

2010

Research methodologies for engineering asset management

Khaled O. El-Akruti

University of Wollongong, khaled@uow.edu.au

Richard Dwight

University of Wollongong, radwight@uow.edu.au

Follow this and additional works at: <https://ro.uow.edu.au/engpapers>



Part of the [Engineering Commons](#)

<https://ro.uow.edu.au/engpapers/5001>

Recommended Citation

El-Akruti, Khaled O. and Dwight, Richard: Research methodologies for engineering asset management
2010.

<https://ro.uow.edu.au/engpapers/5001>

ACSPRI Conference 2010

ACSPRI Social Science Methodology Conference 2010

The University of Sydney December 1, 2010 –December 3, 2010

Stream: Research paradigms and research design

Research Methodologies for Engineering Asset Management

El-Akruti, K and Dwight, R

Mechanical, Materials and Mechatronic

Engineering faculty

University of Wollongong

Research Methodologies for Engineering Asset Management

Abstract

This paper serves as a guide for researchers in Asset Management (AM). Its objective is to establish sufficient reasoning to select and complement research methodologies for AM research studies. It explores literature and adds to existing research approaches in AM. This will lead to a stronger body of knowledge through a better contribution from research.

AM as a discipline, addresses the management of the life cycle of assets utilized by an organisation. This extends from identification of the need to the disposal and liability thereafter. It includes technical and business activities. From this view, AM is a relatively new discipline. The nature of the AM activities is both interdisciplinary and cross functional.

It has been found that most reported research in the area of AM focuses on specific functions and technical activities such as maintenance. Often it is either not apparent that a particular research method has been used, or, not is explicitly identified. Combining case study methods with a retroductive research strategy yields suitable methodologies for improving the research process in AM.

Introduction

AM varies in interpretation and definition. In the financial sector, it refers to the management of financial assets. In capital intensive industry AM is used to identify how an industrial organisation deals with the management of its physical assets through their life cycle to achieve its strategy. The output generated with these assets should justify their ownership. The AM Council (2009) succinctly defines AM as: *"The life cycle management of physical assets to achieve the stated outputs of the enterprise"*. The AM system may subsequently be defined as: *'Control of AM-related functions and their relationships by a set of planning and control activities to ensure achieving the asset life cycle performance that meets the requirement of the intended competitive strategy of the organisation'* (Author 1 and Author 2 2010).

There are two levels of concern relevant to the development of AM theory: discrete contributing functions and the system interrelated functions that constitute AM.

The majority of research publications focus on specific functions or technical activities of AM, particularly maintenance and its management. This technical focus is found in publications on:

maintenance strategy (Tsang 1998; Tsang 2002; Mather 2005; Pinjala 2008); performance measurement (Pintelon and Puyvelde 1997; Tsang and Brown 1999; Author 2 1999b; Kaplan and Norton 2001; Liyanage and Uday 2003; Liyanage 2007); optimization (Dekker and Scarf 1998; Garg and Deshmukh 2006); replacement (e.g., Author 1 1999; Scarf, Author 2 et al. 2007); remaining asset life (Oien 1998), outsourcing (Martin 1997; Buczkowski, Hartman et al. 2005); predictive maintenance (Mckone and Weiss 2002); risk-based aspects (Khan and Haddara 2003); planning, scheduling and information management (Satyanarayana and Prasad 1996; Nagarur and Kaewplang 1999; Tsang, Yeung et al. 2006). This leads to the conclusion that research in AM has often been focused on specific AM related functions. Frolov, Megel et al. (2009) state that historically AM was viewed as a technical activity driven by engineering design and narrowly focused on reliability and maintainability of assets. Charles and Alan (2005) argue that literature is found narrowly focused, revealing that the contribution by AM has not been considered from the whole life cycle approach and limited to the primary drivers within the so called utilisation phase.

Ouertani, Parlikad et al. (2008) argue that although maintenance has an important role to play it is really only one of the 'variables' in managing assets. Others include, for instance, selecting assets, using them, or trading short-term performance against long-term sustainability and managing their information. Some of these occur at early stages of the acquisition phase but have critical impacts on the capability and performance of assets.

The need for a holistic system approach to AM is realized but still not fully developed. Holistic AM has only relatively recently emerged. This shift to a more business related engineering discipline has been reported since late 90s in literature (Hipkin 1998; Dornan 2002; LoPorto and Udo 2003; Mohseni 2003; Amadi-Echendu 2004; Charles and Alan 2005; Narman, Gammelgard et al. 2006; Stapelberg 2006; CIEAM 2008; Haffejee and Brent 2008; Asset Management Council 2009). This holistic approach has become the focus of many organisations (IAM 2004; IPWEA 2006; CIEAM 2008; Asset Management Council 2009). Based on the practice of particular organisations several frameworks and models have been proposed. These result from experience or specific personal understanding and reported or published by individuals or organisations. It has been observed that such publications normally do not declare the research methodology used or the underpinning reasons for using particular research

methodologies. According to Frolov, Megel et al. (2009), the need to develop this holistic approach to AM has been identified and collaboration between organisations and academic researchers to extend the body of knowledge in this area is under way.

