

Engineering change management in a large steel manufacturing company.

D du Toit

20512953

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Supervisor: Prof JIJ Fick

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Abstract

Engineering is inherently a process of constant change. The process of managing engineering changes is however, not a new topic and it is well defined and implemented in various other engineering management philosophies. Yet, on its own, it still remains a very challenging problem to organisations.

This research examines the applicability of engineering change management to a *large steel manufacturing company* who identified the lack of an engineering change management system as the main contributing factor of numerous problems the company experienced over time. The study sets out to determine the high level understanding, the level- and sophistication of practical implementation and quality (identified problems with existing, or the lack of existing systems) of the engineering change management procedures. The study also compared how three surveyed companies relate in terms of their engineering change management systems and how the companies relate to the academic principals found in literature. Furthermore everyday user experience was measured to determine what aspects of engineering change is important and what needed improvement

As part of the research, literature was reviewed and it was found that various authors, practitioners and academics agreed that engineering change management is increasingly important as an engineering management item. The literature revealed high-level requirements, models and constituents that are required for successful engineering change management.

A questionnaire survey was developed as the experiment to measure how engineering change management was perceived practically. The aspects and phases listed from literature were examined and the perceptions, experience and feedback from the engineers that face engineering changes on a daily basis was determined.

The general understanding and feeling towards their engineering change management was analysed and used to identify areas of common problems. The two other surveyed companies: a *petrochemical company* and a *specialised product company* provided means to determine if the process of engineering change management could be generalised and applied to the *large steel manufacturing company*. The analysis of the results of the survey provided valuable information that was used to conclude why some

companies were able to achieve success with their engineering change management procedures and why others failed or struggled.

The research effectively showed how engineering change management is perceived both negatively and positively in industry and identified common areas where improvement can be made. Furthermore, it can be concluded that engineering change management remained generic from a high-level and would thus be applicable to the *large steel manufacturing company*. The study also determined that engineering change management can effectively be used to mitigate and reduce the effects of uncontrolled changes that were listed by the *large steel manufacturing company*.

Keywords: *engineering change management, management of change, engineering management systems, continuous improvement strategies, control of engineering scope, life-cycle engineering.*

Declaration

I declare that this dissertation, submitted in partial fulfilment of the requirements for the degree of Master of Engineering Management and Development at the North West University, is my own work.

It has not been submitted before for any degree or examination in any other university.

Duan du Toit

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Table of Contents

Chapter 1: Introduction	1
1.1 Problem statement and substantiation	2
1.1.1 Research aim and objectives	3
1.2 Research process	3
1.3 Dissertation layout	4
Chapter 2: Literature survey	6
2.1 Background to the large steel manufacturing company	6
2.2 Introduction into engineering change management	7
2.3 Background and importance of ECM	9
2.4 The ECM process	11
2.4.1 The generic model proposed by Jarratt <i>et Al</i> (2011).	12
2.5 The three major aspects of ECM	15
2.5.1 Initiator / Starter	17
2.5.2 Front End Loading	19
2.5.3 Approval.....	22
2.6 Overview of Chapter 2	26
Chapter 3 – Experimental design	28
3.1 Secondary sources	28
3.1.1 A practical view of ECM in the industry	28
3.2 Primary sources	28
3.2.1 Setting up a survey	28

3.2.2	Soft questionnaire skills	31
3.2.3	The Target group for the survey	33
3.3	The survey	34
3.3.1	Qualitative and quantitative data investigated by the survey	34
3.4	Follow-up interviews	36
3.5	Chapter summary	36
Chapter 4: Data analysis & Interpretation		37
4.1	Findings of the practical view of ECM in the industry	37
4.1.1	Initiation	37
4.1.2	Feasibility.....	38
4.1.3	Design phase.....	38
4.1.4	Implementation, execution and testing phase.....	38
4.1.5	Close-out phase.....	38
4.1.6	Review phase	38
4.2	Literature review findings	39
4.3	Evaluation of survey data	40
4.3.1	Sample Demographics.....	41
4.3.2	Understanding of ECM.....	43
4.3.3	Evaluating the effectiveness of ECM implementations	45
4.3.4	Inclusion of different departments or processes in the ECM process	47
4.3.5	Accessibility of ECM data	48
4.3.6	Management of EC's	50

4.4	Aspects of engineering change	52
4.4.1	Communication and decisions	53
4.5	Measuring the effectiveness of implementations of ECM	54
4.6	Room for improvement	57
4.7	ECM at the large steel manufacturing company	59
4.8	Chapter summary	65
Chapter 5: Conclusion, Recommendations and the Way Forward		70
5.1	Introduction	70
5.2	Review of the Research question and objectives	70
5.3	Answering the research question	71
5.3.1	Answering the first research objective	73
5.3.2	Answering the second research objective.....	74
5.4	Recommendations for future research	76
5.5	Overall conclusion	78
Appendix A: Academic data collection survey		1
Appendix B: Survey results		14
Appendix C: <i>Large steel manufacturing company</i>		21
Appendix D: <i>Petrochemical company</i>		29
Appendix E: <i>Specialised products company</i>		36

Table of Figures

Figure 1: Model proposed by Jarratt et Al (2011) 13

Figure 2: Typical phases found in an ECM process 17

List of Tables

Table 1: Role of respondent 41

Table 2: Area of work 42

Table 3: Level of experience..... 42

Table 4: ECSA status 43

Table 5: Measuring the understanding of ECM by individuals 43

Table 6: Effectiveness of engineering change management 45

Table 7: Effectiveness comparison 46

Table 8: Departments that make use of ECM..... 47

Table 9: Type of ECM process 48

Table 10: ECM storage and accessibility..... 49

Table 11: Accessibility of ECM data 49

Table 12: ECM cross search capabilities..... 50

Table 13: Control and management of engineering changes 50

Table 14: Administration of EC..... 51

Table 15: Aspect of engineering change needed for an engineering change close-out 52

Table 16: Level of communication 53

Table 17: Maladministration of changes 54

Table 18: Document control..... 55

Table 19: Capabilities of ECM 56

Table 20: Rating of ECM process..... 56

Table 21: Determining if existing ECMS require improvement	57
Table 22: Aspects for improvement	57
Table 23: Roles at large steel manufacturing company	59
Table 24: Effectiveness of ECM at the large steel manufacturing company	60
Table 25: Accessibility of changes at the large steel manufacturing company	60
Table 26: Extent of risk assessments at the large steel manufacturing company	61
Table 27: Views on aspects of ECMS	62
Table 28: Control of ECMS process	62
Table 29: Aspects of ECM that needs improvement.....	63

Terms and Abbreviations

ECSA	Engineering Council of South Africa
EC	Engineering Change
ECM	Engineering Change Management
ECMS	Engineering Change Management System
ECO / ECR	Engineering Change Order / Engineering Change Request
Service Engineering Division	Engineering performed as services to other plants or industries. Typically infrastructure development, maintenance and support; projects, incident investigation and consulting engineering.

Chapter 1: Introduction

“ It is not necessary to change. Survival is not mandatory. ”

- W.E. Deming

Deming, one of the fathers of quality management once made this statement. In engineering, probably more than any subject, it is a valuable truth. Yet, with any change comes tremendous responsibility to ensure that it is performed under controlled and manageable circumstances.

As a young graduate engineer at the *large steel manufacturing company* during my early work experience at the company I was often faced with this predicament: Ever so often, engineers would notice that the scope of work they were supposed to implement grows as more and more “previous uncontrolled changes” are discovered that affect the success of their proposed change. In many cases, we and the company were extremely lucky to only struggle with scope creep. Case study literature such as the Chernobyl, USSR and Dutch State Mines Nypro Plant, Flixborough (Sandia National Laboratories, 2013) revealed tragic incidents- the consequences of poor change management, claiming lives of hundreds of people and affecting thousands more as many facilities closed down after such incidents.

Indeed, as per Deming’s quote, engineering change is unfortunately constantly required for an organisation to be competitive and profitable- but only so if it is done in a controlled and managed manner. Organisations are constantly prompted to improve their processes, technology, development, life-cycle engineering and projects to address the market needs, constantly improve quality, customer satisfaction and reduce time and costs (Li, Weilin, *et Al.* 2011: 1), (Merrell, P., Summer 2012: 20), (Huang, *et Al.*, 2003: 484).

In the context of the *large steel manufacturing company* with my experience as a young engineer at the plant and at the time of the study; a particular plant of the company was struggling with the management of their engineering changes in their service engineering department (infrastructure and projects). Research indicated that an estimated 35% of today’s manufacturing resources are used to manage changes to

drawings, plans and schedules (Quintana *et Al*, 2011) – all of which are functions of the company’s service engineering department. Although engineering change management exists at other sister plants of the company it was not adopted or introduced at the service engineering department of the specific plant and therefore no standardized procedure existed which resulted in unmanaged changes. It was ultimately up to the individual(s) performing the change to capture the change in the relevant documents, inform the stakeholders and control and mitigate the associated risks with change with the risk of omitting an important step in the process of performing the change. Furthermore, substandard and uncontrolled reviews and approval of changes lead to numerous changes with inadequate risk identification and management which resulted in repetitive process- and equipment failures, unplanned downtime, maintenance inefficiency, operational instability, lack of quality assurance, quality control and continuous improvement, over-expenditure of budgets and inefficient usage of capital, non-compliance to legislation, standards and best practices, safety-health and environmental concerns (Jooma, 2013). Knowledge retention also suffered as knowledge transfer and succession planning of critical business know-how was never captured in change documents. In an attempt to rectify the situation, the department tried to adopt the engineering change management procedure of one of their other plants but it became apparent that the procedure would not adequately address their specific needs.

