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Overcoming integration challenges in organisations with operational technology

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Abstract

Competitive advantage is traditionally an outcome of leveraging people, processes and technologies. Today organisations have several technologies with disparate information. Information integration may assist organisations to remain competitive. Organisations that have technology which manage or control assets have particular integration challenges compared to organisations with corporate business areas. This is because organisations do not view technology managing infrastructure assets in the same way as managing functions such as finance, retail and human resources. The paper defines a current, asset management based taxonomy for organisations integrating Operational and Information Technology. It identifies a number of challenges, such as the commitment to information integration, organisation-wide governance and architectural approaches as well as the aligning of operational open standards with existing information technology standards. Furthermore it highlights opportunities for further research in the area.

Keywords

Integration, Operational Technology, Information Technology, Engineering Asset Management

INTRODUCTION

Organisations have traditionally strived for competitive advantage by leveraging corporate information systems (Leavitt, 1965; Rockart, 1979). As organisations expand corporate information systems also expand and multiply organically and often chaotically, implemented by different organisational functions to support new functions in the lines of business and facilitate strategic decisions. As organisations expand, so does the disparateness of information. Twenty years ago Drucker (1995) identified that "knowledge has become the key economic resource and the dominant and perhaps even the only source of competitive advantage" (p. 271). Leavitt, Rockart and Drucker proposed competitive advantage was based on optimising people, processes and technology, and that competitive advantage is also dependent upon a holistic organisational wide view of information. An organisational wide view of information requires integration of staff, standards and technology integration. As with other organisations, engineering asset management organisations require fully integrated systems in order to maximise their use of information and knowledge assets and thus gain competitive advantage (Too, 2010).

The process of integrating information systems is compounded in organisations that utilise technologies that manage or control engineering and infrastructure assets. Examples of such organisations include power, water, sewerage, telecommunications, utilities, process plants and other infrastructure such as ports, transportation systems and large built structures. Information systems supporting these types of organisations include technologies such as Condition Monitoring Systems (CMS), Supervisory Control and Data Acquisition (SCADA), energy management systems, and sensor monitoring systems such as temperature and emission control systems. The governance and management of these asset control and management technologies and systems have been traditionally overlooked in most engineering and infrastructure type organisations. In those organisations such technologies, collectively known as Operational Technology (OT), are often managed and controlled in an ad hoc manner by engineering personnel. Unlike traditional information systems such as finance, human resources and retail which are managed by Information Technology (IT) personnel and are the responsibility of the IT Director or Chief Information Officer (CIO), Operational Technologies are excluded from such governance.

This paper examines this significant disconnect between Information Technology and Operational Technology. It defines key terms and identifies the challenges to achieving 'from device to the boardroom' integration as a requirement for effective decision making in asset management organisations. The research is part of a larger research project and reports on the first phase of the research.

REVIEW OF LITERATURE

The remainder of the paper will define key terms, provide a literature review of the area, outline the methodology used in this research and finally will report key findings, contributions, limitations and future research.

The term information technology (IT) has an established definition and refers to application of computers and telecommunication equipment to acquire, process, store, retrieve, manipulate, use and disseminate information (International Standards Organisation, 2008; Daintith, 2009). Components include hardware, software, electronics, semiconductors, internet technologies, telecommunications equipment and computer services (Chandler and Munday, 2012). Types of systems include Financial Management (FMS) Electronic Document Records Management (EDRMS), Billing, Enterprise Resource Planning (ERP), Customer Relationship Management systems, email and a plethora of other information systems and applications. Information Technology is differentiated from another class of technologies termed Operational Technology (OT). Although OT was coined as far back as the 1970's (Kariel, 1970), it is more recently popularised by Gartner (Streenstrup, 2008). Operational Technology is defined as hardware and software that detects changes, monitors or controls assets or processes. Such technologies generate real time asset data with embedded software. Operational technology controls or manages functions such as monitoring the condition of machinery, the operation of transportation systems, the control of (often remotely) power stations, oil rigs, automated process plants and other large engineering assets (Kariel, 1970; Steenstrup, 2008).

Operational Technologies are implemented and managed by engineering personnel, and are thus also governed by engineering standards and governance regimes. The main differences between OT and IT are highlighted in Table 1 shown below and represent people, process and technology challenges for information integration.

Table 1. The differentiation of Operational and Information Technology

Element (Pe=People, Pr=Process, Te=Technology)	Information Technology (often managed by IT branch)	Operational Technology (often managed by engineering branch)
Budget (Pr)	Dedicated for Branch	Embedded within another branches budget
Staff (Pe)	Dedicated IT focus – network analyst, engineer, systems administrator	Dual role – Engineering and IT maintenance focus
Staff focus (Pe)	Security	Reliability
Objective (Pr)	Strategy/decision making Control information	Asset performance Control asset
Systems standards focus (Pr)	COBIT/ITIL	NIST CIP, PAS55, ISA-95
Examples (Te)	Customer information, asset management and billing systems	SCADA or real time data tracking systems
Information type	Information non real time	Data real time
Networks (Te)	Consolidated	Own network beyond firewall
Uptime (Pr)	Down for patching/backups	100%

Adapted from Steenstrup (2010)

Recent years, through the dramatic increase in Internet technologies, have seen the corresponding increase of Internet Protocol (IP) enablement of not only corporate information systems but also engineering technologies, systems and even individual components such as motors, sensors and actuators. Today power stations, engineering process plants, mining rigs and other engineering assets can be controlled, often, remotely, through the Internet using IP protocols. Such systems have traditionally been 'closed systems' with their own vendor specific communication protocols. It is therefore becoming much easier for operational technologies, to be integrated with corporate information systems; so too are the challenges of governance and security becoming more critical. Vendors have in the past dominated in providing proprietary Operational Technologies to compliment corporate information system platforms (Lin et al., 2007; Waddington, 2008; Koronios et al., 2009, Thomas, 2009; Haider, 2010; Steenstrup, 2010; Institute of Public Works Engineering Australia, 2011; Strenstrup, 2011; Berst, 2011; Steenstrup, 2012).