In short, despite the popular movement surrounding this new AM discipline it is unclear which research methodologies should be utilised. Research reported on specific functions follow the logic of the relevant discipline such as operation management, industrial engineering or system engineering. Although, these disciplines have been dominated by quantitative research and positivist methodologies, these do not facilitate the exploration of the complexity of the new AM discipline. Some recognize the role of qualitative approaches in theory building research (Kiridena and Fitzgerald 2006). A broad range of qualitative research approaches may be applicable but their usefulness needs to be proven.

This paper firstly identifies the nature of AM, the resulting research areas and possible approaches to AM research. Secondly, it explores the general guiding principles in research design; specifically quantitative and qualitative research approaches, research strategies, and methods to draw on the suitability basis to complement the current methodologies for AM research. Thirdly, it establishes the reasoning logic for selection from existing social science research methodologies for AM.

The Nature of AM and Resulting Areas for Research

The interdisciplinary cross functional nature of AM stems from the fact that it is concerned with the life cycle processes at the different stages and through often temporally separated functions. This can be gleaned from the definition of the asset life cycle from a user-organisation viewpoint as stated by Ouertani, Parlikad et al. (2008) in a succession of four stages:

1. Acquire - all activities involved in technical and financial analysis, justification, and planning for acquisition of new assets, as well as in managing acquisition.
2. Deploy- all activities associated with the installation, testing, and commissioning.
3. Operate/Maintain - all activities involved in most effectively maintaining asset availability (health), longevity, and capability (quality, performance & flexibility).
4. Retire - all activities involved in disposal of assets.

The strategic success of capital intensive organisations often depends on its ability to establish and utilize assets efficiently and effectively throughout these stages. Concurrently organisations

must identify the need, and make decisions, to launch projects for the enhancement of asset design, operation, maintenance or logistics support. This may involve innovation, upgrading, development, expansion or extension, information/technology insertion or knowledge support and refurbishment, replacement or retirements of assets. Undertaking any of these may require knowledge from a range of disciplines such as manufacturing, servicing and process engineering, which integrate with other disciplines including safety and risk management, finance and accounting and marketing.

The AM system incorporates overlapping interdisciplinary activities and is either part of or alternatively controls many functions. It is not a single isolated existing entity within an organisation. The boundaries between the AM sub-functions or sub-systems such as production or operation management and maintenance management are a matter of definition. Even when the focus is on a sub-function or sub-system within AM the interdependence with other AM related sub-functions and their organisational objectives is evident.

The AM system is socio-technical. Physical assets constitute the focus of concern and purpose on which AM is developed, however; human or social aspects provide the means by which AM can manage those physical assets. Industrial systems settings include structures and procedures of activities, human or social aspects, flow of information and knowledge accumulation. Learning is an essential means by which AM can manage those often unique physical assets effectively.

AM problems requiring research often are context related and may be associated with either the acquisition or the utilisation phase of assets. In the acquisition phase research is likely to require quantitative approaches, experimental and/or mathematical modelling or simulation methods. In the utilisation phase, assets need to be managed as part of a socio-technical system of the user organisation. During this phase research problems may be associated with managing the life cycle activities relative to decision making. For example, investigating what activities lead to get the best out of the assets by extending their productive life cycle; minimizing their life cycle cost; monitoring their condition; keeping them reliable; utilizing their full capacity; operating them safely and to upgrading their capabilities or capacities when necessary. This leads to the concept of asset life cycle optimization or life cycle management which is the underpinning focus of AM. In this view AM does not stand alone but is a part of a broad area of management.

AM is additionally concerned with organisational behaviour, work organisation, process management, work procedures and rules.

It is concluded that AM is a system that incorporates overlapping interdisciplinary cross functional activities within an organization. Research in AM needs to consider holistic approaches for exploration of the AM system and building theory on its best form and managing its multidisciplinary nature. Research needs to account for context related problems in delivering a real contribution to managers for handling decision making processes in practice.

Approach to AM Research

Since problems in AM are context related and require fieldwork in the industrial environment, research in AM is likely to require applied research approaches. This requires the involvement of both the researcher and practitioner to define the problem in its industrial context and understand how a solution might be beneficial for the particular organisation. Theory can be developed, tested and validated for the intended benefit of that particular organisation. These coincide with some approaches to strategic management. For example, Freeman and McVea (2001) argue that: *“A pragmatic approach to strategic management would focus academic research on the detailed study of concrete situations. Over time general theories might emerge through frameworks that describe different approaches and different aspects”*.

