management capability that allows for seamless and continuous navigation through the point cloud model regardless of 3D laser scanner position in the plant.

Future research can prototype and test this capability in an industrial application. Due to the software neutral nature of point cloud data, it will not be influenced by software solutions considered for such a future research scope; and it will be possible to leverage the existing point cloud data that was captured in the Brownfields plant to evaluate these new capabilities.

10.1.5 Value Proposition Model Use Cases

The research study specifically focused on quantifying the benefits from the research study scope of work undertaken. The quantified results currently defined in the Value Proposition Model provided sufficient evidence to the business that taking an integrated and holistic approach to plant information management.

The literature survey on the topic indicated many more (currently unexplored) value propositions that can be explored in future to expand the Value Proposition Model developed in the research study. Coupling these additional value areas to the existing Value Proposition Model can provide additional justification for utilities other than power plants.

10.2 Failed Theories

10.2.1 A single Integrated Plant Information System for both EPC and O&M Life cycle

Although the research proved that it is indeed possible to configure and implement an integrated plant information (IPI) system that can handle all aspects of the full asset lifecycle, the complexity created resulted in resistance to adopting the solution.

This was a key reason for abandoning the Project 3 “Proof of Concept” configuration in lieu of a much more simplified OOTB system configuration. Most O&M users could not understand the complexities of the EPC environment around Design Base management, while users of the EPC cycle did not want to operate within the rigidity of the very constrained process centric O&M framework.

While the Power Utility acknowledged Project 3 as a best of breed, world-class integrated plant information management system configuration, it chose to rather adopt a much more simplified SPO “OOTB” configuration that will utilise the Project 3 “ideal configuration” to mature the OOTB configuration over time.

As a result, the Utility-wide system configuration was also subsequently split into a “Design” (EPC) instance and an O&M instance within the software system IT infrastructure. This is the solution currently being implemented and rolled out in the Power Utility.

10.2.2 A Phased System approach can allow for an “as/when required” Phased Engineering Business Process Implementation

Hypothesis 1 stated that a sequential approach to developing the business improvement model and implementation approach will yield the most efficient framework. Implied with this hypothesis was a theory that if a sequential approach is proposed, it would be possible to also implement engineering processes on an “as/when required” basis.

During the Information System Implementation Methodology evaluation of 4 Projects in the Power Utility), evaluation of Project 3 outcomes indicated a notable risk and drawback if only portions of the full engineering process scope are implemented.

Project 3 implemented only 6 engineering processes under its Project Scope (due to the extremely short implementation timeframe allocated to the project execution team at the time). Evaluation of these processes with stakeholders subsequently confirmed that they were considered the most common engineering processes in use in the business, and could thus be

considered “**core**” engineering processes that should form part of **any** integrated engineering management system.

But it soon became apparent during FAT and initial UAT sessions of Project 3 that there were peripheral engineering processes required to complete the 6 main processes successfully, as well as to cover the management of the full plant Design Base scope in the asset lifecycle.

Full implementation of the entire engineering business process scope can be time consuming and result in a strenuous training intervention of engineering users, but can be mitigated by the RAD approach to release engineering processes as soon as first pass design is configured in the system so that users can get used to the new process and start using it in context with other existing engineering processes.

The challenge for implementers of the IPI–BIM Framework would, therefore, be the ability to find a balance between processes needed, the complexity that will be created and proper user change management.