1.1 Problem statement and substantiation

Engineering change must be distinguished from the common business meaning of change. Engineering change management has to do with the alterations or changes to a “product” (Jarratt *et Al*, 2011). The term product can have different meanings in different settings of engineering but for the purpose of this study it can be defined as any change to a piece of equipment, a process, a procedure or a system or any alteration to properties or attribute to these products, except where it is a “replacement in kind” (U.S. Department of Labor, 2000). Engineering change management has been identified as a crucial aspect of safety, quality and business sustainability process, thus:

The purpose of this study is to determine the applicability, high level understanding, the level- and sophistication of practical implementation and quality of application (identified problems with existing, or the lack of existing systems) of the engineering change management procedures in the service engineering division of three different

companies in order to draw a comparison with the service engineering division of the large steel manufacturing company that would ultimately assist and provide information to the large steel manufacturing company in order to develop a workable ECM system.

1.1.1 Research aim and objectives

The research aims to answer the following research objective to support the research question:

1. How does the existing ECM at the three companies compare to each other and collectively compare to ECM as found in literature?

Substantiation: The objective was set in order to obtain a better understanding of how ECM is performed at the companies and how it compares to what is commonly found in literature. Should there be a significant difference, the difference should be understood. Likewise, it is important to understand if ECM can be generalised.

2. What aspects are deemed important by everyday users of ECM and what aspects need improvement?

Substantiation: Practically, management systems have limitations; the purpose of this objective was to identify the important aspects as seen by users of ECM systems. It further aimed to identify the aspects of ECM that need improvement in order to achieve the full benefits of the management system.

1.2 Research process

This section of Chapter 1 provides a high level systematic view of how the research was conducted. At first, various literatures were examined and reviewed to develop a comprehension of ECM and why it is needed, the review was further expanded to provide insight into the aspects and activities that are commonly performed with ECM. As ECM is a management system, the automation and control of the process was examined to understand what is needed for ECM to function properly. Lastly, a high level practical ECM implementation was examined to bridge the theoretical to practical implementation gaps. The literature survey was used to develop a list of experimental design questions that was defined in Chapter 3. The questions were in the form of an online survey (www.esurv.org) that included selective (close-ended response type), multiple choices and one open-ended question were asked to a sample group of

selected individuals that were known to work in the service engineering division in three different companies:

- a. The *large steel manufacturing company*.
- b. A *petrochemical company*.
- c. A *specialised products manufacturing company*.

Although the sample group was admittedly small, it should be noted that the service engineering department within the large steel manufacturing company was relatively small as well (only 22 engineers and technical managers in total) and thus a good representative of the population. The sample comprised of engineers and managers in the service engineering department of their company regardless of their engineering field, age or experience (although these attributes were used to draw conclusions from the results obtained via the survey). Details of how the survey was developed can be found in Chapter 3. The answers to the questions were obtained from the survey results and examined and compared between the three companies were applicable. The findings of the survey can be found in Chapter 4. Lastly, conclusions and recommendations of the study were drawn and can be found in Chapter 5 of this dissertation.

1.3 Dissertation layout

The research in this dissertation is focused on ECM for the *large steel manufacturing company* but drew on knowledge gained from other industrial engineering companies as well. It was believed at the time to be beneficial to know how these companies perceive engineering change management in their own companies, if certain aspects (or ECM itself) were common problems in engineering and how well ECM was implemented in general.

The dissertation will follow in the following sequence:

Chapter 2 examines existing literature focussing on ECM in general, the constituents of ECM, the process of ECM and finally the practical implementations.

Chapter 3 develops an experiment to test the research question and objectives via the process of performing a survey. The process and the development of the survey is

explained and piloted to examine engineering change management implementations. The actual survey questionnaire is as found in the appendix.

Chapter 4 examines, interprets and analyses the results from the experiment quantitatively and qualitatively, focussing on the aspects that were important to address the research question and objectives.

Chapter 5 is the conclusion and recommendations that recapitulates the research of the dissertation. The chapter addresses the research question and objectives analytically and discusses the limitations of the research. It finally provides additional research questions for future work that could be conducted on engineering change management.

Appendix A- E depicts the actual survey used to obtain the primary data and the results from the survey in different formats.

Chapter 2: Literature survey

The purpose of the literature surveys was an important aspect of research. It revealed what work was performed in a particular research field; it opened up room for future investigations and provided a solid background to support research objectives.

An appropriate definition of engineering change management (ECM) can be defined as the process of changing attributes and (or) properties and (or) associations of a part, system, process, and (or) design after the original design was implemented (Huang, Yee et al. 2003), (Wright, I.C., 1997:33), (Veldman, J. & Alblas, A., 2012), (Quintana et Al, 2011), (Jarratt et Al, 2011).

Jarratt et Al (2011) quotes that: “change is an active revisiting of a task that has been considered completed”.

A lot of research on ECM was done for this dissertation, particularly focussing on the process flow of an ECM and the important phases and aspects of ECM. Different views were taken into account: e.g. health, safety and environment, quality, operational requirements; risk management as well as knowledge retention. The subsequent paragraphs are summaries of the important findings and provide a solid background for the research objectives and the experimental design that aims to answer these objectives set out in Chapter 1.

2.1 Background to the large steel manufacturing company

The following information on the *large steel manufacturing company* is based on personal experience while the researcher was working at the company in the specific service engineering department. The other information that follows below was based on information that was commonly available from the company profile.

The *large steel manufacturing company* is an ISO 9001 certified Mining and Metals Company. The service engineering department is tasked with the responsibility to upkeep and control infrastructure equipment, processes and supplies (e.g. air, gas, steam, water, electricity as well as power generation) throughout the works (a collection of plants). The infrastructure in this company is fairly out dated (greater than 40 years) and on an ad hoc basis engineers perform the task of re-engineering certain parts of equipment or processes. The company also lost knowledge from key personnel that

were solely responsible for certain areas (this includes the equipment and processes) within the department. Most of the documents, drawings and reports are also paper-based or was (is) digitally stored on the employee's personal computer and not a centralised, controlled archive. As a result, new employees in the specific department are often asked to investigate and improve certain equipment and (or) processes using the limited available documentation. The employees of this department are also responsible for failure investigations, small to very large projects, continuous improvement strategies and maintenance. Many of the tasks assigned to the employees have been performed hap hazardously by previous employees that have left the company (in many cases leaving the changes open). Unfortunately due to the nature and history of the company there is often work that needs to be reworked and additional changes to previously undocumented changes. It was observed that failures and (or) malfunctioning of the equipment and processes the department is responsible for- and ultimately additional changes and reworks (costing vast amounts of time and money) regularly occurred. Since this department operates "at the heart" of the company, it is crucial to manage the engineering changes to ensure continuity, stability and uptime of all the downstream processes which provides the income to the company (less "fire-fighting" and more proactive engineering). The specific department does not have an engineering change management system or process to describe the process of performing an engineering change in the company. It is ultimately up to the individual assigned to the EC task to devise his own methodology to perform the work which frequently leads to confusion and discontent by peers and other functional departments in the company because they were ill-informed of the upcoming change. Knowledge transfer is also a major challenge to the company as major investments are made in employees who gain the unique knowledge and then leave the company without transferring the knowledge and data (documents, drawings, reports, etc.) to the replacement or colleagues. The *large steel manufacturing company* was particularly interested in finding a solution to manage their engineering changes. The research in this document is aimed to assist and provide information that could potentially be implemented as a working ECM system.

2.2 Introduction into engineering change management

Engineering change management is an effective management tool to ensure that a change, regardless of size, is properly executed and recorded taking into account the

technical, engineering and safety aspect (Health and Safety Executive, 2013). The importance of engineering change management have been recognised by international bodies on safety as one of the most crucial elements to manage to ensure health and safety of workers, equipment, processes and the environment. Not only has it been recognised for its safety implication but it is also important to ensure that critical knowledge of key personnel is captured that will ultimately lead to the sustainability of a company. Historically engineering change was somewhat simpler to manage – mostly because hard copy documents and drawings were available from only a single document archive. The management of changes in the digital age have subsequently increased the difficulty to control changes as it now offers the ability to download and use drawings on a personal computer without the awareness of others. Although many modern ERP systems exist to ensure that document changes are now captured; a lot of the changes performed over the course of time before the implementation of such software or control measures have been without proper management. Many engineers (especially young graduated professionals) face this reality on a daily basis; the result of which is inefficient work execution as additional time must be spend to establish the “as-built” reality which is then used to adjust the latest revision of documents to reflect the changes that were performed over time before any “engineering” can be performed (Pikosz & Malmqvist, 1997), (McNair, 2013). A simple change can thus grow to a substantial bigger project other than that that was planned- placing great pressure on resources. Engineers also have limited documentation (such as investigation reports, design reviews, etc.) available to understand the reasoning behind a historical change if the documents weren’t stored at a single easily accessible location (digitally or paper-based) within the company. Although the engineering governing body in South Africa, the Engineering Council of South Africa, indirectly require change management from an ethical and professionalism point of view, it is not governed by the council nor is it enforced on its members in any way. Engineers can also operate freely without ECSA registration and are thus not required to embrace standpoints of a governing body (ECSA, 2013).

In the United States of America, management of change became a health and safety requirement governed by the Occupational Safety and Health Administration (OSHA) through a standard named “Process Safety Management” that was developed to prevent hazardous chemicals or energy releases. Although this standard is inherently applicable to chemical companies operating in the United States of America, a lot can

be learnt and adapted from the standard in which change is managed in any engineering environment. This dissertation was written with a focus on the engineering services division as its target environment as this division of engineering is generally similar between companies (e.g. supply, service, and maintenance, support of infrastructure and energy sources). The *large steel manufacturing company* was used as a reference to a company with a lack of engineering change management (as recognised within the company). The *large steel manufacturing company* will be used in the subsequent chapter to establish the reasoning behind the need to have a controlled procedure or management system to manage any engineering change in highly complex manufacturing companies. Insight from other companies with proper engineering change management systems was used to establish a baseline or model for a practical engineering change management system.