As more and more of asset management organisations move away from government ownership and they themselves become more 'corporate', a need exists for the provision of complimentary information technology to assist organisations to achieve integration with 'the business'. Some industry researchers (Zimmerman, 2007; Steenstrup, 2008) have suggested that the level of integration may follow a particular maturation path. Terms suggested to indicate the stages along the maturation path include 'convergence', 'alignment' and 'integration' of people, processes and technology. They thus suggest that full integration of corporate information technology can be achieved through the passage from convergence to alignment and then integration of people, processes and technology.

Furthermore, taxonomies have been devised by practitioners and academic researchers. Examples include Teo and King's (1997) information systems strategic planning, Steenstrup's (2008) converge, align and integrate, Zimmerman's (2007) parallel and Hoque et. al's (2005) Build Transform Maximise (BTM) taxonomies. The taxonomies describe similar stages, albeit not consistently. For example, convergence is defined by Steenstrup (2010) as integration of platform, programming language and standards as activities undertaken by the vendor. Villars and Perry (2011) define it as the percent of data centre storage, memory, server nodes, network Input/Output virtualisation, and virtual operating system images that can be deployed from a pooled collection. Both definitions are technically hardware and networks based.

Whilst Zimmerman's taxonomy is based also on asset organisations, people and process compared to technical elements are highlighted. Convergence at the technical level is occurring with asset intensive industry *v*endors such as Ventyx and MDM Porta offering converged hardware and software solutions that are increasingly based on IT chips, routers and communication protocols (Jaffe, et. al, 2011; Romero, 2011; Berst, 2011; Rhodes, 2011). Such a technically oriented definition was not shared with earlier authors. Hoque et. al (2005) defines it as business and technology activities intertwining and leadership teams interchangeable. This is similar to Teo and King's (1997) classification of full integration.

Alignment is defined by Hoque (2005) as the state when technology supports and enables rather than constrains business strategies. Teo and King (1997) agree but refer to the step as sequential integration. Steenstrup (2010) defines alignment as occurring after convergence has been accepted by the organisation, leading to synchronized standards and architecture plans between the IT and OT systems. Luftman (2000) provides further qualification of this step with five stages of initial, committed, established, improved and optimized.

The discussion above highlights the emerging issues with the disconnect between Operational Technologies and Information Technology and the need for additional research to identify the activities and challenges in achieving information integration in engineering asset management organisations. The issues extend to reaching consensus on terminology and the taxonomies to describe the fiend as well as to identify the steps for full integration to be achieved. Once a taxonomy baseline is defined, applicable to the operational technology environment of asset management organisations, further challenges of information integration can be addressed. A summary of example taxonomy differences appear in Table 2 below.

Table 2. Convergence, alignment and integration taxonomies

Industry based		**Academic based**	
Steenstrup (2010)	**Zimmerman (2007)**	**Hoque (2005)**	**Teo and King (1997)**
Converge (OT and IT share same client, server, network tiers IT and IP based activities often undertaken by vendor)	Parallel Path (doing things more consistently between the groups, common understanding and respect)	Alignment (technology supports, enables and not constrains business strategies)	Sequential integration (business goals considered, formulate IS strategy to perform business strategy)
Align (occurring after convergence has been accepted by the organisation, leading to synchronized standards and architecture plans between the IT and OT systems)	Complimentary Path (IT and controls separate entities with different approaches, mindsets and methodologies, but are moving closer together, better defined responsibilities)	Synchronisation (IS expert resources, support business strategy)	Reciprooal integration (IS expert resources, support business strategy)
Integrate (an outcome of the alignment pending the impact	Converged Path (Controls engineering and IT groups have	Convergence (business and technology	Full integration (joint development of strategies,

of communications such as bandwidth reduction and firewall conflicts on performance, integrity and reliability of the two technologies)	some formal reporting structures ensuring at least one individual is focused on facilitating and taking advantage of convergence)	activities intertwining and leadership teams interchangeable)	senior management involvement, critical to success fo business)

A number of issues with the taxonomies identified in Table 2 will now be discussed. The convergence and alignment steps of the Steenstrup (2010) taxonomy are technically orientated and have not been empirically validated compared to Hoque (2005) and Teo and King's (1997) taxonomies. Hoque,Teo and King's taxonomies for information technology have been applied to integrating IT systems from a corporate information perspective, compared to an OT perspective. The Zimmerman (2007) and Steenstrup taxonomies provide organisational technology perspective of asset intensive organisations often overlooked in earlier literature such as Hoque. Each of the taxonomies, whilst providing documented stages of convergence, alignment and integration lack context such as who should be involved, when and how organisations should move between the stages.

Such people, process and technology elements indicate other issues that need investigation for practical application of the taxonomies. Moving between the maturity stages requires personnel from corporate and operational areas of organisations to identify roles in the integration process. Organisational and cultural issues also need investigation as the integration of OT and IT can provide a source of conflict in organisations when it comes to oversight and governance of the systems. This is because engineering personnel being reluctant to surrender control over what were traditionally in their domain.

Current literature does not provide guidance and often has opposing points of view as to whether the IT function or Engineering should be responsible for the governance and management of OT (Steenstrup 2008; Schneider, 2006; Kern, 2009). Identification of roles is further exacerbated by the number of information, security and computer governance frameworks, standards and principles that organisations may use to converge, align and integrate OT and IT. Examples include COBIT (embodied in International Standard 38500), NERC CIP security guidelines for the utility industry (International Electrotechnical Commission, 2007; Kassakin, 2011), MIKE 2.0 (Hillard, 2010) and Information Data Governance (IBM, 2007; Thomas, 2009). Furthermore, relevant engineering asset management standards exist and include PAS 55, ISA 95 and several industry players such as Rockwell Automation and Ventyx publish white papers covering roles, challenges and outcomes of information integration.