10.2.3 Interoperability of the SharePoint Portal with External data sources

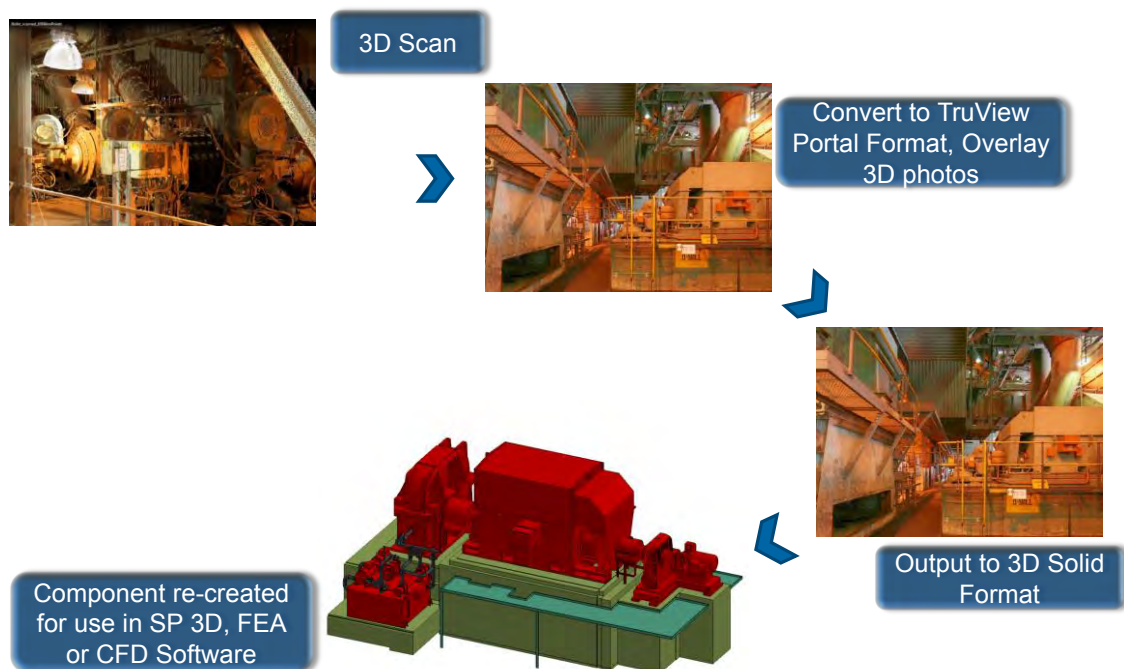
Although interoperability with external data sources could be demonstrated, the research found that some of these sources are not very reliable. It may, therefore, affect the value proposition of having access to the information if its availability cannot be guaranteed.

Unfortunately, some of these data sources are totally out of the control sphere of the Power Utility so there is limited remedial action that can be taken; save for trying to identify alternative similar data sources or implementing internal technology data sources that can replace the external capability.

10.2.4 Conversion of 3D Point Cloud content to solid 3D CADD models would be viable for Information Delivery

The initial strategy for Brownfields 3D laser scanning scope of work was to convert point clouds to solid 3D CADD models to use in the visualisation platform. Figure 11–2 depicts the research PoC process that was undertaken to use 3D laser scanning to create solid CADD models that can be enabled for visualisation purposes in a portal environment.

Figure 10–4: Using 3D point cloud data to create solid 3D Models



The research found the process of converting scan data to 3D solid objects very time-consuming and labour intensive. Even with improvements in technology, significant timelines were still involved if a solid 3D CADD model was the output for 3D visualisation. The cost and timeline for this effort did not make this a viable solution.

10.2.5 Static Process Analysis as a holistic solution

Static process analysis and calculations provide an indication of process change impact, but does not take process transient and settling times into consideration and can potentially give a false indication of expected behaviour.

Transient and dynamic analysis plant process analytics was proven to be a more trustworthy indication of plant behaviour and more closely correlated to actual plant behaviour under similar conditions and the plant behaviour when simulated in the Operating Training Simulator.

10.3 Final Thoughts on Business Improvement as a Driver for Social Change

Business is about the delivery of goods and services and ultimately creating wealth. Good business leadership requires responsibility towards humanity and the society in which it operates [Fitzgerald et al., 2006]. Issues like environmental management, sustainable use of water and other scarce resources, customer pricing for the goods delivered (price versus quality of supply) are many times the cause of societal outrage (and ultimately business failure) when a company does not consider the direct, indirect and often long term impact of poor business practices on the society they operate in.

Innovation is key to business survival in a globalised economy, and some of the primary roles of the engineering fraternity in today's society are to drive innovation and assisting business leaders to make use of available resources efficiently in a socially responsible way. Sustainable, responsible and efficient business operations holds especially true for process plant industries whose impact is usually very direct on society and its well-being.

Ironically, as societies strive for high standards of living and increased economic growth, there is a growing discontent that this often seems to happen at the expense of society, humanity and the environment they live in.