2.3 Background and importance of ECM

Engineering change management has roots in many management systems such as the configuration management discipline of which to ensure that data integrity is maintained and made available to all parties involved (IEC 15288:2002: 20), quality management (e.g. ISO 9000 series (Curkovic, S, & Pagell. 1999)) as well as health and safety procedures and legislation (e.g. Process Safety Management (U.S. Department of Labor, 2000) & Plant Modification / Change Procedure (Health and Safety Executive, 2013)). Jarratt *et Al* (2011) pointed out that engineering change management is the nucleus of the much larger configuration management process. Pikosz & Malmqvist (1997) viewed engineering change as a core process of the configuration management system. It can thus be said that the purpose of all the change management procedures is common to that of configuration management- which is to record, control and manage changes (including from the initial baseline) while taking into account the associated risks with change.

Inherent to the nature of engineering; change is often required to meet the demands of clients, legislation, quality and safety which are often triggered by the inadequacy or deficiency of an existing product (Balcerak, K.J. & Dale, B.G., 1992: 126), (Jarratt *et Al*, 2011). The interdependencies of components and equipment often lead to additional engineering changes effectively creating a snowball or avalanche effect of changes. This traceable dependency (Allan, G., 1997), (Health and Safety Executive, 2003) makes uncontrolled changes difficult to manage and the consequences of such is:

injuries and fatalities, equipment damage, additional changes, rework, rescheduling, unavailability of maintenance parts, poor service delivery and general deterioration of performance in downstream processes, equipment- and equipment capabilities, quality, maintainability and operability (Veldman, J & Albas, A., 2012). It is thus not only good engineering practice to ensure that any engineering change regardless of the size or implication is properly documented and recorded but from a business point of view required to stay competitive in the market. The importance of a good engineering change management system can be confirmed by the 95% adoption of ECM in UK firms in the design and manufacturing sector (Jarratt *et Al*, 2011). The effect of poor change management cannot be understated. Many companies have failed to implement a proper change management procedure which resulted in fatalities, injuries and equipment damage (Health and Safety Executive, 2013). In some severe cases, companies faced plant rebuilds only to discover that the drawings in document storage do not reflect the true plant installations. The consideration of the associated risks and effects on other equipment was found to be one of the leading causes of failures (Health and Safety Executive, 2013). Implementing a proper ECM system could have prevented the disasters by ensuring that the engineering change is performed- taking all the considerations of good ECM practice in mind.

In the United States of America, the U.S. Department of Labor (2000) has also made it a legal requirement for companies operating in the USA to manage engineering change to any process chemicals, technology, equipment, procedure and change to a facility that affect a covered process. The “covered processes” definition is limited to hazardous chemicals but it is generally assumed to be good practice for any company to implement an engineering change management system. These requirements as depicted in the Process Safety Management document (U.S. Department of Labor, 2000: 22) describe the change process as follow:

1. Establish a technical need for the proposed change;
2. Evaluate the safety and health impacts;
3. Address the change in operational procedures;
4. Establish a timeline for the change, and lastly
5. Develop the authorization requirements for the change.

ECM in short can thus be defined as structured and standardized process of controlling any change to ensure that a system exist to plan, implement, monitor, control and report

configuration and changes (Allan, G., 1997: 328) all while mitigating and reducing risks associated with the change. Although various researches as indicated by Balcerak & Dale (1992) are of the opinion that not all issues concerned with engineering changes can be resolved with an EC procedure; an ECMS still effectively allows changes to be managed and ensures that all the documentation is in place, the people are rightfully informed, trained and consulted and also to ensure continuity in the event that there is a loss in knowledge due to critical human resources changes (Huang & Mak., 2003: 483).

Curkovic & Pagell (1999) determined that engineering change management is of crucial importance – especially for companies certified as an ISO 9000 company (it is a certification requirement to have documented changes). They effectively established that change management would lead to a) a reduction in time to develop and implement the change; b) reduction in start-up time; c) overall reduction in cost.

From all of the above it can be concluded that from a systems, quality, commercial, configuration management and health and safety engineering point of view it is extremely valuable to have a good, workable engineering change management system in place. Not only can it reduce injuries and fatalities but it can also ensure that quality engineering can be fulfilled at all time while ensuring that costs are kept to a minimum. Engineers are by nature people with a good understanding of logic and orderly conduct – having a structure that ensures that all the “right boxes are ticked” would thus prove to be extremely beneficial to the individual as well.

2.4 The ECM process

Achieving the full benefits of an ECMS has some basic requirements. Balcerak & Dale (1992) identified four key points that need to be addressed by the organization implementing an ECMS:

1. The EC terminology needs to be standardized and clearly comprehended by the organization.
2. The EC requests must be classified and enforced by a well-defined standard.
3. The EC must include commercial justification (risk included).
4. The EC must provide a basis for analysing EC and their common initiators.

2.4.1 The generic model proposed by Jarratt et Al (2011).

The model proposed by Jarratt et Al (2011) in Figure 1, although very generic is the underlying concept on which many implemented ECM processes were built. Jarratt et Al (2011) proposed six steps for the successful implementation of an engineering change:

1. The engineering change request is opened by means of the submission of an engineering change request form. This form could either be paper-based or an electronic form. The request outlines the basic reasons for change, the priority and the affected items by the change.
2. The second step can be likened to a feasibility study. Various options are reviewed and evaluated both technically and commercially. Various tools exist to evaluate the proposals e.g. cost / benefit and are all designed to narrow solutions down to only a few. Jarratt et Al (2011) did however find that the engineer responsible for the engineering change usually stops at the first possibly successful solution.
3. Risk is determined in phase three. There are various techniques to determine the risk such as HAZOP for the operational risk and Risk Analysis for the general and commercial aspects of risk. The key to successful ECM is the reduction or mitigation of risks.
4. Solutions are proposed to an engineering change management board. The board is responsible for the review of the cost/benefit analysis for the company and also the final approval for the implementation of a change. In most companies the board consists of highly technical and senior staff and includes members across all disciplines and functions in the company.
5. Jarratt et Al (2011) suggest that the change can be implemented immediately or gradually phased in. The type of implementation is mostly depicted by company resources and urgency of implementation. If a change affects safety, it will most likely be implemented immediately. This phase also requires that the documentation is updated to ensure that the latest revision is reflected for maintenance, operations and manufacturing personnel.

6. Jarratt et Al (2011) found that it is extremely valuable to review the change post-implementation. The purpose is to establish if the change was addressed correctly and if the change functions as required. It is further important to note if any lessons can be learned for future engineering change processes.

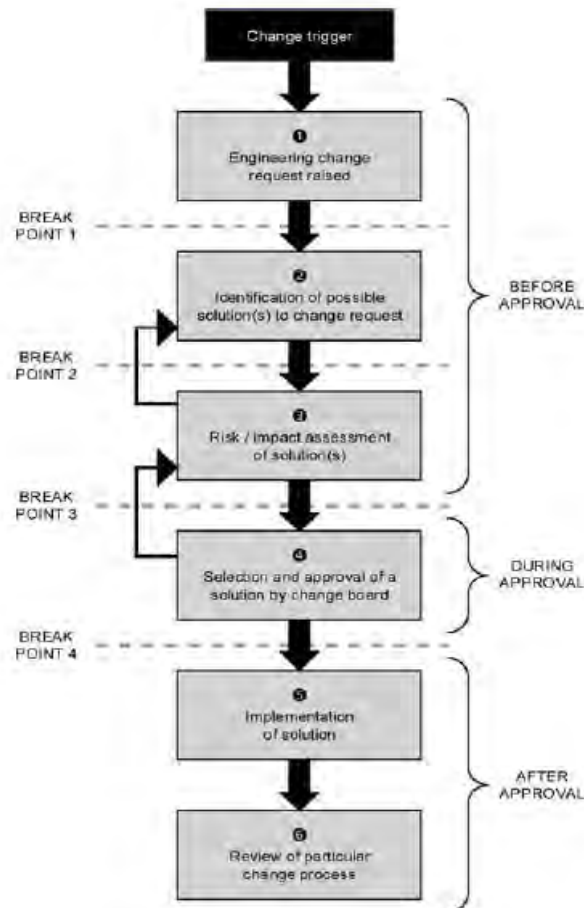


Figure 1: Model proposed by Jarratt et Al (2011)

The work from Jarratt et Al (2011) provides key insight into what is required for an ECM system to function successfully. Jarratt et Al (2011)'s proposal is similar to those of other authors as will be seen below.

Studies from Veldman & Alblas (2012), Huang & Mak (2003), Quintana et Al (2011) and Terwiech & Loch (s.a.) all list similar steps or phases that an engineering change goes through. These steps can be summarised as follow:

1. The need phase: A request is initiated or registered with a problem statement into a project or quality management program. The system is used to allow tracking of the request. At this stage the change is in the form of an Engineering Change Request.

2. The assessment phase: Risks that affect the attributes of the process or product are determined and affected plants are identified.
3. The information phase where a proposed solution and business case is presented. This step is crucial as an ECMS can only function correctly if it receives the correct and updated information (Wright, I.C., 1997: 35). Audits can also be performed to determine the physical aspects and compliance to practices and standards (Allan, G., 1997).
4. The approval phase: The request- now in the form of an Engineering Change Proposal is assessed by a cross-disciplined team and a decision based on the information, assessment, proposed design and testing in a controlled environment (to determine the causes) is given to allow or disallow the change request.
5. Execution phase: If the change request is approved, the necessary changes are made by means of an Engineering Change Order and validated by the change request management team.
6. Communication phase: All relevant parties are informed of the implemented change by means of an Engineering Change Notice. The request is closed-out and the change is evaluated for “fit for purpose”.