In this context, the value of a theory will depend on its ability to help managers ‘make sense of their world’, rather than any other theoretical agenda. The research issues would depend on the circumstances under consideration. The drivers for research are part of the world of practice and business environment around it. The real interest is to gain insights on decision making. Managers need effective analysis, planning and control of the acquisition and utilisation of assets to guide their organisation. Author 2, Martin et al. (2007) point out that there are future challenges for academic and industrial communities to ‘close the gap between research and practice’. *“... Applied research is by nature much more problem oriented and could potentially alleviate the problem to value the applicability of envisioned research output”* (Author 2, Martin et al. 2007). Starkey and Madan (2001) argue that the key in approaching management research should be its applied nature. A new form of research and knowledge development as opposed to the traditional approach has been identified by Starkey and Madan (2001) and Gibbons, Limoges et al. (1994). According to them this approach is less concerned with the discipline agenda and more with knowledge relative to the nature of arising problems from practice.

The General Guiding Principles of Research Methodology

There exists extensive literature on principles of research methodology. This paper builds on the work found in (Platt 1976; Mitchell 1983; Majchrzak 1984; Miles 1984; Pettigrew 1985; Hakim 1987; Eisenhardt 1989; Gummesson 1991; Gay 1992; Platt 1992; Ragin and Becker 1992; Sekaran 1992; Walton 1992; White 1992; Guba 1994; Blaikie 2000; Creswell 2003; Saunders 2003; Yin 2003; Cooper 2006). Interpretation of terms is diverse, e.g. methods and methodologies are ambiguously used, Yin(2003) considers a case study as a research strategy while Blaikie (2000) consider case study as a method of data selection and present four types of research strategies. To avoid confusion, key principles for the focus of this paper are highlighted. These include both quantitative and qualitative approaches, research strategies and research methods.

Qualitative versus Quantitative Research

The commonly used typology of research in literature is related to the two types; quantitative and qualitative research and classified using other criteria: e.g. exploratory or explanatory; basic or applied. Although the distinction between quantitative and qualitative approaches relates to the nature of the data used, differences incorporate the assumptions made, sources of data, methods or procedures of data collection and the philosophical paradigms assumed. As expressed by Kiridena and Fitzgerald (2006) quantitative research relies on a variety of assumptions including a close system, constrained conditions, manipulation of variables and isolation from context and ideal and rational decisions. These characteristics imply that it is fit for the investigation of some aspects of AM but may be inadequate for research into the holistic system of AM. In contrast, qualitative research has some characteristic that overcome some of these limitations. Case studies, field studies, historical studies and others allow the exploration of possible theory and insight relevant to the context (Ragin and Becker 1992; Walton 1992; White 1992; Platt 1996; Yin 2003).

Research Strategies and Methods

The research strategy and method may be defined as:

1. Research strategy refers the logic of enquiry applied through the research. This includes the approach to answering the research question, the assumptions concerned with what is

believed to constitute reality, and the claim or assumption about possible ways of gaining knowledge of reality. Most literature on research methodology identifies three types of strategy: inductive, deductive and abductive. Blaikie (2000) adds retroductive to this list.

2. Research method defines the procedures and techniques of data selection, collection and analysis, e.g. qualitative; quantitative; case-study; experiment; survey; mathematical modelling; simulation.

Any strategy and method or group of strategies and methods constitute a particular research methodology. The various strategies and methods are not mutually exclusive but there is superiority in selecting one, pair or group of strategies and/or methods for a particular research question. Appropriate selection connects the research objective/questions, data and the findings or the research contribution to knowledge and to what extent it can be generalized.

The Choice of Strategies: Reasoning the Logic of Inquiry

To facilitate the selection of a research methodology for an AM problem, the possible routes that can be followed have been mapped in Figure 1. It includes strategies based on the description by Blaikie (2000) or derived from common use in literature, e.g. Hakim(1987); Sekaran (1992), Blaikie(2000), Saunders(2003). These routes can guide the selection of a specific methodology based on the intended contribution from research. Rather than establishing boundaries between research strategies, it facilitates understanding their logic and establishes a conceptual map linking strategies to the research question. It merely suggests that different research strategies are suited to different research puzzles. The vertical structure represents the common use of these strategies as identified by Blaikie (2000), singly or in combination. He indicates that they are not mutually exclusive and their use depends on the researcher's choice. The superiority of one strategy or more over others to handle a particular research problem depends on the nature and circumstances of the problem and the research objective. The focus here is to select one strategy or more to handle the identified nature of AM and provide the basis for the holistic approach to its system.

Chapman(2006) uses a theoretical framework to guide his methodological approach to study causes of socio-technical failure resulting in accidents or disasters. Although the research strategy is not identified the methodology used is consistent with a retroductive strategy. In building on the 'contextualist' methodology introduced by Pettigrew(1985): Chapman concludes