The literature also highlights the challenge of identifying the critical success factors for integrating information. Daniel (1961) initially identified critical success factors (CSF's) for organisational competitiveness. Rockart (1971) popularised Daniel's model with the identification of CSF's within contexts, indicating that contexts such as engineering asset management have three to six key areas that determine an organisations business success. Little literature is evident on the identification and application of CSF's to the asset management context for system integration. Mendoza et. al (2006) identifies system integration success requires configuration, data model standardisation, outsourcing management, justified change, senior management support, manage project scope, security strategy and communication but does not identify application to the asset management context. Others such as Yeoh et. al (2009), Parekh (2007) and Haider (2011) and Too (2010) highlight success factors for EAM organisations. The factors, such as interoperability, cross sharing of IT and engineering skills, enterprise wide care and information governance are not applied to the integration of technologies.

As a summary, the key issues and gaps from the literature review include;

1. Taxonomy - Establishing a maturation path to integration that has a consistent definition, empirically validated and for the asset management context.
2. People challenges – Is engineering, IT, vendors and or the organisation responsible and for what parts of the taxonomy and what role do differences in perceptions about security and reliability play
3. Process challenges – Are existing, empirically validated critical success factors applicable to the OT and IT integration context and which standards should be applied
4. Technical challenges – Consolidation of hardware, network, application, information and data tiers

RESEARCH DESIGN

Myers (2009) distinguishes between qualitative and quantitative research methods. Quantitative methods such as laboratory experiments were designed to study natural phenomena, whereas qualitative methods such as observation, interviewing, questioning and reviewing documentation were designed to study social and cultural phenomena. When and whom in an organisation should converge, align or integrate operational and information technologies is not a natural but a social phenomenon. The current research is of a qualitative nature because it explores the extent information integration is being applied in the social context of practice (Chua and Garrett, 2009) of engineering asset management.

The aim of this research is to understand the social context of engineering asset management organisations integrating information for competitive advantage. The specific aim of the research is twofold:

1. Firstly to identify a current, asset management, practitioner based taxonomy clarifying the maturation stages, if they indeed exist, of information integration;
2. Secondly to identify the people, process and technology challenges of information integration in engineering asset management organisations.

The Delphi qualitative research method was chosen to meet the research aims as it facilitates, through consensus of expert practitioner, understanding of information integration in an asset management context. Chua and Garrett (2009), Myers (1997) and Kaplan and Maxwell (1994) identify the need to choose research methods which allow the study of the social context of practice. Mintzberg (1979) and Eisnehardt (1989) highlight the choice of methods should lead to data validity and theory building. Delphi research method has been used, as in the current study, for technical forecasting (Dalkey, 1959; Gordon and Helmer, 1964; Cornish, 1977) in the information systems domain for the past thirty years (Pare et. al., 2013). The method provides for subjective individual judgements, meeting time and cost efficiencies, a way of efficiently structuring group dialogue and bringing together different organisational functions such as IT and Engineering in a non-competitive environment (Sitt-Ghodes and Crews, 2004; Powell, 2003; Turoff, 1970).

Three survey rounds covering key Delphi components of brainstorming, selection and ranking phases as a means for consensus-building using a series of questionnaires to collect data from a panel of geographically dispersed participants (Pare et. al, 2013) were undertaken. In the first round thirty participants from twenty seven Australian consulting, utility, mining, councils, IT solutions, planning and development government agencies and engineering manufacturers agreed to respond to open ended questions relating to convergence, alignment and integration of operational and information technology in organisations with engineering asset management functions.

Theoretical sampling of practitioners as opposed to statistical sampling was used in the study to facilitate validity and reliability through replication as defined by Yin (2009), model building and applicability of theory (Eisenhardt,1989; Benbasat, et al., 1987). Practitioners were drawn from asset intensive organisations that have professional information, engineer and IT staff and hardware or software that detect or cause a change through the direct monitoring and or control of physical devices, processes and events (such as Asset Management Systems, SCADA, telemetrics and geological monitoring (GIS systems) convergence, integration and alignment OT and IT and if information governance facilitated these activities. Table 3 Below summarises the cohort of practitioners consistently responding to three rounds of questionnaire's.

Table 3. Delphi study participant details

Organisation Type	Job title	Location
Utility	Asset Owner Business Manager Information Technologist Business Manager Asset Manager	Northern Territory New South Wales Queensland Queensland New South Wales
Contractors	Project Manager Asset Advisor Information Manager Legal Advisor Information Technology Advisor Asset Owner Researcher Asset Engineer Business Analyst	Northern Territory Queensland Northern Territory New South Wales Victoria Queensland Victoria Victoria Brazil
Machinery provider	Chief Information Officer	Northern Territory
Software/hardware provider	Managing Director Technologist Systems Engineer	Queensland Queensland Queensland
University	Academic	Queensland

Asset intensive Government agency	Chief Information Officer Asset Manager Information Manager	Northern Territory South Australia South Australia
Mining	Asset Manager Technologies	South Australia South Australia
Council	Technologist IT Manager	South Australia South Australia

Fifteen responses (50%) to the first questionnaire were received over four weeks in October and November 2012. Thirteen responses were received via email, and two were elicited via telephone calls, and one by social media. Other respondents indicated that they were not familiar the convergence of operational technology and information technology to adequately respond. Responses were thematically analysed and provided rankings of key terms for use in round two and three questionnaires. A Likert scale was added to the questionnaire to facilitate identification of consensus. Twelve individuals of the fifteen participating in Delphi questionnaire for round one responded (80%) to questions covering .when organizations should converge, align and integrate OT and IT, whom should be responsible, why organisations should undertake such activities and if information governance could facilitate convergence, alignment and integration activities in organisations with engineering asset management functions. Responses were received over three weeks in November and December 2012. Eleven responses were received via email and one via telephone.