Thus, from a high level perspective the above mentioned process view provides key information towards engineering change management. It is clear from research that various authors agree on what is supposed to be managed during the process of performing an engineering change. Huang & Mak's (2003) survey found that most companies use a common set of tasks to manage EC requests. Nine of the tasks were identified in his literature survey and all nine of the tasks were performed by the companies in his case study. The tasks listed in his survey were:

1. Requests for engineering change are submitted.
2. Records are kept of the changes.
3. The effects or risks of an engineering change request are determined.
4. The engineering change request is evaluated and approved or disapproved
5. A date is set for an engineering change to be implemented.
6. Actions are determined and planned for the engineering change.
7. All disciplines are informed of the pending change.
8. A record is kept of the approved changes.

9. The actions defined or planned are monitored for implementation.

These tasks (that ultimately form part of the ECMS) are mostly driven by company policy but are somewhat generic on a macro level (Jarratt *et Al*, 2011). These tasks can be used to provide proper structure, guidelines and insight into what activities are required to perform the process of engineering change. The process of engineering change management is where the differences become apparent. In a case study by Pikosz & Malmqvist (1997), three engineering companies with different ECM processes and different levels of complication determined that a generalized or “off-the-shelf” ECM process will not be a feasible option if an optimized process is the objective of the company. This is further supported by Huang & Mak (2003) who states that the content and formats of the ECMSs he studied differs as different companies require different aspects and data on their EC’s. Pikosz & Malmqvist (1997) further establish that on a high systematic view of the ECM processes in different companies it remains similar but differs drastically in the second level where the activities are performed. On a task level however, it was found that once again the activities that are performed are aligned between companies (Pikosz & Malmqvist, 1997). According to Wright (1997) the ECMS used to perform EC is very particular to the industry the company operates in or the products the company manufactures. Much literature indicated that companies decided to write their own programs instead of using an “off-the shelf” package. Jarratt *et Al* (2011) found various reasons why companies decided not to implement computer-based tools:

- A lack of awareness of these tools
- The systems does not support the user’s needs
- The available systems are time-consuming and not user friendly.
- Too much data is required as inputs to the system.
- The systems do not deliver what was expected.

2.5 The three major aspects of ECM

Engineering change management is a systematic approach to handling and ensures that change is executed with control and the necessary authority. Engineering change can vary in size and is also involved in the full life-cycle of a product. Jarratt *et Al* (2011) determined that change activities are also associated with maintenance, upgrades and replacement of items with long-life periods. Jarratt *et Al* (2011) further

determined that practical implementations of ECM and literature suggest that the principal of managing engineering change is the same on a macro level and differences are only seen when the process is investigated in much greater detail. This is due to the fact that each company has particular needs from a process which cannot be generalized. Literature from various authors (Park, 2012), (McNair, 2013), revealed that engineering change has three major aspects in order for change to be controlled effectively (Figure 2). Each phase is characterized with an initiator or starter, a front-end loading (or information) and an approval or acceptance aspect. It is typically assumed that all engineering change requests are to be implemented and completed. However, Jarratt *et Al* (2011) pointed out that a study of German manufacturing firms determined that only 40-60% of the change requests are actually necessary to be implemented – it is thus important to only allow changes that will benefit the company to proceed but it should be necessary for the procedure or system to allow for premature close-outs as well. These change requests can be kept on a system for implementation or reinvestigated at a later stage.

McNair (2013) described that the starting point of any engineering change management systems should be the definition of what is meant with engineering change in the organization. Two views can be taken on ECM:

1. Investigating the process of ECM from inception to completion.
2. Investigating is commonly found in the three major aspects that form part of the ECM process.

By researching the latter, a generic ECM process can be developed from the aspects, which can be adopted and tailored by any company. Holistically Figure 2 depicts the three aspects of engineering change management with a few commonly found phases.

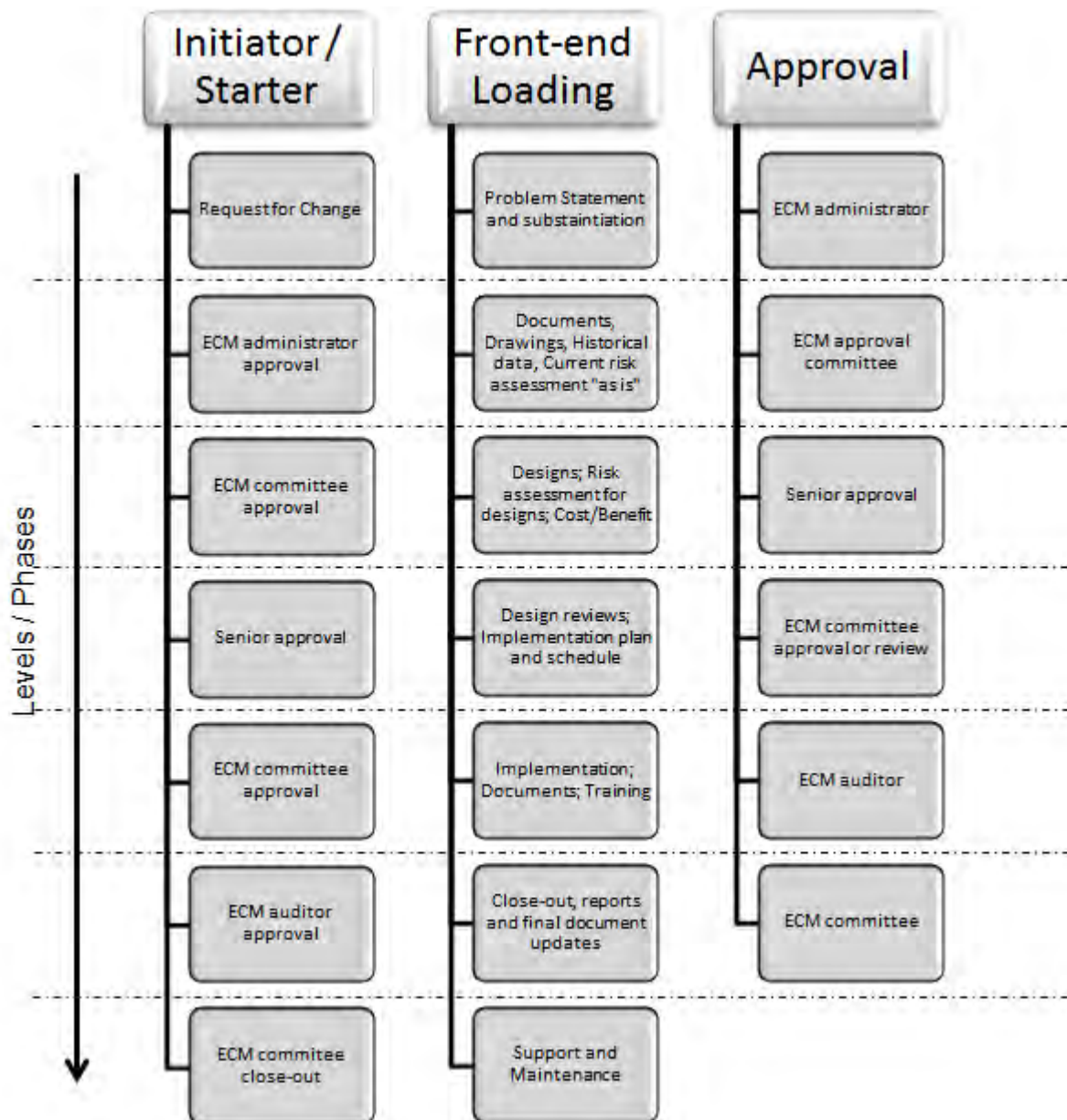


Figure 2: Typical phases found in an ECM process

2.5.1 Initiator / Starter

2.5.1.1 The level 1 starter: Engineering change requests

Pikosz & Malmqvist (1997:9) viewed the initiation for engineering changes in a manner very similar to configuration management in projects. In their research Pikosz & Malmqvist (1997) described the initiators as:

- Changes in customer requirements or specifications.
- Incorrect interpretation of client specifications.

- Inability to meet technical requirements (technology / manufacturing limitations)
- Snag items identified during project testing.
- Issues that could result in quality problems.

Huang & Mak's (2003) research took a different perspective and describes the engineering changes in the product development engineering sector categorically as: design office initiated, shop floor workshop initiated and customers initiated. Veldman & Alblas (2012) suggests the same and classified engineering changes in the service engineering division as Problem-driven, Improvement driven, Customer initiation or Necessary. Jarratt *et Al* (2011) limits the initiators to engineering change as one of two fundamental reasons:

- To remove mistakes in original designs to ensure a working system (emergent changes), or
- Improve, enhance and adapt (initiated changes).

Jarratt *et Al* (2011) further substantiates that approximately 35% of changes are due to the implementation of another change.

In the service engineering division – *the large steel manufacturing company* viewed their initiators of engineering change as requests initiated by one of three types: a) Failures, maintenance interventions or near-miss investigations; b) Continuous improvement initiatives (small projects), or c) Non-compliance interventions or deficiencies in original designs- or equipment (large projects) (Jooma, 2013)). Any of the three types initiates a change on the original implementation. Fundamentally, as mentioned above this is similar to the proposed initiators by Jarratt *et Al* (2011).

An engineering change is thus firstly initiated with an engineering change request. The engineering change request becomes the essential management item throughout the engineering change management process.