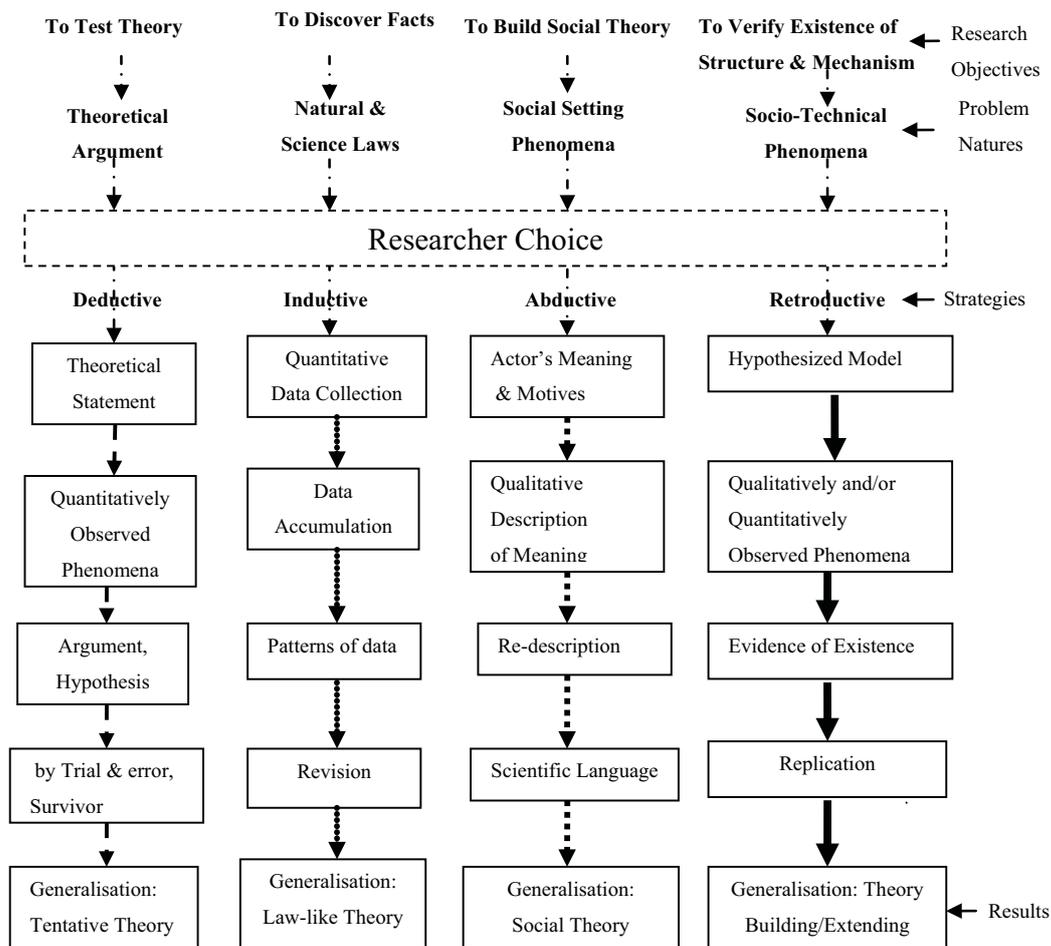


Figure 1: Conceptual Map for Selecting Research Strategies

that “... data collection and analysis needs to be guided by a clearly articulated theoretical framework and an action or time-based flow of events Ultimately, the finding can be generalized to other settings with similar parameters” (Chapman 2006). The findings were focused on social settings ‘human choice making’ and were generalised to other similar cases. His framework is related to the human settings, not the design or existence of the system that control or guide the human choice. This raises the possibility that a retroductive strategy may be applicable to AM research if associated with appropriate methods. The retroductive strategy allows the proposal of a hypothesized model or framework as an instrument for describing socio-technical systems. Such a framework then provides a basis for the observation and collection of qualitative and quantitative data. Other strategies may be used to measure this data as output or input parameters, however; all measurements have to be directed and interpreted using the postulated

model or framework. As cited in (Yin 2003) “*Logical inference is the process by which the analyst draws conclusion about the essential linkage between two or more characteristics in terms of some systematic explanatory schema – some set of theoretical propositions (Mitchell 1983)*”. Knowledge development by this type of research is related to providing frameworks for the proper design of the AM system and its embodiment in an organisation. As Flynn, Sakakibara et al. (1990) suggest: “*Theory building study is not a hypothesis, but rather, some assumptions, frameworks, a perceived problem or perhaps, very tentative hypothesis*”. The cause-effect relation can be verified by observing consequences as outcomes and then arguing for the plausibility of connection between evidence and the hypothesized model propositions.

It is proposed that the retroductive strategy can enhance research relative to the holistic approach to AM. It utilises models that are adapted or developed to describe the complexity and open-nature of a system. It is argued that such models can facilitate theory building to explore the holistic AM system comprising dynamic and interrelated socio-technical relationships.

The Choice of Research Methods: Reasoning the Use of Methods

There are many factors that influence the reasoning for the selection of a research method. As established previously, the nature of the AM problem researched influences the choice of research methods. For example, the use of ‘controlled experiment’ may be limited to technical aspects. Research methods already used for AM include: trial of application, case studies and surveys. Reported on a case study, Iravani and Duenyas (2002) indicate that the common practice of making maintenance and production decisions separately can be rather costly and that there are significant benefits for making these decisions in an integrated fashion. The same was demonstrated for a make-to-stock production system consisting of a single deteriorating machine, which produces a single item. Based on survey responses, Muchiri, Pintelon et al.(2010) analyse the influence of the manufacturing environment and maintenance objectives on key performance indicator choice and their role in decision support and improvement.