Being able to deliver on business goals, while continuously driving business improvement initiatives that is measurable and can be proven to provide real business benefit, is the challenge of all CEO's and management boards. Their leadership and the means/resources they provide to their employees to help realise these goals, will drive the success of the company and the level of societal acceptance.

Business is ultimately a reflection of the sum of the skills, experience and commitment of its employees. Enhancing and empowering employees with tools like business improvement methodologies ultimately enhances their ability to contribute into making the business more efficient, and ultimately adding value to the society they live in.

The IPI-BIM Framework of this research study provides a business improvement model for stakeholders and society alike to determine how efficient a process plant is in managing their assets and the resources they consume; and what is being done to improve its operations. It also empowers the business to justify and report on their process plant improvement initiatives not only in a monetary manner (important to shareholders) but also using other non-financial benefits (that are many times much more important to society than financial gains).

The credibility of a company to be socially responsible will be reflected on how effectively it runs its business operations and how responsibly it uses the resources society entrusts to it. Lack by businesses to show commitment towards continuous business improvement and social responsibility will activate the affected society to speedily find an alternative supplier of the goods/services – one that is perceived to be more trustworthy and cognisant of the needs of the society it functions in.

The conditions needed for positive societal change is motivation, ability and opportunity [Ute et al., 2013]. In this context, the IPI-BIM Cost Model provides the motivation and benefits for improving plant operations (reasons to change), the IPI-BIM Framework enhances the ability of the business to identify, initiate, drive and manage the change; and the proof of concept outcomes delivered as part of the research study highlights typical opportunities available to effect positive change in the process plant operations.

The complexity of the IP-BIM Framework and implementation methodologies are in a sense a reflection of the complex interlocking interests and needs of the different stakeholder groups in society when it comes to doing business.

Business leadership must ultimately consider and balance all the demands of regulatory and environmental compliance, a globalised economy, competitiveness, risk management, improved performance, financial profits and social accountability. This is a balancing act that is many times difficult and complex to execute – but achievable and very rewarding.

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ANNEXURES

ANNEXURE A – The ideal Plant Engineering Baseline

The table below indicates the organizational view on the ideal Plant Engineering Baseline (PEB):

Generic Information/Documentation/Records (Relevant to ALL Engineering Disciplines)		
Plant, Equipment and Component Design Calculations	Bills of Material	Images/Photographs of Plant, Equipment, Components
Plant 3D Models	Datasheets	Plant/Equipment/Component Brochures and Catalogues
3D Drawings	Diagrams and Sketches	Isometric Drawings
Plant Arrangement Drawings	Erection Material Take-Off List	Sectional Drawings
Specification Sheet	Statutory Approvals	Maintenance Technical Specifications
Legal Waivers/Exemptions	Test and Inspection Plans	Equipment Design Specifications
Technical Legislative Permits, eg CAPCO licenses	Test Certificates	Operating Technical Specifications
Technical Procedures	Software/Computer Code and Software Configuration	Plant Reports
Registers and Data Lists	Licenses	Technical Staff Authorisations
Plant Breakdown Structure (PBS)	Plant Tags (Unique KKS Codes)	Compliance Certificates/ Performance Certificates
Plant/Equipment Check-sheets	Commissioning Plans	Plant Process Descriptions
Plant Operating Procedures (Commissioning, Start-up, Shut-Down, Normal Operating, Alarm, etc.)	Plant Maintenance Procedures (including Cold Storage/Long term outage maintenance storage)	Plant Philosophies (Design, Operating and Maintenance)
Maintenance Manuals	Design Briefs	Design Review Reports
Non-Conformance Reports	Parts Lists	Plant/Project Modification Packages (Engineering Change Proposals)
Operating Manuals	QC Check-sheets	Quality Control Plans (QCP's)
Plant Occurrence/Incident Reports	Corrective Action Reports/Records	Temporary Plant Modification Records
Temporary Plant Operating Instruction Records	Plant Operating Specific Instruction Records	Risk Analysis
HAZOP Studies/Analysis	RAM Studies/Reports	Design Codes/Standards relevant to the Plant/Equipment/Component
Terminal Point (TP)/Limits of Service/Supply (LOSS) Registers	Condition Monitoring Requirements	Plant Health Monitoring Requirements (Activity/Frequency)
Engineering Data Exchange Schedules	Flow Analysis and Simulation models and reports	Environmental Impact Analysis Studies and Reports
Primary Energy Analysis Reports	Transmission Line Studies	FEA Analysis Reports
Guarantee/Warranty Certificates	Environmental Assessments (EIA's) Impact	Contractor/Vendor Document Submittal Schedules (CDSS/VDSS)