2.5.1.2 Subsequent phases: Signed approvals as initiators

Each of the subsequent phases, post-registration of an engineering change request is started by an approval of an authority. The approval can be seen as hold points typically found in project management (Jarratt *et Al*, 2011). Approvals are necessary to ensure that the engineering change is managed and controlled without being

implemented hap hazardously. Classification of changes is important to ensure that changes with high priority (e.g. changes that pose a high safety risk) are expedited through the process. Jarratt *et Al* (2011) found supporting literature that determined that 70% of UK firms' poor change management performance was due to bureaucracy in the system. This should obviously be avoided but no literature gave any clear guidelines on possible solutions.

2.5.2 Front End Loading

Each phase (e.g. feasibility, design, design review, implementation and execution, close-out, maintenance) all have a front-end loading aspect. The front end loading is typically the information aspect where the necessary work is performed to support the reason for change and different proposals to solve the change. Much iteration is possible for each phase in order to ensure that the proposals reach the appropriate level of work that is required.

2.5.2.1 Documents

Document (including drawings, operational procedures, work instructions, manuals and service history) is probably the most important aspect of engineering change management. Quintana *et Al* (2011) determined that the main purpose of an ECM process is to study, review, mark-up, change, validate, approve and release engineering drawings: Simply put – drawings and other documentation is the source of control (legal document) by which technical changes are performed.

Ensuring that the *status-quo* is reflected in documents is the most important aspect to the design engineer. All subsequent steps in the ECM process depend on the information and knowledge captured in these drawings.

Allan (1997) established that during a change's design phase the interrelated and interconnected objects with their related documents should be identified instead of determining them during the project integration and implementation phase. This reduces the risk twofold: one - the "as built" situation is indeed verified as correctly documented and two- all interconnected objects that can be affected by the change are rightfully identified. In the years before digital systems, drawing and document control was fairly easy to implement as these documents were only physically available from a single archive. The documents were checked out from the archive and as a

result it was not possible for other people to work on the documents at the same time (Terwiech, C., Loch, C.H., s.a.: 7). Nowadays, document control is of crucial importance, and, if not controlled can be likened to additional reworks and changes which ultimately affects time and cost spent on a problem. Balcerak & Dale (1992) identified a need to include configuration management with revision level numbering suffixes to the documents (with digital descriptions) to a) identify the change, b) know when the document was changed and c) know why and how the document was changed. Allan (1997) quoted that configuration management can be used in project management as a tool for milestone planning and to further monitor and control the changes of the specifications of the goals. The applicability of configuration management for document control is almost self-explanatory. Document revisions can be assigned, controlled, compared, evaluated, reported and locked out using a proper configuration management system (Allan, G., 1997). This is especially true if the configuration management system is digital. Looking at what is required- the British codes of practice for configuration management (BS 5515:1984) state that any amendment to any system or subsystem should, as a minimum, identify the following:

1. The reason for implementing a change;
2. The date of the request and authorization received;
3. The date the change was completed;
4. And the date the change was first used operationally.

(Allan, G., 1997: 327)

2.5.2.2 Paper-based ECM versus digital ECM

Paper-based systems are in many ways out dated and limited to its applicability and capabilities in the current information age. Jarratt *et Al* (2011) comments that paper-based engineering change management systems reduces efficiency as only one person or group can access information at a time. In many modern companies – drawings, procedures and other documentation is stored digitally and allows different users to access the documents simultaneously. Although it has its advantages, when evaluated from an ECM point of view, version control becomes a problem and documents can be updated and changed by multiple users at the same time or can be stored on a local location (e.g. local hard drive or flash memory) instead of the official digital archive. Although document updates are usually prompted during a change, it is not enforced

and as a result the documents available from a digital archive can be out dated. Newer versions of the documents can get lost on personal computers and is particularly a problem if the individual decides to resign from the company. Pikosz & Malmqvist (1997) described the use of digital vaults (e.g. online read only access for information purposes) and workflows (used when a document needs to change and electronic signatures are required) to effectively mitigate the problem and it can be further expanded to include lock-out or signed out statuses on documents and drawings being edited. Although many companies are aware of computer aided ECMs, Huang's (2003) findings indicated that none of his surveyed companies used them.

In Huang & Mak's (2003) surveyed companies- word processing and spread sheets programs for their reports and electronic mail as a means to propose, approve and evaluate ECs was used. Wright (1997) explained that various other authors found that a simple ECMS can be implemented on a system that can support two aspects: Firstly it needs to deal with the analysis of costs via spread sheets and secondly be able to track EC requests via a database management system.

2.5.2.3 Historical data & Records

Obtaining the right information concerning an engineering change is crucial. If the change is due to a failure or continuous improvement initiative; historical data can reveal if an engineering change occurred before and if it is equipment-, brand- or process related. History on similar problems might reveal a better, cost effective solution to the problem as well. The records of operation can reveal if the item was showing signs of pending failure prior to the initialization of the engineering change request. The historical data could also reveal if a change was made, why it was made and by whom. The front-loading of an engineering change request is extremely important to ensure that enough information is available to make subsequent decisions.

2.5.2.4 Risk Assessment

Risk assessment is crucial to the success of ECM. Various case studies in literature (Health and Safety Executive, 2013) determined that poor risk assessments were a leading cause of catastrophic industrial failures. Not only does it affect the operability of a plant (e.g. how safe is it really for an employee to work?) but the commercial aspects are also considered. The lack of a risk assessment can lead to excessive costs that

can ultimately lead to the closure of a business. Various risk assessment techniques exist (e.g. HAZOP) but as risk assessment is a major subject on its own, it will not be discussed further in this research.

2.5.3 Approval

It is common practice for the engineering department within a company to handle engineering change requests (Balcerak, K.J. & Dale, B.G., 1992: 127). Proper classification and prioritization of engineering changes must thus be ensured to prevent overloading of the administrator with “equally important” engineering change requests. The use of workflow is now a common practice in industry and can be fulfilled by most Enterprise Resource Planning (ERP) systems or even local intranet servers (such as SharePoint by Microsoft.) A computer-based workflow process can eliminate piles of paper-based change requests with effective email-based request and also allows for an auditable trace (Park, 2012: 2). A request can also be automatically classified and prioritized if the systems allow it (with proper setup and control) - or the change request can be sent to the correct engineering change manager or administrator who could then manually classify and prioritize it immediately (usually by company specific criteria). Pkosz & Malmqvist (1997) determined that the best results are achieved when the engineering change request is reviewed by a cross-discipline and cross-functional team of reviewers. Establishing a multi-functional and multi-disciplinary committee to review the technical and commercial feasibility of an engineering change on some periodic schedule would thus ensure that a proper and standardised method of examination is constantly provided (Diprima, 1982), (Wright (1997). The committee can then assign certain action items to individuals or groups for implementation using their discretion to ensure that each change is managed by the proper specialist(s) associated with the engineering change request. Although most authors agree that the use of a change committee is good practice Huang & Mak (2003) determined that many companies chose not to involve a committee or administrator for EC's.

2.5.3.1 Reducing lead time

Classifying the changes is extremely beneficial to reduce lead time and expedite the change through the ECM process (Pkosz & Malmqvist, 1997).

Huang & Mak (2003) identified a need to improve the time for each EC that is processed. This need was also identified in a case study by Balcerak & Dale (1992) where adherence to agreed EC implementation dates was one of engineering change management's greatest concerns. In a study by Terwiech & Loch (s.a.) an observation was made that the process lead times are quite often determined by the slowest single activity (or bottleneck activity) that is over utilized. Jarratt *et Al* (2011) mentions from a case study that some engineers in a company left the structured and formalized ECM system in order to implement a change in the required time. It is thus clear that the ECM system should be streamlined to ensure that there are no hold-ups in the process of managing the engineering change. With this observation made, it is obvious that control measures need to be in place to prevent backlog or hold-up with EC requests. If the ECMS does not prioritize and classify EC requests and does not demand a progress report or updates regularly; effects such as open or unresolved requests would be inevitable. Terwiech & Loch (s.a.) observed in studies that some requests remained on the agenda for over a year. This was noted as a key concern to an ECM in their study. An electronic workflow system could potentially decrease the lead time and also allow the ECMS to query the assigned personnel for a response, a task assignment update or approval periodically with relative ease.

Congestion of an EC request can also occur: Terwiech & Loch's (s.a.) study indicated that congestion due to over-utilization was identified by case studies as a major cause of delays and excessive lead time. The time it takes to process an EC request was in some of his cases more than 10 times the actual implementation time. In order for an ECMS to work effectively, the ECMS should be able to optimally utilize the engineers performing the changes. Workload needs to be shared among the workforce (Terwiech, C. & Loch, C.H., s.a.) as over-utilization of one engineer could jeopardise the whole ECMS efficiency and inevitably increase the lead time for the implementation of EC requests (Li, W. & Moon, Y. B., 2011).

Handling congestion is thus a critical part of an ECMS that needs to be managed. It was noted that congestion also occurs when long and regular meetings by the EC committees trying to cope with the requests are held. Large volumes of EC requests need to be managed in some way and the system needs to be able to prioritize the EC request according to some classification system. This need was also identified by the case study done by Balcerak & Dale (1992). Two classification strategies were

identified: one by which EC is described in terms of the documents it will affect, and a second where the EC is described by the urgency of implementation. The classification rating is thus as simple as:

- a. The impact the change within the organization has, and;
- b. The urgency at which it needs to be implemented

(Wright, 1997).