All respondents of the Delphi cycles 1 and 2 were invited to respond to the cycle 3 questionnaire. Comprehensive feedback of the group consensus was given to all participants of the Delphi study after each cycle. Non responding participants were followed up by telephone in January 2013. Of the sixteen invited to respond, 10 responded (62.5% down from 80% in cycle two). Four changes were made by respondents between rounds one and two did not alter consensus rankings from cycle two. An almost 20% drop in responses between cycles indicated there would be little benefit from undertaking subsequent cycles particularly where the same depth of concept description means overselling is a risk to busy experts (Linstone and Turoff, 2002; Goodman, 1970).

Several statistical measures were used to measure consensus of practitioners as there is no one agreed set of statistics to indicate consensus (Hasson, Keeney and Mckenna, 2000). The mean (average answer on the Likert scale) was calculated to identify group response to indicated if organisations should always or never undertake a task. Measures of central tendency such as correlation coefficients, percentages, mean, median, and Inter Quartile Range (IQR) have been used to identify consensus in Delphi studies (Dalkey, 1969 and Linstone and Turoff, 2002; Santos, Araújo and Correia, 2012; Raskin, 1994; Rayens and Hahn, 2000; Von Der Gracht, 2008). Percentages were not used in the current research as the previous literature did not indicate consistency of the point range, ranging anywhere from 15% change in mean score between rounds to between 51% - 100% (Stitt-Gohdes and Crews, 2004; Hasson, Keeney, McKenna, 2000; Green et al (1999); Sumsion, 1998; Loughlin and Moore, 1979 and Mckenna, 1994).

A standard deviation closest to 0 was calculated to indicate consensus polarisation by the practitioners. The Interval Quartile (or interquartile) Range (IQR) was also calculated. The Interval Interquartile Quartile Range (IQR) was calculated as this has been used to indicate consensus in original Delphi studies (Dalkey, 1969; Linstone and Turoff, 2002) and recent studies in IT contexts. An IQR of less than 1 with closer to 0 representing higher consensus. Consensus levels were identified as Strong, Medium, Low or No consensus based on a combination of the three statistics as in Table 3 below.

Table 3. Ranking points for three survey rounds conforming to Delphi method

Mean	**Standard Deviation**	**Interquartile Range**	**Number of responses**	**Likert scale**
$\bar{x}$ Strong consensus = above 8	σ Strong consensus = less than 2	IQR Strong consensus = less than 1	N More than half responding	1 = Never 3=Sometimes 5=Always

The people, process and technology elements were chosen to group results for presentation and discussion as the balanced elements required for organisations to be effective (Leavitt, 1965; Rockart, 1979) and account for current theories of integrated asset management (Too, 2010; Brown et. al., 2011) .The research was also based on the most current taxonomy covering the majority of the organisational effectiveness elements applicable to the asset management context. Steenstrup's taxonomy terminology of convergence, alignment and integration was used as the basis to confirm practitioner understanding of what are, roles, when and why organisations move through the maturation stages, culminating in integration. The results provide empirical validation for Steenstrup's (2008) taxonomy and existing integration critical success factor identification, whilst providing new insights, particularly at the pre convergence stage, to enable detailed application of taxonomy by researchers and practitioners in the asset management context.

FINDINGS

The overarching aim of the research was to identify a current, asset management, engineering and information technology practitioner based taxonomy clarifying the maturation stages of information integration and to identify the challenges of achieving such integration. This could be used as a basis for identifying the critical success factors for achieving integration and to build a framework for doing so; these are intended activities of the next stage of this research.

A summary of the key taxonomy, people, process and technology challenges identified by practitioner consensus and current literature appear in Table 4 below.

Table 4. Delphi study findings of OT and IT integration challenges for asset management organisations

Challenge	Issue	Literature	Delphi consensus findings
Taxonomy	Consistent definition Current taxonomy applicability to asset management context Empirical validity of Current taxonomies	Asset Management context Zimmerman (2007), Steenstrup (2008-2013) Corporate information context Hoque (2005), Tao and King (1997) People, Process and technology elements for efficient organisations Leavitt (1965), Rockart (1979) Gap = Empircally validated definition for asset management context	One size not fit all ($\bar{X}$4, σ .77, IQR -1); Asset management context pathway; Converge to align when; Hardware consistent but applications disparate ($\bar{X}$4.09, σ .7, IQR -.05); business needs accounted for ($\bar{X}$4.36, σ .81, IQR -1); costs ($\bar{X}$43.45, σ .82, IQR -1) Align to integrate when; When data use requires it ($\bar{X}$ 3.82, σ .75, IQR 0); when IT/OT structures aligned ($\bar{X}$ 3.82, σ .75, IQR 0) and when market competitiveness requires it ($\bar{X}$4.36, σ .67, IQR -1)
People	Engineering or IT responsible Vendor or organisation responsible Reliability or Security importance	Managed separately Jaffe et al (2010) Roles Steenstrup (2008), Barber (2012); Schneider (2006), Kern (2009) Security v reliability Griffith (201), Barwick (2013), Chaudary, (2012), Beggs (2012) Gap = integration	a. Combined ($\bar{X}$4.73, σ .47, IQR -.5) b. Vendors converge, organisations align and integrate (66%, ($\bar{X}$1.58, σ .92)
Process	Critical Success Factors applicable to asset management context such as costs, training, management support, standards, planning, project governance	Identifying CSF's for context Daniel (1961), Rockart (1979) CSF's for managing system integration - Configuration, data model standardisation, outsourcing management, justified change, senior management support. Manage project scope, security strategy, communication Mendoza et. al. (2008) CSF's for asset management OT/IT context Standards PAS 55, ISA 95, COBIT/ISO38500, ISO15489, NERCCIP System implementations in EAM orgs Yeoh, et al. (2009), Interoperability of IT and Engineering platforms and standards Office of the National Coordinator for Smart Grid Interoperability (2010), International Electrotechnical Commission (2007),	High consensus Agreed enterprise level architecture ($\bar{X}$3.91, σ .54, IQR 0) Medium consensus Strategic vision ($\bar{X}$4.27, σ .47, IQR -.5); research, plan and execute ($\bar{X}$4.45, σ .69, IQR -1); open data and communication standards ($\bar{X}$ 4.18, σ .6, IQR -.5); manage as a project ($\bar{X}$4.18, σ .75, IQR -1); mutual collaboration ($\bar{X}$ 4.09, σ .71, IQR -1 Input from all ($\bar{X}$4.27, σ .9, IQR -1); ease of use ($\bar{X}$3.55, σ .82, IQR -1); engineering and IT role to catalyse business