Civil Discipline	C&I Discipline	Electrical Discipline
Architectural Drawings	Cable Block Diagram	Cable Block Diagram
Structural Drawings	Cable List/Schedule	Cable List/Schedule
Civil Drawings	Cable Racking and Routing Layout	Cable Racking and Routing Layout
Plant Layout/Arrangement Design Drawings	Cable Schedule	Cable Schedule
Maps	Control and Instrumentation Drawings	Earthing Diagram
Digital Terrain Models	Control Panel General Arrangement	Electrical
Geotechnical Surveys	Field Connection/Wiring Diagram	Electrical Layout Drawing
Architectural Requirements Analysis/Reports	I/O List	Electrical Single Line Diagram
Meteorological Data Surveys and Analysis (Site Atmospheric and site specific conditions)	Installation Detail Hook-Up Drawing	Field Connection/Wiring Diagram
Geospatial Surveys and Data Analysis	Instrument Index	Hazardous Area Drawing
Aerial Photography and Survey Data/Reports	Instrument List	Ladder Logic Diagram
Contour Survey Maps and Reports	Instrumentation Location Plan	Lighting
Soil Surveys, Analysis Reports	Ladder Logic Diagram	Loop Diagram
Structural Load Maps	Panel Lay-Out Drawing	Panel Lay-Out Drawing
Railway siding planning/analysis	PLC Schematic	Power Block Diagram
General infrastructure layout (roads, drainage, cable tunnels, trenches, buildings)	Pneumatic Circuit Diagram	ICT Infrastructure Planning/Analysis
Plant Orientation and Lay-out, Grid and Co-ordinate lay-out	Schematic Diagram (Control)	Racking and Routing Drawing
Plant Space allocation	Signal Block Diagram	Schematic Diagram (Electrical)
Structural Steel Shop Detailing Reports and 3D Models	Trip/Alarm Schedule	Certificates of Compliance (CoC's)
	Alarm Response Procedures	Electrical Reticulation Networks
	Set-point Lists	Power Distribution Diagram
Process/Mechanical Engineering		HVAC
Functional PFD	Pneumatic Circuit Diagram	HVAC Drawings
Hydraulic Circuit Diagram	Primary PFD	HVAC Routing Diagrams
Mechanical Drawings	Secondary PFD	
P&ID (Piping/Process Diagrams)	Boiler Tubing Lists/BOM's	
Heat/Mass Balance Diagrams	Weld Lists	

ANNEXURE B – Verification and Validation of Rankine Cycle reverse engineering

An example of calculations to verify Rankine Cycle model against Design Base criteria is provided below.

Model Calculation Run – 08-Feb-16 09:32:47

Gross Generation: 618.041 MW

Net Generation: 618.041 MW

Aux Power: 0 MW

Net Unit Heat Rate: 9455.8 kJ/kWh

Gross Unit Heat Rate: 9455.8 kJ/kWh

Gross Turbine Cycle Heat Rate: 8321.1 kJ/kWh

Run Complete: 08-Feb-16 09:32:47

Boiler

Heat Input: 1428.551 MW

Results

Description	Value
Ash Production (kg/s)	40.573
Boiler Fuel Eff Efficiency – IO Method (LHV) (%)	0
Boiler Fuel Efficiency – IO Method (HHV) (%)	88
Boiler Gross Efficiency – IO Method (HHV) (%)	88
Boiler Gross Efficiency – IO Method (LHV) (%)	0
CO2 Production (kg/s)	156.244
Dry Excess O2 (%)	0
Excess Air (%)	0
Flue Gas Recirc Flow – Pct	0
Furnace B Burner Tilt	0
Furnace Burner Tilt	0
Furnace Gas Tempering Flow –Pct	0
Heat Input (MW)	1428.551
Loss Efficiency	Fuel Flow = 102.458 kg/s CO2 Production = 156.244 kg/s Ash Production = 40.573 kg/s
Low Pressure Reheat Spray Flow 1 (kg/s)	0