This classification philosophy is however somewhat flawed as the human nature drives a person to feel that their request is the most important request (Balcerak, K.J. & Dale, B.G., 1992: 127) which would ultimately lead to all requests being marked as “urgent”. The use of an EC administrator would, to a certain extent, allow certain minor changes (as predetermined by company policy) to be performed without being vigorously screened and approved by the EC committee (Balcerak, K.J. & Dale, B.G., 1992: 131) – e.g. maintenance where a replacement is made in “kind”. All other major change requests could then be presented in front of an EC committee who then has the authority to approve and schedule the EC request based on the technical and commercial feasibility (Balcerak, K.J. & Dale, B.G., 1992: 129). However, it is still deemed necessary to make use of a classification system to improve the process. Although limited literature is available to answer the “How?”; it was found that many authors identified that it can be done by using an assessment rating system driven by a risk assessment and (or) cost/benefit analysis. The use of such a classification system would also address the priority of changes that are due to the product being unsafe or non-compliant to legislative requirements and standards.

Reasonable effort should also be put in to choose a realistic implementation date. Balcerak & Dale (1992) found that the lack of guidance regarding the urgency of an EC request often lead the design engineer to simply schedule an average task implementation time such as six to eight weeks. Their study further indicated that the lack of proper, realistic implementation dates and obvious understanding of the urgency by the assigned person responsible for the change lead to changes that were never implemented.

Terwiech & Loch (s.a.) identified a few key aspects that can contribute to handling efficiency improvement of engineering changes:

1. Merge several related tasks into one single EC request with multiple actions (reducing the time necessary to obtain individual approval).
2. Balance the workflow between the different units in the system.
3. Ensuring that the resources to perform an EC are shared and available when needed.
4. Improve the IT platform to reduce time necessary for physical meetings. The EC requests can be captured and approved while tasks, responsibilities and resources can be assigned by a simple approval system with email based alerts. The capital investment required to implement an ECMS is in most cases fairly high. It would thus be beneficial to introduce an ECM system onto available infrastructure reducing investment cost to the bare minimum.
5. Most companies have a dominating culture of cost saving with limited emphasis on time management of tasks. If tasks were implemented on time, there can be an expected decrease in associated costs.
6. A lack of awareness of the actual consequences of an EC request should be improved. Changes have an adverse effect on connected systems and can thus lead to additional changes as well as unexpected failures.
7. Introduce a cross-functional engineering team to evaluate and control ECs – this leads to improved performance, knowledge transfer and awareness.

2.5.3.2 Proper Engineering Change versus implementation time

In the corporate world, the effectiveness of any change can be measured by a definition such as a: The achievement of the identified goals (with the associated quality goals) in the available time and budget while delivering sustainable benefit to the company (Merrell, P., Summer 2010: 20).

The general definition of a proper engineering change management system can be defined as the process to ensure that the integrity of the product being changed is kept intact (Quintana *et Al*, 2011). Terwiech *et Al* (s.a.) factually states in his research that one third to one half of engineering capacity is consumed with implementation of ECs and in the motor industry the costs for EC accounts for approximately 20-50% of the die-tool cost. Quintana *et Al* (2011) supports the claim by stating that more than 35% of 2011's manufacturing resources are devoted to manage changes on documents, plans

and schedules. Even though this could lead to the understanding that ECs are firstly a waste of resources such as time and cost; the hidden costs of improper management (e.g.: reduced efficiency, unplanned downtime, deterioration of quality) of engineering change and the cost of reworks and re-engineering significantly outweighs the negative aspects of engineering change from a business perspective.. A single undocumented and unplanned engineering change can have a snowball (or ripple) effect with subsequent changes in related equipment if the engineering changes are not managed effectively (Terwiech, C. Loch, C.H., s.a.: 4). Furthermore, it is believed that the earlier an engineering change is managed shifts the balance between the negative effects and the positive effects of engineering change management in favour of the positive effects.

2.6 Overview of Chapter 2

In Chapter 2 different literature on EC and ECM was reviewed to obtain a better understanding of the process, activities, approval and control required. Various authors agree that an ECMS is generic from a high level view at most companies. A description was also made of the controls that need to be in place for an ECMS to work. Sources of engineering changes vary from company to company but it was found that maintenance is often a source of engineering changes and as such it is thus of crucial importance to have up to date documentation to prevent time-consuming down-times and poor maintenance efficiency. A vast amount of time is spent on managing and executing engineering changes. Having a proper engineering change management procedure or system prevents the negative effects (such as an increase in paperwork and time lost to approvals) is thus crucial for successful change execution. Changes are interlinked. Changing a single part of a piece of equipment or process can lead to a snowball effect of additional, uncontrolled changes resulting in additional usage of resources. Change management is crucial for process safety and can result in loss of life, equipment, plant and (or) environment.

The preceding literature identified various important aspects that need to be part of an ECM that can be summarised as follow:

1. The use of an administrator to manage, classify and prioritize the requests and the use of an ECM committee to review the commercial and technical aspects of a request is important for ECM efficiency.

2. Proper scheduling is required for an ECMS to work. The ECMS should also be able to request feedback and updates to ensure that the change implementation is kept on track.
3. Although ECM exists in most companies, in most cases it is neither enforced nor prompted during a change.
4. Employees that use ECM systems are not fully satisfied with the results from having an ECM system.
5. ECM systems can manage the change effectively but are still limited in the ability to track and ensure document (especially drawings) changes are recorded sufficiently. Document control is of crucial importance in an ECMS to ensure that all related or interfaced systems are identified and addressed when a change is made. Documents with proper revision and change history are also important to ensure that future changes have reliable data to work with.
6. There is no well-known software available that can fulfil all the requirements of an ECM.
7. ECM can result in significant savings, ensure health and safety of an operation, provide proper guidance to new employees and lastly ensure knowledge retention and business continuity.

In Chapter 3, questions were developed to determine the level of understanding, the applicability, the need and the awareness of engineering change management and the consequences with the lack of such a management system or procedure.

Chapter 3 – Experimental design

Chapter 3 is all about the experiment. In this Chapter the techniques and tools are described that were used to develop the experiment to address the research questions.

An observational study was chosen as the experiment and does not entail any testing of respondents to treatments but rather the expression of opinions and experience of individuals in the area of concern.

The research conducted for this topic has been performed in two parts:

3.1 Secondary sources

Literature survey as in Chapter 2 has been performed to formulate a general understanding of the research topic (in a sense, building a vocabulary of common terminology, procedures and systems), what research was performed by other researchers and lastly the applicability of the research in the area of focus in this research.

3.1.1 A practical view of ECM in the industry

Practical investigation of engineering change management procedures is important to conclude the research on ECM. A particular company (kept anonymous to preserve the identity) with a fairly high ECM success rate was interviewed to understand the underlying principles of their ECM process. The findings of this research are portrait in paragraph 4.1.

3.2 Primary sources

A survey was conducted on a sample group in the population to investigate the objectives of this study which will finally be used to make deductions and interpretations. The deduction and interpretations was used to compare the *large steel manufacturing company* to the *petrochemical company* and *specialised products company* in order to address the objectives of the research as set out in Chapter 1.

3.2.1 Setting up a survey

Questionnaires are sensitive to noise and human perception of a question. In order to ensure that a questionnaire is well designed, the following characteristics need to be

taken into consideration (FAO, 1997), (Work Group for Community Health and Development, 2013):

- a. The wording of a questionnaire should be structured to ensure that the respondents receive the same stimuli;
- b. Prescribed definitions, terms and abbreviations need to be explained prior to the question to ensure consistent understanding, unless the purpose of the question is to understand the comprehension of a definition, term or abbreviation;
- c. The questionnaire should have a prescribed and consistent format to ensure that all respondents answer the questions similarly.
- d. The questions should be clearly formulated to ensure that the respondents receive the same stimuli when a question is asked. The questions should not lead the respondent to provide false information, leave out a question or conceal emotions.
- e. The questions should provide the necessary information to the respondent and the answers that are obtained should be recordable and interpretable.
- f. The survey should be short and to the point in order to ensure that the respondent remains interested throughout the survey.

Setting up a survey for experimental analysis requires forethought and careful planning. FAO (1997) & Work Group for Community Health and Development (2013) was used to develop a checklist that was used to create the survey:

1. The structure and questions of a survey should be developed in order to reach the objectives of the research. Formulation of a survey starts with a clear statement of objectives and the questions should follow in order to address the research objectives. A common way of testing a research question is to ask “What do I need to measure from the respondent in order to answer my research objective?”
2. Careful planning and consideration should be taken into the population to be sampled. The population should not be generic and should be targeted by the survey. Careful consideration should be taken to address age, gender, education and experience in the survey.
3. Questions: Only data relevant to the study or data supporting the objectives should be collected: All variables should be defined and the population determined. Only questions that would provide information contributing to the

research objectives should be included. The type of questions must be selected carefully. Close-ended questions provide the respondent with an easy way of answering and do not require the respondent to formulate his or her own answer or rely on memory. Open-ended questions allow the respondent to give a broader and clearer answer to a question other than an answer that is suggested – however, the answers must then be interpreted by the researcher. It would also give the researcher answers that weren't taken into account previously. The use of open response-option questions provides the benefit of both (open and closed type) questions by allowing the respondent to answer by selection and offering the option to expand the answer with some formulated response. The questions should also be tested against the following criteria:

- i. Does the question allow for answers with sufficient information?
 - ii. Can the question be answered correctly (e.g. the question does not request information to which the respondent does not have exposure to? The question does not require recalling memory and lastly the question does not require the respondent to articulate an answer when the respondents have an inability to do so).
 - iii. The question is not subjected to external biased (immediate events that will influence the answers).
 - iv. The meaning or terms used in a question should be common amongst all respondents.
 - v. The questions should not be leading in any way.
 - vi. There should not be any implied alternatives within the question.
 - vii. The question must be understood by the individual being questioned.
 - viii. The question should not contain any ambiguity.
 - ix. Vagueness should be avoided in the questions.
 - x. Questions should not be personal or potentially expose the respondent to any risks or embarrassment.
4. The population frame: define sampling units and construct the list of sampling units.