		Enterprise wide asset care and Information governance Parekh (2007); Debois (2012); Cross sharing of IT and Engineering skills Boone (2008), Haider (2011) Gap = applicability to OT and IT integration context	change ($\bar{X}$3.64, σ .81, IQR -1) Low consensus Interoperable solutions ($\bar{X}$3.82, σ .87, IQR -1.5) Robust framework ($\bar{X}$3.91, σ .7, IQR -1); systems thinking analysis ($\bar{X}$3.91, σ .7, IQR -.5) Appropriate training ($\bar{X}$4.18, σ .87, IQR -.51)
Technology	Integration of OT and IT such as data and information, networks, communications, hardware, software tiers Why How	Integration is or should occur Zimmerman (2007) Steenstrup (2008-2013), Lin et al. (2007); Waddington (2008), Koronios et al.(2009), Thomas (2009), Haider, (2010), Steenstrup (2010), Institute of Public Works Engineering Australia (2011); Strenstrup (2011); Berst (2011), Steenstrup (2012), Parekh et al. (2007), British Standards Institute (2008); Brown (2011); Institute of Public Works Engineering Australia (2011); Government Asset Management Committee (2004) Gap = Empirically validated why & how OT & IT integration occurs in asset management practice	a.Why High Efficient exchange of data; efficient management of information ($\bar{X}$4.55, σ .52, IQR -1) increased reliability($\bar{X}$4.36, σ .67, IQR -1) Medium Decreased costs ($\bar{X}$3.55, σ .82, IQR -1); single platform ($\bar{X}$3.09, σ .83, IQR 0) b. How High Information governance facilitate enterprise level technology change coordination ($\bar{X}$4.18, σ .75, IQR -1) Medium Business analysis ($\bar{X}$4.36, σ .81, IQR -1); joint business effort ($\bar{X}$4.27, σ .679 IQR -1); standardised platforms ($\bar{X}$3.64, σ .81, IQR -1) Low Governance informs strategy ($\bar{X}$4.09, σ .83, IQR -1.5)

The key taxonomy, people, process and technology challenges identified by practitioner consensus are identified below according to the elements for competitive advantage identified by management theorists such as Teo and King (1997), Hoque (2005), Rockart (1979) and Leavitt (1965). The order of presentation is;

1. Taxonomy - Establishing a maturation path to integration that has a consistent definition, empirically validated and for the asset management context
2. People challenges – Is engineering, IT, vendors and or the organisation responsible and for what parts of the taxonomy and what role do differences in perceptions about security and reliability play
3. Process challenges – Are existing, empirically validated critical success factors applicable to the OT and IT integration context and which standards should be applied
4. Technical challenges – Consolidation of hardware, network, application, information and data tiers

Taxonomy challenges

The research set out to establish a maturation path to integration that has a consistent definition, empirically validated and for the asset management context. Compared to previous taxonomies the current research identified pre convergence or first stage tasks of business analysis, documenting convergence strategy, alignment of open and communication standards, mutual collaboration between IT and Engineering using project management techniques and documenting critical success factors. Respondents confirmed Steenstrup's identification that convergence occurs when technical components used are the same for OT and IT. Such technical elements are not evident in the other taxonomies.

The current research identifies that asset management organisations should converge when there is consensus between business and IT functions to work collaboratively and move from converging to aligning OT and IT when hardware is consistent but applications are disparate, when business needs are accounted for and when IT structures are aligned. At this point Steenstrup's taxonomy identifies synchronised standards and architecture plans, which in the current research were indicated by practitioners as occurring prior to the convergence stage. The other taxonomies focus on the collaborative people elements at this stage.

Respondents to the current study agreed that organisations should move from alignment to integration when market competitiveness and data use requires it, providing guidance to organisation when to strive for integration. The Steenstrup taxonomy does not indicate characterisation of the ultimate information integration goal, indicating organisations should manage firewalls, bandwith, impacts on performance, integrity and reliability, and, as with the other taxonomies focusses on collaborative elements of OT and IT staff. The current research fills this gap by indicating integration is characterised by agreed enterprise level architecture, standardised platforms, efficient exchange of data, efficient management of information, increased reliability, decreased costs and collaboration between Engineering and IT.

These findings provide a significant contribution for systems integration knowledge in the asset management context by empirically confirming for researchers and practitioners with definitions, activities and roles at stages along the path to integration whilst empirically confirming where on the continuum asset organisations are currently at and how and when to move to actualising information integration for competitive advantage.