Low Pressure Reheat Spray Flow 2 (kg/s)	0
Mill Tempering Air Flow (kg/s)	0
Reheat Spray Flow 1 (kg/s)	13.623
Reheat Spray Flow 2 (kg/s)	0
Superheat Spray Flow 1 (kg/s)	56.469
Superheat Spray Flow 2 (kg/s)	0
Temperature Profile String	
Wet Excess O2 (%)	0

Design

Description	Value
Auxiliary Steam From Steam Drum (kg/s)	0
Auxiliary Steam From Steam Drum On	False
Blowdown Flow (kg/s)	0
Blowdown On	False
Carbon in Ash	2
Carbon in Ash (ppm)	20000
CO In Flue Gas	100
CO in Flue Gas (ppm)	100
Coal Mill Outlet Temperature (°C)	76.7
Coal Selection	0
Design Dry Excess O2	0
Design Excess Air	16
Design Fuel Flow (kg/s)	98.36
Design Low Pressure Reheat Flow (kg/s)	0
Design Low Pressure Reheater DP (bar)	0
Design Reheat Flow (kg/s)	478.855
Design Reheater DP (bar)	0.8
Design Superheat DP (bar)	21.3
Design Superheat Flow (kg/s)	509.763
Design Wet Excess O2	0
Economizer Exit Gas Temperature (°C)	336
Estimated Radiation Loss (%)	0.5
Gas Recirc Percent (%)	0
Gas Selection	0
Oil Selection	0
Once Through Superheat Control Temperature (°C)	535
Overfire Air	0
Quality of Auxiliary Steam From Steam Drum (%)	100
Set Boiler Efficiency (%)	88
Set Low Pressure Reheat Spray Flow (kg/s)	0
Set Low Pressure Reheater Percent DP (%)	0
Set Reheat Spray Flow (kg/s)	13.623
Set Reheater Percent DP (%)	7.34

Set Spray Flow (kg/s)	56.469
Set Superheater Flow (kg/s)	475.805
Set Superheater Outlet Pressure (bara)	161
Superheater Percent Pressure Drop	23.33
Target Hot Low Pressure Reheat Temperature (°C)	-17.8
Target Hot Reheat Temperature (°C)	531.2
Target Main Steam Temperature (°C)	528.8
Use Constant O2 or Excess Air	True
User Specified Constant Excess Air or O2 (%)	17.5

Water Nodes

Name	Description	MassFlow (kg/s)	Pressure (bara)	Temperature (°C)	Enthalpy (kJ/kg)
ndAuxSteam	Auxiliary Steam From Steam Drum	0	154.21	344.35	2602.68
ndBlrBlowdown	Boiler Blowdown	0	154.21	344.35	1627.6
ndFWInlet	Feedwater Inlet	419.35	190.19	208.91	899.38
ndRHInlet	Reheater Inlet	457.53	40.15	338.68	3066.06
ndRHOutlet	Reheater Outlet	471.15	37.2	531.22	3518.72
ndRHSpray	Reheater Spray	13.62	56.35	168.17	713.83
ndSHOut	Superheater Outlet	475.82	154.21	528.81	3386.12
ndSHSpray	Superheat Spray	56.47	190.22	208.91	899.38

Condenser, BFPT

Results

Description	Value
Circulation Water Inlet Temperature (°C)	19
Circulation Water Temperature Rise (delta °C)	12.1
Condenser Duty (MW)	17.693
Last Zone Circ Water Outlet Temp (°C)	31.1
Total Power Input (kW)	0
Zone 1 Condenser Pressure (cmHga)	3.78
Zone 2 Condenser Pressure (cmHga)	0
Zone 3 Condenser Pressure (cmHga)	0

Design

Description	Value
Circulating Water Density	62.4
Circulating Water Inlet Pressure (barg)	1.379
Circulating Water Pressure Drop (bar)	0.345
Circulating Water Specific Heat	1
Condenser Zones	1
Condenser/Cooling System Type	1
CW Flow in GPM (m ³ /s)	0.35
CW Inlet Temperature (°C)	19
Design Circulating Water Flow (m ³ /s)	0
Fan Diameter (m)	0
Natural Draft Velocity (m/s)	0
Natural Heat Loss	0
Number of Cells	0
Number of Cells in Service	0
Power Input per Fan (kW)	0