3.2.2 Soft questionnaire skills

The FAO (1997) & Work Group for Community Health and Development (2013) list a few soft skills to take into consideration with the development of a survey:

1. The opening question: sets the scene for the survey. The question should be simple enough to be answered and easily understood in order to encourage the respondent to continue.
2. Question flow: The questions should flow in some psychological order – leading easily to the next question. Questions of the same subject should be grouped together.
3. Question variety: The questions (or answer set) should vary enough to keep the respondent interested and excited to answer the questions. An open ended question often provides relief to predefined list of answers (even if the question is not analysed statistically).
4. Closing questions: The FAO (1997) argues that the respondent becomes indifferent to the questionnaire as it draws to a close. Later questions in a long questionnaire are often treated carelessly, thus it is important to have these questions closer to the start of the questionnaire. Sensitive information should be left to the end so that all the important questions are answered in case the respondent decides to avoid answering the sensitive questions.
5. Piloting the questionnaire: Testing the questionnaire prior to a full-scale survey has the following advantages:
 - a. It tests whether questions are worded correctly in order to achieve the objectives
 - b. The order of the questions can be shuffled to achieve the best results.
 - c. Tests whether the questions will be understood by the target group.

Statistical data acquired from questionnaires are particularly sensitive to the quality of the selection of questions, the phrasing, understanding and emotional connection to the subject. If the individual performing the questionnaire experienced a negative association toward the subject being surveyed the answers can become biased and meaningless. It is also important for the designer to take this into consideration as well as his or her own perception surrounding the subject.

In order to develop a meaningful questionnaire, the survey was piloted by a few non-biased individuals to obtain their objective assessment toward the formulation of the questions. A few of the individuals were specialists in the field of engineering and worked at companies that have a fully working and effectively implemented engineering change management system. Other individuals were non engineers – the purpose of these individuals' comments on the questionnaire was twofold:

1. To test whether or not the questionnaire was biased in any sense; and
2. To check the syntax and formulation of the questions in general according to the guidelines that was found in literature on survey data.

3.2.2.1 Feedback from the pilot survey

Three reviewers (each, respected experts in their field: Language, Engineering Data Collection and Survey Compilation) were asked to pilot the survey prior to the launch of the official survey to the target group. The feedback was received and was incorporated in the final survey to adequately address the research questions:

1. Various spelling, grammar and tense problems were identified and corrected.
2. The sequence of the questions were revised in order to ensure that the required data is collected before personal and confidential questions such as name, surname, company, role at the company and work- performance and ethics were asked. This ensures that the data is collected regardless whether or not the respondent chose to answer questions that might make him or her feel uncomfortable.
3. Certain questions were rephrased to ensure that it is not structured to offend the respondent (e.g. certain aspects or answers aren't viewed as common sense by all the respondents).
4. Certain questions were changed in order not to lead the respondents to a certain answer in following questions (or answering of a question based on previous question structure).
5. Certain Likert-scale questions were changed to prevent "neutral" responses to questions (e.g.: changed a 1 to 3 rating question to 1 to 10 in order to obtain a better spread of data).

6. Some of the Boolean questions (e.g. Yes / No; True / False; Applicable / Not Applicable) were changed to Likert-Scale questions to allow for better statistical analysis.
7. Sentences containing strong words such as “All”, “Always”, “Never”, “None” were changed and avoided.
8. Ambiguous terms such as “some” were avoided to prevent respondents with limited knowledge on a subject to give answers that cannot be statistically analysed.
9. Certain questions were changed to match the style and formatting of other text and illustrations on the survey form.

3.2.3 The Target group for the survey

As stipulated in Chapter 1, the purpose of the study was to investigate the importance of ECM in the service engineering division. The survey was thus set up to test implementations of ECM in the service engineering division. Because this division has limited university graduated engineering professionals in each company, it was decided to include production engineers (with responsibilities such as maintenance, continuous improvement and projects) in the survey as well (creating a diversified or homogeneity sample). The decision was taken for the following reasons:

1. Literature indicated that moderate to great success was achieved in production engineering with the use of ECMS to manage changes- thus; a lot can be learned, adopted and applied by understanding why ECM works in production engineering.
2. Understanding limitations in ECMS from production engineering environments will assist to understand what limitations can be expected in service engineering environment.
3. In most cases (except perhaps product development and research and design) engineering remains similar between divisions– thus, a negligible difference in views was expected from the production engineering compared to the service engineering groups.

The target group was further defined as:

1. Any technical person working in the engineering environment or any person managing engineering personnel or projects.
2. Any age, gender or experience (the level of experience was requested in order to understand how experience affects change management)
3. Education level: Technician to engineering specialist.

3.3 The survey

Firstly it is necessary to look at the types of data that can be obtained:

1. Qualitative: Qualitative data is a measure of quality or categorical variables such as a type. Qualitative data is also used to gain a better understanding of a theory or used in the generation of a new theory (FAO, 1997).
2. Quantitative: Quantitative data is data that can be represented numerically. Quantitative data is used to gain truth into the research objective and questions from previous and other authors (FAO, 1997).

From the above it is clear that both quantitative and qualitative data is required as the experiment is based on the expression of individuals working in the field with ECM as well as numerical representation such as frequencies (e.g. how many times you have used an ECM).

3.3.1 Qualitative and quantitative data investigated by the survey

Both qualitative (collection of exploratory information for the purpose of better understanding or testing hypotheses) and quantitative (test and quantify specific research questions using statistical analysis) have been used in the survey.

The survey was conducted electronically using *www.esurv.org* as the survey's platform. The use of electronic surveys allows flexibility, instantaneous and real-time results and the ability to follow up and track invites to the survey (Evans, J.R & Mathur, Anil, 2005).

From the literature survey, the following interpretations have been developed that were ultimately used to develop the questions for the survey:

- a. Although ECM exists in most companies, it is neither enforced nor prompted during a change.

- b. Employees that use ECM systems are not fully satisfied with the results from having an ECM system.
- c. Most ECM systems manage the change effectively but lack the ability to track and ensure document (especially drawings) changes that are recorded.
- d. There is no well-known software or system available that can fulfil all the requirements of an ECM.
- e. ECM can result in significant savings, ensure health and safety of an operation, provide proper guidance to new employee and lastly ensure knowledge retention and business continuity.
- f. An administrator is important to ensure that engineering change is correctly managed, classified and prioritized.
- g. The use of an ECM committee to review the commercial and technical aspects of a request is important.
- h. Do existing ECMS request frequent or periodic feedback and updates to ensure that the change implementation is kept on track?
- i. What is the importance of other aspects such as digital storing, archiving, configuration management, workflow, assignment of tasks, feedback reminders and approval levels, inter-departmental and cross-functional communication and brainstorming?

The survey was developed from questions that arose during the literature review and preliminary interviews- and discussions with people working in the service engineering field that worked or experienced problems with engineering change on a daily basis. The questions of the survey were mostly close-ended, Likert-scale or open response-option (multi choice with "other" option) questions where an option was given to enter additional detail which might be useful to the question. The answers to the questions were mostly qualitative of nature in order to understand the level of satisfaction, understanding and applicability of ECM by the targeted group; other questions were structured quantitatively in order to create classification in the results as well as to determine frequencies (e.g. "5% of the participants agreed that...") The survey was finally scrutinized by various non-technical people to determine if the questionnaire was in any sense biased or faulty. Pilot tests were also performed and the results were used to formulate clearer questions. Finally, the survey was sent out to various participants in the case study as well as other companies using an ECMS. The request was sent with a cover page, clear instructions as well as a guarantee that all information gathered

by the questions will be kept confidential. This was done to improve the responses, honesty of answers to questions and also to avoid identifying individuals or companies in the process.

The actual survey can be found in Appendix A.

3.4 Follow-up interviews

Informal follow up interviews were discussed either in person, via email or telephone call subsequent to the survey closure if interesting or unclear answers were given. The purpose of the follow-up interviews was to understand the reasoning behind an answer.

3.5 Chapter summary

The chapter provided the necessary information and process of the development of the research experiment. A survey was chosen to derive conclusions on the research question and research objectives. Further informal interviews were used for in-depth understanding of certain answers. The next chapter presents the survey results with an analysis, evaluation and validation of the findings using the literature review chapter as reference.

Chapter 4: Data analysis & Interpretation

Chapter 3 contains the outline to the experimental design and the detailed questions that were asked in the primary source: the survey. In Chapter 4 the data is explored that was obtained from the experimental design. The subsequent Chapter depicts the conclusions and recommendations for future work that were made that were deduced from the data analysis.

The results from the survey were captured automatically from *www.esurv.org* website. It was thus not necessary to re-present the data using tables and charts as the data was already available in this form. For this reason, the results were captured in the addendum as three different scenarios:

- a. summary of data;
- b. data from a petrochemical company with an established and implemented ECMS, and
- c. data from the large steel manufacturing company

Certain results that required more in-depth investigation were also extracted in individual respondent form to perform better analyses.

4.1 Findings of the practical view of ECM in the industry

The information that follows describes the ECM process on a very high level. Each of the phases has a gate or approval hold point prior to the commencement of the following step. The preceding literature indicated that the approval levels vary from company to company and are determined by the level of control that is needed. The level of control on the other hand is determined by the associated risk engineering change brings to the company.

4.1.1 Initiation

The surveyed company indicated that their engineering change management system request a post registration report from the engineer who is evaluating the findings of the change request. The report includes a risk assessment for the situation “as is”.