Integration of functions within the holistic AM system is argued to be a central issue. Jonsson (1999) argues that the integration of the maintenance function with others produces better results. Data gathered and analysed from 293 Swedish maintenance managers in manufacturing firms showed that integration and long-term planning of maintenance affects prevention, quality improvement and manufacturing capabilities. Integration of functions such as maintenance, operation and procurement by information systems can be a major factor for improvement(Garg

and Deshmukh 2006). The nature of AM tends to focus research on the longitudinal effects of actions on the organization. A difficulty here is in predicting future conditions. In designing research for this situation, there also exist a variety of problems of interdependence and unclear boundaries due to the open-system nature of the AM. This makes it hard to assign variables to causal relations and therefore limiting the use of formulation and prediction. Surveys are mostly used as a tool to prove a theoretical point, such as evidence of the existence of a relationship between parameters. Jonsson (1999) established that integration of maintenance produces better results. How the relation takes place or how it can be managed is not elicited. In contrast, case studies can provide a holistic approach to explore these complex relationships of the AM system.

Context influences the selection of a research method. Research in AM requires applied research whose finding may be unique for each organisation. Appropriate management of similar assets may vary even within organisations depending on many contextual factors such as operating environment, market characteristics, location, and local legislative requirements (Author 1 1999). This is consistent with contingency theory, e.g. Herbert, Roitblat et al.(1995) maintain that :
“...integrated and situated systems in contrast to the reductionist and environment-free frameworks often seen in standard cognitive science”(Herbert, Roitblat et al. 1995). Context is an essential consideration for AM research; not just for obtaining data but for setting the research question and the intended contribution from research. The researcher has no control over context and cannot construct a controlled experiment. These factors indicate the need of comprehensive methods to research the holistic ‘contingent’ nature the AM system. Research methods so far employed in AM vary but typically: conducting case studies or surveys are of common use as shown earlier in this paper.

The Case studies Choice

case study methods can develop new insights into the relationships between functions or activities and the control and decision making process for those functions. This coincides with the typical AM research problem identified previously. As Blaike (2000) states, case studies allow an investigation to address the holistic and meaningful characteristics of real life events, such as individual, organisational and managerial processes, changing environmental events, external relation and the maturation of industries. Case studies can be applied to analyse an event, an entity, a decision, program, implementation process, organisational change, strategy,

policy, or the trade or capital flow between two entities(Yin 2003). Case studies have been used for many purposes; exploratory, descriptive and explanatory research and to generate theory and initiate change (Ragin and Becker 1992; Blaxter 2001; Yin 2003). There are many different purposes for the application of case study: to develop theory; to explain the causal links in real life intervention that is too complex for survey or experiment; to describe an intervention and the real life context in which it occurred; to explore those situations in which intervention being evaluated has no clear single set of outcomes (Platt 1992; Ragin 1992; Walton 1992; White 1992; Yin 2003). According to Sloan (2005), Andrews (1987) stresses the important of case study research in the development of organisational strategy. Yin(2003) argues that case studies can be used to investigate a contemporary phenomenon within its real-life context; when boundaries between phenomenon and context are not clearly evident; and multiple sources of evidence are needed.

Positivists criticise the credibility of case studies for generalization. Mitchell(1983) and Yin (2003) for example raise this issue. They argue that the critics of case study representativeness were operating from the logic of statistical inference appropriate to sample surveys. On the other hand, a different kind of logic is required to test a proposition or answer the research question. Mitchell(1983) called it 'logical inference'; Yin(2003) called it 'analytical generalisation' or replication logic. Mitchell(1983) made a very clear distinction of logical inference from statistical inference that generalize to some wider population from some sample of that population to which the observer has access. "*Logical inference is the process by which the analyst draws conclusion about the essential linkage between two or more characteristic in terms of some systematic explanatory schema – some set of theoretical proposition*". Yin's argument stems from the analogy to laboratory experiment in distinguishing 'analytical inference' from statistical inference. Knowledge can not be developed from a single experiment. He identifies the analogy of replication of holistic cases and through sub-cases within an embedded case. The embedded case study is relevant to the studying of the relationship between organisational strategy changes and AM cross functional actions. In an embedded case, a cause-effect relationship can be uncovered, for example, an action may result in changes within functions and relationships between functions but they still translate into changes in the organisation's strategy. The aim is to build theory that coveys reality relative to the socio-technical phenomena and can be generalized to similar context or cases with similar parameters(Chapman 2006).