The research results have provided a unique contribution of knowledge. Thus being a current, asset management, OT and IT integration contextual, empirically validated maturation taxonomy. The empirically validated results indicate asset management organisations planning to integrate OT and IT for competitive advantage should;

1. Plan for convergence when external factors such as a corporate vision and consolidated industry standards are in place. Organisations should prepare by analysing business needs and objectives, planning and research options available and developing a convergence strategy. At this point vendors may sell l a vision of convergence to organisation.
2. Move to convergence when there is consensus between business and IT. Convergence is established when vendors provide hardware which is IP addressable and has the same chips and routers as provided in other parts of the organisation and engineering, information management & IT provide input into application development.
3. Move from convergence to alignment when the hardware is in place but applications and information are disparate. Alignment is characterised by an architecture aligned by IT & Engineering with advice provided by vendors.
4. Move from alignment to integration when market competition and need for cost savings arise. The integration stage is characterised by enterprise wide data exchange.

A summary of how the theoretical contribution contributes to existing taxonomy body of knowledge is provided in Table 5 below.

Table 5. A new taxonomy of information integration for organisations with operational technology

New asset infrastructure OT and IT consolidation taxonomy	**Existing IT and OT consolidation taxonomies**		
Kuusk - See Johnson and Steenstrup (2013) Operational and corporate technology, industry and academic focus	Steenstrup (2010) Operational technology industry focus	Hoque (2005) Corporate technology academic focus	Teo and King (1997) Corporate technology academic focus
Pre convergence (Business analysis, convergence strategy, open and communication standards, mutual IT & engineering collaboration)	Elements not identified	Elements not identified	Elements not identified

Convergence (Consistent hardware provided by vendor; IT & engineering consensus and input into application development)	Converge (OT and IT share same client, server, network tiers IT and IP based activities often undertaken by vendor)	Alignment (technology supports, enables and not constrains business strategies)	Sequential integration (business goals considered, formulate IS strategy to perform business strategy)
Alignment (Architecture aligned by IT and Engineering; Hardware in place but applications disparate)	Align (occuring after convergence has been accepted by the organisation, leading to synchronized standards and architecture plans between the IT and OT systems)	Synchronisation (IS expert resources, support business strategy)	Reciprocal integration (IS expert resources, support business strategy)
Integration (Efficient exchange of information and data; driven by market competition and cost savings)	Integrate (an outcome of the alignment pending the impact of communications such as bandwidth reduction and firewall conflicts on performance, integrity and reliability of the two technologies)	Convergence (business and technology activities intertwining and leadership teams interchangeable)	Full integration (joint development of strategies, senior management involvement, critical to success of business)

People challenges

The research set out to establish what roles and responsibilities engineering, IT, vendors and organisation play in achieving integration. Respondents indicated that vendors provide converged hardware, organisations align and integrate with the assistance of vendors. Results indicated integration should be the combined task of IT and Engineering, possibly IT and not by Engineering personnel on their own. The results also indicate that with a combined approach to integration discrepancy between engineer and information technology risk tolerances and perceptions of security and reliability may impede the two areas working together. The literature review identified security as a reason for integrating, whilst this was not highly rated in the current study as reliability was identified as a higher ranking element. Such cultural risk tolerances and perceptions need further study for application to the asset management context.

Process challenges

Several empirically validated critical success factors related to people, process and technology integration are provided in existing literature. The research set out to identify the applicability of such critical success factors to OT and IT integration in asset management. Factors identified in the existing literature, such as manage as a project, training, ease of use and agree on standards prior to embarking upon integration activity were confirmed in the current study. The results also contribute further critical success factors to those commonly identified in information systems literature, indicating specificity for the asset management context. Management support was not identified as a factor, whilst agreed enterprise level architecture ranking as medium to high factors differentiating previously identified critical success factors to those applicable to the asset management context.

Several engineering, IT and information governance standards have been identified in the literature. Analysis of respondent results indicated medium consensus for standardised platforms, and in responses to a separate questions, consensus qualified this to be open data and communication standards. Further research may further define standards used in system integration activities by asset management organisations.

Technical challenges

The research set out to establish challenges for consolidation of hardware, network, application, information and data tiers when integrating OT and IT. In relation to hardware, consensus of practitioners indicated organisations move to alignment when hardware is consistent but applications are disparate and indicating moving to the maturation point of integration when technology tiers are aligned and data use requires integration. This validates the need for integration information to achieve competitive advantage. Medium consensus was identified for achieving a single platform from integration.

A significant contribution of the results is validating the applicability of information integration to the competitive advantage goal of asset management organisations. Efficient exchange of data and management of information was the highest ranked consensus item of any responses across the survey questions and is increasingly important as asset managers move to predominantly public from private ownership and therefore different governance frameworks and competitive challenges.

The significance of the findings are discussed in the next section.

DISCUSSION

Engineering asset organisations with substantial Operational Technology supporting their operations face challenges when striving for competitive advantage in an environment of increased competition. For many such organisations competition is quite foreign as they have been in many cases government monopolies. The organisations may be supported in their quest for competitive advantage from information integration by applying the preliminary framework identified by practitioner responses in the current research. The research findings contribute unique and empirically validated insights into OT and IT integration in the asset management context. Such unique insights are explored, albeit briefly below by comparing the existing literature to the findings. The discussion covers the main challenge areas of taxonomy, people, process and technology.

The research set out to establish a maturation path to integration that has a consistent definition, empirically validated as it may apply to engineering asset management context. . Results in this study suggest that the time to move from converging to aligning activities is when a number of disparate systems exist within these organisations. Furthermore, it suggests that organisations should move from alignment to integration after an whole-of organisation enterprise architecture activity has been completed. From the governance perspective explicit roles and responsibilities need to be further clarified. In particular the professional and cultural risk definitions and tolerances that engineers and information technology personnel bring to the integrated project team table need further investigation as an impediment to achieving integration and therefore competitive advantage.