Water Nodes

Name	Description	MassFlow (kg/s)	Pressure (bara)	Temperature (°C)	Enthalpy (kJ/kg)
ndCircIn	Circulation Water from Cooling System	0	0	-17.78	0
ndCircOut	Circulation Water to Cooling System	0	0	-17.78	0

ndDrainIn	Drains Inlet	0	0.05	-17.78	0
ndOutlet	Condenser Hotwell Outlet	7.87	0.05	33.06	138.45
ndTrbStm0	Cond Zone 1 Turbine Steam	7.87	0.05	33.06	2387.86

Condenser, Main

Heat Output: 791.231 MW

Results

Description	Value
Circulation Water Inlet Temperature (°C)	12.8
Circulation Water Temperature Rise (delta °C)	14.3
Condenser Duty (MW)	791.231
Last Zone Circ Water Outlet Temp (°C)	27.1
Total Power Input (kW)	0
Zone 1 Condenser Pressure (cmHga)	2.13
Zone 2 Condenser Pressure (cmHga)	3.13
Zone 3 Condenser Pressure (cmHga)	0

Design

Description	Value
Circulating Water Density	62.4
Circulating Water Inlet Pressure (barg)	1.379
Circulating Water Pressure Drop (bar)	0.345
Circulating Water Specific Heat	1

Condenser Zones	2
Condenser/Cooling System Type	1
CW Flow in GPM (m ³ /s)	13.2
CW Inlet Temperature (°C)	12.8
Design Circulating Water Flow (m ³ /s)	13.2
Fan Diameter (m)	0
Natural Draft Velocity (m/s)	0
Natural Heat Loss	0
Number of Cells	0
Number of Cells in Service	0
Power Input per Fan (kW)	0

Water Nodes

Name	Description	MassFlow (kg/s)	Pressure (bara)	Temperature (°C)	Enthalpy (kJ/kg)
ndCircIn	Circulation Water from Cooling System	0	0	-17.78	0
ndCircOut	Circulation Water to Cooling System	0	0	-17.78	0
ndDrainIn	Drains Inlet	7.85	0.04	29.74	138.38
ndOutlet	Condenser Hotwell Outlet	359.06	0.04	29.09	121.85
ndTrbStm0	Cond Zone 1 Turbine Steam	175.6	0.03	23.22	2374.35
ndTrbStm1	Cond Zone 2 Turbine Steam	175.6	0.04	29.74	2374.36

EFP A

Heat Input: 0 MW

Results

Description	Value
Motor Power (kW)	0

Design

Description	Value
Bleed Pressure (bara)	0
Control Valve Mode	1
Control Valve Outlet Pressure (bara)	68.948
Design Temperature (°C)	15
Efficiency Mode (Constant-0/Curve-1)	0
Initial Inlet Flow (kg/s)	200
Initial Inlet Pressure (bara)	111.2
Initial Out Flow (kg/s)	495.135
Initial Outlet Pressure (bara)	210
Motor Efficiency	95
Pump Calculation Mode (Simple-0/Complex-1)	0
Pump Delta H (kJ/kg)	12.61
Pump Delta P (bar)	98.8
Pump Efficiency	81
Pump Head Mode (Constant-0/Curve-1)	0

Pump Head Pressure (bar)	82.737
Pump IP Delta H (kJ/kg)	0
Pump IP Delta P (bar)	0
Pump Power Mode (Calculate=0/Curve=1)	0
Reverse Pressure	2
Simple Pump Enthalpy Rise Method (Delta H=0/Efficiency=1)	True
Total Pressure Mode (Constant=0/Curve=1)	0
Total Pump Pressure (bara)	82.737
Use Pump Head	True
Use Pump head curve for Flow	False

Water Nodes

Name	Description	MassFlow (kg/s)	Pressure (bara)	Temperature (°C)	Enthalpy (kJ/kg)
ndBleed	Interstage Bleed	0	111.8	167.43	713.79
ndInlet	Pump Suction	0	111.8	167.43	713.79
ndOutlet	Pump Discharge	0	191.67	168.88	724.65