As earlier shown, the use of case studies for AM research has been for description rather than theory building. However, Walton(1992), demonstrates that generalisation in social science are developed from case study methods. He identifies progression from limited to more general interpretation of casual processes through developing theory from cases for further application. He argues that if cases are provocative, inviting models for further application, then they lead to conceptual and methodological modification. Walton(1992), Ragin and Becker (1992), Platt(1992) and White(1992) consider case study methods as theory building methods and indicate the use models and frameworks to construct a theoretical case. This is consistent with the underpinning principles of the hypothesized model or framework in the retroductive strategy. Walton demonstrates how cases can be reformulated into a theoretical form by demonstrating its causal connection to a hypothesized general process: “.....*case reformulation adapts available models or fashion new ones to address distinct substantive problems. The old do not fit, because the new phenomenon is either a different kind of case or one that cuts across conventional boundaries*”(Walton 1992). The reformulation of case study methods through the causal connection to a hypothesized model or framework can then lead to theory development. Platt considers the role of cases in changing theory. White points to a use of theoretically reformulated case studies “ *...to account for why events unfold in one way and not another, with the idea that such knowledge can be used to control situation or fix them in some way*”. This is relevant to the control of the AM system with the idea that such knowledge can be used to directly control for achieving the strategic objectives, avoiding future risk or capturing predicted opportunities.

A Retroductive Case Study Methodology to Enhance Asset Management Research

It has been established that AM is a socio-technical system that incorporates overlapping interdisciplinary cross functional activities within an organization. Additionally research in AM needs to consider holistic approaches to build theory on the form of the AM system and to establish how to manage its multidisciplinary nature. Further the situations confronted threaten to require individual solutions. Research methodologies must be found that provide some promise of general theory building.

It is proposed here that combining the retroductive strategy with case study methods yields a suitable research methodology to enhance the research process in AM. In addition to the ability

to explore the complex nature of the AM system, available through this combination, it is considered to facilitate theory building.

As illustrated earlier, to follow the retroductive research strategy a model or framework must be hypothesised. For AM research, it is suggested that system theory comprising the system design approach e.g. Hunger (1995) and Al Marsomi (1997) may be used to reflect possibly useful models. The structure and mechanism of the frameworks should reflect the AM system in terms of the related functions, activities, relationships and logic of control. If these activities, relationships and control exist and act as postulated by the framework then they will explain the asset life cycle performance and its impact on the strategy of the organisation.

Testing the relevance of the postulated model can be done through case study methods. These allow studying the reaction of the organisation to particular events, studying the rationale for particular actions of the organisation, and reviewing the causes of particular outcomes. These reactions, rationale, and causes are developed through reference to the postulated model. In the case of the AM system this may involve testing the value delivered relative to the expected value if the postulated model were in place. This value may be defined in terms of asset life cycle performance in achieving the organisation's strategic objectives. The role of the combination of the retroductive strategy and case study methods are proposed to be useful in building theory in the form of conceptual frameworks that reflect the appropriate AM system structures and underlying mechanisms. These frameworks can be verified through application to other organizations using the embedded case study method. It is concluded that the resulting methodology can enhance research in AM and strengthen the research process. This is because it can produce general conceptual frameworks reflecting the dynamic system of AM that can be generalized to a broader range of organisations than the results of descriptive case studies that can be generalized only to organisation with similar parameters. The aim is to generalize to 'what could be': to account for how organisations succeed or fail in achieving their goals or ideals with the idea that frameworks can be used to control practice. This can be verified based on evidence of performance or outcomes reflecting the extent of existence or absence of these frameworks based on useful insights provided by case study methods.

Findings and Conclusion

AM research has been challenged to provide new insights into the decision making process that concern the design and management of the AM system. Research in AM needs to build on currently applied qualitative approaches to research methodology in order to explore this new discipline and achieve better contribution in terms of evidence-based solutions. The main concern of research in AM is decision making processes involving interfaces between and integration of discrete activities.

The current status of AM as a discipline is such that it is critical that sound theory is developed utilizing appropriate research techniques. Research in AM often lacks the binding of theoretical credibility and practical validation. New research methodologies need to be introduced for the objective and added to the mix to handle the challenge.

Qualitative methodologies, retroductive research strategies and case study methodologies are identified as candidates with the potential to complement and strengthen the AM research and improve its contribution. The qualitative methodologies have potential to serve in exploring the holistic AM system, as an interdisciplinary, cross functional and strategic activity of capital-intensive organisations. Combining the retroductive strategy with the appropriate case study methods, results in a credible methodology that is capable of generating general frameworks. This is in contrast to the findings of descriptive case studies that may only be generalized to organisation with similar parameters.

Al Marsomi, M. (1997). *Industrial system analysis and design*, Higher Institute of Industry.

Amadi-Echendu, J. E. (2004). Managing physical assets is a paradigm shift from maintenance, Singapore, Institute of Electrical and Electronics Engineers Inc.

Asset Management Council (2009). "Asset Management " Asset Management Council and MESA Newsletter April-May 2009

Blaikie, N. W. H. (2000). Designing social research : the logic of anticipation / Norman Blaikie. Malden, MA :, Polity Press.

Blaxter, L. (2001). How to research / Loraine Blaxter, Christina Hughes, and Malcolm Tight. Buckingham :, Open University Press.

Buczkowski, P. S., M. E. Hartman, et al. (2005). "Outsourcing prioritized warranty repairs." International Journal of Quality & Reliability Management **vol. 22**(No. 7): pp. 699-714.