A number of critical success factors were confirmed, dismissed or added as applicable to IT/OT governance in engineering asset management organisations. Notable contributions of the research include an additional pre convergence stage to existing taxonomies, top level management commitment not being a significant factor whilst confirming information integration for competitive advantage in the asset management context, a commitment to open data and communication standards, agreed vision and architecture at the outset as particularly relevant to the asset management context.

LIMITATIONS AND FUTURE RESEARCH

Whilst progress has been made in the development of a taxonomy for organisations with operational and information technology, further validation is required. A number of challenges have been identified in closing the gap between Operational Technology and Information Technology governance. Work still remains in identifying the steps for achieving this less from the technology standpoint and more from the organisational, cultural and people issues within engineering asset management organisations. The Delphi study poses some methodological limitations in terms of validity and generalisability. Further research using in-depth case studies of multiple engineering asset management organisations will provide additional insights to refine the current research findings.

CONCLUSION

This paper defines a current, asset management based taxonomy for organisations integrating Operational Technology and Information Technology. It has identified a number of challenges, such as the commitment to information integration, organisation-wide governance and architectural approaches as well as the aligning of operational technology open standards with existing information technology standards. Furthermore it highlights opportunities for further research in the area.

REFERENCES

Barwick, H. 2012. “SCADA systems in Australia easy target for malware: Security expert”. *CIO Australia.* 9th August.

Beggs, C. 2008. " A holistic SCAD security standard for the Australian context". In *Proceedings of the 9th Australian Information Warfare and Security Conference*. Perth:Edith Cowan University,

Benbasat, I; Goldstein, D and Mead, M.1987." The Case Research Strategy in Studies of Information Systems," *MIS Quarterly*, (11:3), pp369-386.

Berst, J. 2011. "Smart grid technologies putting pressure on utility IT spending, says new report". *SmartGrid News*. 26th October.

Boone, T. and Ganeshan, R. 2008. "Knowledge acquisition and transfer among engineers: effects of network structure," *Managerial and Decision Economics*, (29:5),pp 459–468.

British Standards Institute. 2008. *PAS 55: Specification for the optimized management of physical assets.* London:British Standards Institute.

Brown, K, Laue, M., Keast, R., and Montgomery-Hribar, J. 2011. *Guide to Integrated Strategic Asset Management.* Brisbane:Australian Asset Management Collaborative Group.

Chandler, D and Munday, R. 2012. "Information technology", *A Dictionary of Media and Communication* (first ed.), Oxford: Oxford University Press.

Chaudary, .A. 2012. "Is the Business Network Connected to SCADA?Need for Auditing SCADA Networks.*"* *ISACA Journal*, (6).

Chua Chia, F and Garrett, T. 2009. *Understanding Ontology and Epistemology in Information Systems Research.* IGI Global:Hershey.

Cornish,W. 1977. *The study of the future*. Washington, D.C.: World Future Society.

Daintith, J, Ed. 2009. "IT", *A Dictionary of Physics*, Oxford University Press, retrieved 1 August 2012

Dalkey, N. 1969. *The Delphi Method: An Experimental Study of Group Opinion*. Santa Monica: RAND Corporation.

Daniel, D. 1961." Management Information Crisis". *Harvard Business Review*, (39:5), pp 111-116.

DeuBois, L and Tero,V .2010. *Practical Information Governance: Balancing Cost , Risk, and Productivity*. IDC: Framingham.

Drucker P. 1995. *Managing in a Time of Great Change*. Truman Talley: New York.

Eisenhardt, K. 1989. **"**Building Theories From Case Study Research," *The Academy of Management Review;* (14:4), pp, 532.

Gordon, T. and Helmer, O. 1964. *Report on a Long Range Forecasting Study*. Santa Monica: RAND Corporation.

Goodman, J. 1970 "Delphi and the law of diminishing returns", *Technological Forecasting and Social Change***,** (2:2).

Government Asset Management Committee**.** 2004. *Total Asset Management Manual*. Sydney: Government Asset Management Committee.

Griffith, C .2012. "Hackers tap into local essential services." *The Australian*, August 7th.

Haider, A 2010. "Enterprise architectures for information and operational technologies for asset management,". In E*ngineering asset management and infrastructure sustainability:5th World Congress on Engineering Asset Management* (Mathew, J et al. Ed.), p. 315, Brisbane, Australia.

Haider, A. 2011. "IT Enabled Engineering Asset Management: A Governance Perspective," *Journal of Organizational Knowledge Management*.

Hasson, F; Keeney, S and Mckenna, H. 2000. Research guidelines for the Delphi survey technique", *Journal of Adbvanced Nursing*, (34:4), , pp 1008-15.

Hillard, R. 2010. *Information-Driven Business: How to Manage Data and Information for Maximum Advantage*. New Jesey:Wiley.

Hoque, F., V., Z., Trainer, T., & Wilson, C. 2005. *Winning the 3-Legged Race: When Business and Technology Run Together*.1st Ed. Upper Saddle Riv-er, New Jersey: Prentice Hall.

Institute of Public Works Engineering Australia. 2011. *International Infrastructure Management Manual.* Syndey:Institute of Public Works Engineering Australia.

International Electrotechnical Commission. 2004.*Application integration at electric utilities:System interfaces for distribution management.* Geneva: International Electrotechnical Commission.

International Standards Organisation. 2008. ISO/IEC 38500 IT governance standard . Geneva: International Standards Organisation.

Jaffe, S., Torchia, M, Feblowitz ,J & Nicholson, R. 2011. "The Virtual Power Plant: Integrating Operations Technology and IT," *IDC Energy Insights*. Framingham:IDC.