Chapman, J. A. (2006). A new application of contextulist methodology in case research. Proceeding of the ACSPRI Social Science Methodology Conference, Sydney, Australia.

Charles, A. S. and C. B. Alan (2005). "Asset life cycle management: towards improving physical asset performance in the process industry." International Journal of Operations & Production Management **25**(5/6): 566.

CIEAM. (2008). "Cooperative Research Centre for Integrated Engineering Asset Management (CIEAM). <http://www.cieam.com/>."

Cooper, D. R. (2006). Business research methods / Donald R. Cooper, Pamela S. Schindler. Boston ;, McGraw-Hill Irwin.

Creswell, J. W. (2003). Research design : qualitative, quantitative, and mixed methods approaches / John W. Creswell. Thousand Oaks, Calif. :, Sage Publications.

Dekker, R. and P. A. Scarf (1998). "On the impact of optimization models in maintenance decision making: The state of the art." Reliability engineering and system safety **vol. 60**(No.2): 111-9.

Dornan, D. L. (2002). "Asset management: remedy for addressing the fiscal challenges facing highway infrastructure." International Journal of Transport Management **vol. 1** pp. 41-54

Author 2, R., H. H. Martin, et al. (2007). How academic can help industry and the other way around. Proceedings of MIMAR 2007-6th IMA International Conference on Modelling in industrial maintenance and reliability, Manchester, UK, The Institute of Mathematics and its Application.

Eisenhardt, K. (1989). "Building Theories from Case Study Research." Academy of Management Review **Vol.14**(No.4): PP.532-550.

Author 1, K. and R. Author 2 (2010). Life Cycle and Risk Management, Licture Notes. . Wollongong, University of Wollongong.

Author 1, O., Khaled (1999). Replacement Optimization Modeling Of Electric Arc Furnaces' Refractory Lining. Industrial Engineering. Misurata, Libya, Higher Institute of Industry. **Master of Technology in Industrial Engineering**: 206.

Flynn, B. B., S. Sakakibara, et al. (1990). "Emperical research methods in operations research." Journal of Operation Management **9**(2): 250-285.

Freeman, R. E. and J. McVea (2001). "A Stakeholder Approach to Strategic Management." SSRN eLibrary.

Frolov, V., D. Megel, et al. (2009). Building an ontology and process architecture for engineering asset management. Proceeding of the 4th World Congress on Engineering Asset Management, Marriott Athens Ledra Hotel, Athens.

Garg, A. and S. G. Deshmukh (2006). "Maintenance management: Literature review and directions." Journal of Quality in Maintenance Engineering vol. 12(N.3): PP. 205-238.

Gay, L. R. (1992). Research methods for business and management / L.R. Gay, P.L. Diehl. New York : Toronto : New York :, Macmillan Pub. Co. ; Maxwell Macmillan Canada ; Maxwell Macmillan International.

Gibbons, M., H. Limoges, et al. (1994). The new production of knowledge/ The dynamics of science and research in contemporary societies. . Sage, London.

Guba, E. G. (1994). Competing paradigms in qualitative research [electronic resource]. Handbook of Qualitative Research D. Nk and L. YS, Sage publication, Thousand Oaks.

Gummesson, E. (1991). Qualitative methods in management research / Evert Gummesson. Newbury Park, Calif. :, Sage Publications.

Haffejee, M. and A. C. Brent (2008). "Evaluation of an integrated asset life-cycle management (ALCM) model and assessment of practices in the water utility sector." Water SA 34(2): 285-290.

Hakim, C., Ed. (1987). Research design: Strategy and choices in the design of social research London, Allen & Unwin.

Herbert, L., Roitblat, et al., Eds. (1995). Comparative approaches to cognitive science Complex Adaptive Systems, Cambridge, mass.:MIT Press.

Hipkin, I. B. (1998). "A new look at world class physical asset management strategies." South African Journal of Business Management vol. 29: pp. 158-163

Hunger, J. W. (1995). Engineering the system solution: A practical guide to developing systems, Prentice Hall PTR, Englewood Cliffs, New Jersey.

IAM (2004). PAs-55 (Publicly available specification - 2: guidelines for the application of PAS-55.

IPWEA (2006). International infrastructure management manual (version-3) : Institute of Public Workes Engineers.

Iravani, S. M. R. and I. Duenyas (2002). "Integrated maintenance and production control of a deteriorating production system." IIE Transactions **Vol. 34** (No. 5): pp. 423-35.

Jonsson, P. (1999). "Company wide integration of strategic maintenance: An empirical analysis." International Journal of Production Economics **Vol.60-61**: pp. 155-64.

Khan, F. I. and M. M. Haddara (2003). "Risk-based maintenance: a quantitative approach for maintenance/inspection scheduling and planning." Journal of Loss Prevention in the Process Industry **vol. 16**(No. 6): pp. 563-73.

Kiridena, S. B. and A. Fitzgerald (2006). Case Study Research in Operation Management. Proceeding of the ACSPRI Social Science Methodology Conference, Sydney, Australia.

LoPorto, J. and V. Udo (2003). Using Knowledge Management to Enable Enterprise Asset Management at Conectiv, Dallas, TX, United states, Institute of Electrical and Electronics Engineers Inc.

Majchrzak, A., Ed. (1984). Method for policy research. Beverly Hills, CA:Sage.

Martin, H. H. (1997). "Contracting out maintenance and a plan for future research." Journal of Quality in Maintenance Engineering **vol. 3**(No. 2): pp. 81-90.

Mather, D., Ed. (2005). The maintenance scorecard: Creating strategic advantage. New York, NY, Industrial Press, inc.

Mckone, K. E. and E. E. Weiss (2002). "Guidelines for implementing predictive maintenance." Production and Operations Management **vol. 11**(No. 2): pp. 109-24.

Miles, M. B. (1984). Qualitative data analysis : a sourcebook of new methods / Matthew B. Miles, A. Michael Huberman. Beverly Hills :, Sage Publications.

Mitchell, J. C. (1983). "'Case and Situation Analysis.'" Sociological Review **31**(2): 274-92.

Mohseni, M. (2003). What does Asset Management Mean to You?, Dallas, TX, United states, Institute of Electrical and Electronics Engineers Inc.

Muchiri, P. N., L. Pintelon, et al. (2010). "Empirical analysis of maintenance performance measurement in Belgian industries." International Journal of Production Research **48**(20): 5905-5924.

Narman, P., M. Gammelgard, et al. (2006). A functional reference model for asset management applications based on IEC 61968-1, Department of Industrial Information and Control Systems, Royal Institute of Technology, KTH 2006.

Oien, K. (1998). " Improved quality of input data for maintenance optimization using expert judgment " Reliability Engineering and System Safety **Vol. 60**(No. 2): pp. 93-101.

- Ouertani, M. Z., A. K. Parlikad, et al. (2008). Asset information management: Research challenges, Marrakech, Morocco, Inst. of Elec. and Elec. Eng. Computer Society.
- Pettigrew, A. M. (1985). Contextualist Research: a natural way to link theory and practice. In E. Lawler III & associates, Doing Research that is Useful for Theory and Practice. San Francisco, Jossey Bass.
- Pinjala, S. K. (2008). Dynamics of maintenance strategy. Department Werktuigkunde. Leuven, Katholieke Universiteit Leuven. **PhD**: 266.
- Platt, J. (1976). Realities of social research : an empirical study of British sociologists / by Jennifer Platt. London :, Chatto and Windus [for] Sussex University Press.
- Platt, J. (1992). Cases of Cases ...of Cases. What is a Case?: Exploring the foundation of social inquiry. . C. Ragin and H. S. Becker. New York, Cambridge University press.
- Platt, J. (1996). A history of sociological research methods in America : 1920-1960 / Jennifer Platt. Cambridge [England] ; New York :, Cambridge University Press.
- Ragin, C. (1992). Cases of " What is a Case". What is a Case?: Exploring the foundation of social inquiry. C. Ragin and H. S. Becker. New York, Cambridge University press.
- Ragin, C. and H. S. Becker, Eds. (1992). What is a Case?:Exploring the Foundation of Social Inquiry, Cambridge University Press.
- Saunders, M. (2003). Research methods for business students / Mark Saunders, Philip Lewis, Adrian Thornhill. Upper Saddle River, NJ :, Prentice Hall.
- Sarf, P. A., R. Author 2, et al. (2007). " Asset replacement for an urban railway using a modified two-cycle replacement model." Journal of the Operational Research Society v **58**, n **9**(Sep 26, 2007): p 1123-1137.
- Sekaran, U. (1992). Research methods for business : a skill-building approach / Uma Sekaran. New York :, Wiley.
- Sloan, P. (2005). Strategy as synthesis: Andrews revisited. Canada, Universite de Montreal (Canada).
- Stapelberg, R. F. (2006). Risk based decision making (RBDM) in integrated asset management. Brisbane, Australia: CIEAM.
- Starkey, K. and P. Madan (2001). "Bridging the Relevance Gap: Aligning Stakeholders in the Future of Management Research." British Journal of Management **12**(s1): S3-S26.

Tsang, A. H. C. (1998). "Strategic approach to managing maintenance performance." Journal of Quality in Maintenance Engineering **4**(2): 87-94.

Tsang, A. H. C. (2002). "Strategic dimensions of maintenance management." Journal of Quality in Maintenance Engineering **8**(1): 7-39.

Walton, J. (1992). Making the Theoretical Case. What is a Case?: Exploring the foundation of social inquiry. C. Ragin and H. S. Becker. New York, Cambridge University press.

White, H. C. (1992). Cases are for Identity, for Explanation, or for Control. What is a Case?: Exploring the foundation of social inquiry. C. Ragin and H. S. Becker. New York, Cambridge University press.

Yin, R. K. (2003). Case study research : design and methods / Robert K. Yin. Thousand Oaks, Calif. :, Sage Publications.