Johnson, G & Steenstrup, K. 2013. "IT and OT practitioner survey indicates best practices for IT/OT integration". 2556715. Gartner, USA.

JohKariel, H and Karile, P.1970. "Toward an operational definitoin and measurement of technology". *The Annals of Regional Science* (4), pp15-25.

Kaplan**,** B**.,** and Maxwell**,** J. A. 1994**. "**Qualitative research methods for evaluating computer information systems"**.** In *Evaluating health care information systems**:** Methods and applications* (J. G. Anderson**,** C. E. Aydin, & S. J. Jay Eds.), p 45, Thousand Oaks:SAGE.

Kassakian, J, Schmalensee, R, Hogan, W., Jacoby, H., 2011. *MIT study on the future of the electric grid.* Cambridge:Massachusetts Institute of Technology.

Kern, A. 2009. "IT/automation convergence revisited:Keeping automation close-coupled to operation is key." *Hydrocarbon processing*. (June), pp 61 – 62.

Koronios A, Steenstrup C and Haider A, 2009. "Information and Operational Technologies Nexus for Asset Lifecycle Management." In *4th World Congress on Engineering Asset Management*(D. Kiritsis Ed.), p 112, Athens, Greece.

Leavitt, H. 1965. *Applied Organizational Change in Industry*. Pittsburgh:

Lin, S, Gao, J, Koronios, A and Chanana, V.2007. "Developing a data quality framework for asset management in engineering organisations*". International Journal of Informaiton Quality*, (1:1), pp 100-126

Linstone, H and Turoff, M.Eds. 2002. *The Delphi method:Techniques and applications*. Murray Turoff and Harold Linstone. Available at http://is.njit.edu/pubs/delphibook/. Last accessed 30th July 2013. "

Luftman, J.2000. "Assessing business IT alignment maturity". *Communications of the Association for Information Systems*, (4:14), pp 1-50.

Mendoza, 2006. "Critical success factors for managing systems integrations," *Systems Development*, Spring.

Mintzberg, H. (1979). *The Structuring of Organizations*. Englewood Cliffs: Prentice Hall.

Myers, M. 1997. "Qualitative Research in Information Systems,", *MIS Quarterly*, (21:2), pp 241-242.

Office of the National Coordinator for Smart Grid Interoperability . 2010. *NIST Framework and Roadmap for Smart Grid Interoperability Standards*. Gaitherburg: National Institute of Standards and Technology.

Pare, G , Camneron, A., Poba-Nzaou, P., Templier, M. 2013. "A systematic assessment of rigor in information systems ranking-type Delphi studies." 2013. *Information & Management*. (50:5), pp 207-217.

Parekh, K., Zhao, J., McNair, K and Robinson, G. 2007. "Utility enterprise Information governance Strategies." *Grid Interop Forum*, Albuquerque

Powell, E. And Renner, M.2003. Analysing qualitative data. Program Development and evaluation. Madison: University of Wisconsin.

Prusak, L and Davenport, T.1997. *Information Ecology*. Oxford University Press, London.

Rhodes, R. 2011. *A Guide to Adapting IT Tools for Smart Grid OT*. Gartner:USA. .

Rockart, J. 1979. "Chief Executives Define Their Own Data Needs," *Harvard Business Review*, (57:2), pp 81-93.

Romero,C. 2011. *Convergence of Information and Operation Technologies (IT & OT) to build a successful smart grid.* Ventyx: Atlana.

Schneider, J., Gaul, A., Neumann, C., Hografer, J., Weelbow, W., Schwan, M., Schnerrlter, A. 2006. "Asset management techniques," *Electrical Power and energy Systems*, (28), pp 643-654

Stitt-Gohdes, W. L., & Crews, T. B.2004. "The Delphi technique: A research strategy for career and technical education. " *Journal of Career and Technical Education*, (20:2),pp, 55-67

Steenstrup, K.. 2008. *IT and OT: Intersection and Collaboration*. Gartner, USA.

Steenstrup, K 2010. *Operational Technology Convergence with IT: Definitions*. Gartner, USA.

Steenstrup, K. 2011. *IT and OT: Intersection and Collaboration*. Gartner, USA.

Steenstrup, K. 2012. *User survey analysis:Utility IT and OT integration and ownership*, *2012*. Gartner, USA.

Teo, Thompson S.H., and William R. King. 1997. "Integration between Business Planning and Information Systems Planning: An Evolutionary-Contingency Perspective", *Journal of Management Information Systems*, (14,) 185-214.

Thomas, G. 2009. *The DGI Data Governance Framework.* Orlando:Data Governance Institute.

Too, E. (2010. "A Framework for strategic infrastructure asset management," In *Definitions, concepts and scope of engineering asset management* (Amadi-Echendu, J; Brown, K; Willett, R; Mathew, J Eds.). Springer, London

Turoff, M. 1970. "The design of a policy Delphi", *Technological Forecasting and Social Change* (2:2).

Villars R & Perry, R. 2011. *Measuring the business value of converged infrastructure in the data center.* Framingham:IDC.

Waddington, D. 2008. " Adoption of Data Governance by Business," *DM Review*, (18:12), pp 32-34.

Yeoh, W, Gao, J. and Koronios, A. 2009. "Empirical investigation of critical success factors for implementing business intelligence systems in multiple engineering systems in multiple engineering asset management organisations," In *Infrastructure system research methods, epistemology and applications* (Cater-Steele, A & Al hakim, L Eds.). New York:Information Science.

Yin, R. K. 2009. Case study research, design and methods. Newbury Park: Sage Publications.

Zimmerman, R and Fraser, J. 2012. *Come together: IT controls engineering convergence furthers manufacturers' success*. Milwaukee: Rockwell Automation.

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