4.1.2 Feasibility

This phase in the interviewed company's implemented ECM process is where technical conceptual designs are developed for multiple solutions and a business case is developed for each solution. In this phase a risk assessment such as a HAZOP study is performed to support the solutions. The business case is necessary in order to establish the commercial feasibility of the change.

4.1.3 Design phase

The design phase is the development of the technical solution determined in the feasibility phase. In this phase the specifications are developed and evaluated against standards for compliance. The design phase includes documentation such as operating, start up and maintenance procedures.

4.1.4 Implementation, execution and testing phase

In this phase, the design is implemented and executed to determine if the design is sufficient to address the deficiency that was noted in the original or subsequently altered engineering change request. Testing of the change is important to ensure the safety and operability of the change. Testing also ensures that the operating procedures fully address the conditions that will be faced by the operators of the equipment.

4.1.5 Close-out phase

The close-out phase is required to ensure that the change is properly documented and handed over to the process or equipment owner. The close-out phase requires training of operators and maintenance personnel on the change and also allows proper communication to be distributed to ensure that all the employees are aware of the change that was implemented.

4.1.6 Review phase

The review phase involves the engineering change committee. An auditor is appointed to ensure that the change was properly documented, executed and closed-out. The review phase also evaluates additional changes that may be needed subsequent the implementation of the change.

4.2 Literature review findings

Literature reviewed that ECM is an effective management tool to ensure that EC is executed and recorded perfectly regardless of size or type taking into account all the relevant risks to safety, technical capabilities, and economic justification. The lack of proper risk assessment was found to be the leading cause of EC failure and can result in tragic safety incidents such as the Chernobyl, USSR and Dutch State Mines Nypro Plant, Flixborough, These incidents paved the way for ECM to become a crucial safety requirement to prevent injuries and fatalities in some countries such as the United States of America and the United Kingdom. Not only is it crucial to safety but the lack of ECM can result in equipment damage, additional changes and reworks, rescheduling, unavailability of maintenance parts, poor service delivery and a general deterioration of performance in downstream processes, equipment and equipment capabilities – affecting quality, maintainability and operability. Therefore, ECM is also involved in the full life-cycle of a product.

The management process of ECM is interlinked to other management systems such as configuration management, quality management, health and safety management as well as project management. Literature revealed that ECM forms part of the much larger configuration management process of a company. ECM is triggered by deficiencies or inadequacy of existing components or products, or the result of another change needed for continuous improvement. The nature of engineering makes processes and equipment dependent on each other, and as a result, a change on one could potentially affect another. To manage the traceable dependencies between components and equipment change management must be implemented and controlled correctly.

The process of performing an EC can be generalized but on task level it becomes dependent on company requirements. Jarratt *et Al* (2011) provided 6 concepts that are required for ECM to perform effectively: a) initiate a change request; b) identify possible solutions; c) perform a risk assessment on solutions; d) selection of an appropriate solution by a change board; e) implementation of the solution, and f) review of particular change process. Documentation control is the main purpose of ECM and should be adequately addressed in order for an ECM to work efficiently. A standardized ECM process would thus provide consistent means for implement changes in the workplace,

it further ensures that documentation is in place, people are rightfully informed, trained, and consulted, and it provides a means for critical business knowledge retention.

An effective ECM would lead to an overall reduction in time to develop and implement a change, reduction in start-up time and an overall reduction in cost.

Limited “of-the-shelf” solutions are available and most companies chose to implement their own written program to manage EC. Literature indicated that paper-based systems are mostly out dated and reduces system capabilities and efficiency. A basic ECM needs to address three aspects for each in order to function properly: a) initiator of phase; b) information and front-end loading, and c) approval.

Management of EC is crucial to ensure that the system performs adequately – it was found that many engineers abandon a formalized EC process in order to implement a change in time. Bureaucracy in a company was found to be the main culprit of poor ECM performance. The management of changes varied in literature and most companies decided not to make use of an administrator to manage change but managed it through the company’s engineering department. The use of a multi-disciplined change management board was highly recommended in literature in order to address all the EC risks and concerns, the ECMS can be further optimized by allowing changes to be classified to some rating system and then allowing different routes and requirements based on their rating and type of the engineering change.

4.3 Evaluation of survey data

The key objective of the survey was to collect data to establish the importance of engineering change management in the engineering services division of three different companies localised in South Africa.

Evaluating the survey data identified the importance of certain key aspects of engineering change management and also established what key aspects of engineering change management is lacking in current available ECMS. The one company (a *petrochemical company*) has a well-established and widely implemented engineering change management system adopted from the Process Safety Manual (U.S. Department of Labor, 2000) standard that is a compulsory requirement for any change regardless of size or type. The other company (a medium sized *specialised product manufacturing company*) has two types of ECMS: a local, plant specific paper-based

ECMS, used for changes that do not affect product performance or properties; e.g. maintenance, and an electronic corporate ECMS used for changes to process technology, trials and qualification of raw materials. The paper-based engineering change management system of the *specialised products company* was of particular interest as it was used specifically for changes in the service engineering department of the company. The third company (*a large steel manufacturing company*) for which this study was performed had no ECMS for changes in the service engineering department at the time but was evaluating ECMS options and was in the process of adopting and tailoring an ECMS from one of their other plants. The *large steel manufacturing company* did however have a change management system to control changes that affect their product quality and associated properties.

4.3.1 Sample Demographics

Table 1: Role of respondent

Role	Percentage of respondents
Service Engineers	28%
Technical Manager	28%
Process Engineer	24%
Design / Projects engineer	12%
Other	8%

The survey was set up to gain insight from people operating in the service engineering division. The results reflected the targeted demographics as 28% of the respondents where service engineers and another 28% of the respondents were technical managers (all of them were managers in the service engineering field). A further 24% of the respondents were process engineers (the rest of the result that follow indicated that most of the process engineers operated in the service engineering industry: e.g. a process engineer for a specialist infrastructure production department such as air

supply or the quality department of a company – see Table 2), 12% was in the design and projects environment that also formed part of the service engineering division.

Table 2: Area of work

Area of work	Percentage of respondents
Services	60%
Production	16%
Research & Development	8%
Quality	8%
Health, Safety and Environment	4%
Other	4%

As this study surrounded engineering change management, the respondents’ roles were very important.

A large percentage (45, 83%) of the respondents was operating as seniors in their organisation while the rest of the respondents were graduates or specialists. The survey target group was specifically set up to obtain information from these three groups (in order to establish how experience and seniority affect the views on ECMS). Surprisingly, a large extent (half of the group) the respondents weren’t registered as Professional Engineers and were thus not required to adhere to the council’s ethics and standards (ECSA’s). No clear link between the effectiveness of ECM and professionally registered engineers was found.

Table 3: Level of experience

Level of experience	Percentage of respondents
Senior	45,83%
Graduate	16,67%

Specialist	16,67%
Junior	12,50%
In practical training	8,33%

Table 4: ECSA status

ECSA status	Percentage of respondents that are
Registered as a candidate	30, 77%
Professionally registered	11, 54%
Not registered	46, 15%
Other	11, 54%

4.3.2 Understanding of ECM

The survey question was structured in such a way that it needed to be analysed qualitatively. The following list of keywords was drawn up to analyse the understanding of the question based on the findings from literature of what constitutes ECM, ECM activities, tasks and phases (Allan, G., 1997), (Jarratt *et Al*, 2011), (Balcerak & Dale, 1992), (Huang & Mak, 2003). Literature indicated that the following engineering change constituents needed to be performed in order for ECM to be successful:

The respondents' answers were analysed for the keywords that follow in order to draw a correlation between literature and the primary data:

Table 5: Measuring the understanding of ECM by individuals

Literature keyword	Qualitative measure	Percentage of respondents that mentioned
Assessment, Risk mitigation and	Risk management / mitigation	34, 62%

reduction		
Need analysis, Planning, implementing, actions	Control of scope, work and (or) schedule; Project management, life- cycle engineering or phases	50, 00%
Approval, Workflow	Approval levels, signoffs or workflow	19, 23%
Control, monitor	Configuration management, management of items versions or configurations, management of changes	53, 85%
Reduction in cost	Cost management or cost/benefit analysis	11, 54%
Communication	Stakeholder involvement, change communication	26, 92%
Updates, Documentation	Documentation updates, capturing data, traceability	57, 69%
Report	Reporting	7, 69%
Archiving	Archiving, future reference	26, 92%

The respondents' answers were fairly different to this question but the following analysis can be made from the data:

- Documentation updates was one aspect that was mentioned by 57, 69% of the respondents. This is conclusive with what was found in literature. Quintana et Al (2011) determined that the main purpose of the ECM process is to study, review, mark-up, change, validate, approve and release engineering documents.
- 53, 85% of the respondents mentioned that configuration of items are part of the ECM definition which concurs with Jarratt et Al's (2011) statement that ECM forms part of the much larger configuration management process and Pikosz &

Malmqvist (1997) who viewed that EC as the core process of the configuration management system.

- 50% of the respondents linked ECM as a similar process such as management of a project. Although it is not entirely the same (e.g. some engineering changes do not require the full project management process), the process of performing an EC is inherently related to project management as well as other management systems – an association that Jarratt et Al (2011) made – where change management activities are associated with maintenance, upgrades and replacements of items with long-life periods (e.g. projects). Thus, engineering change management can be initiated within a project and vice versa.
- The lack of “approval” in the answers (only 19, 23%) was also found in literature where 70% of poor change management performance was due to bureaucracy in the system (Jarratt et Al, 2011) and case study evidence from Jarratt et Al (2011) determined that some engineers left the structured and formalized ECM to implement the change in the scheduled time.
- The lack of communication (26, 92%), reporting (7, 69%) and economic justification (11, 54%) was also concerning as these are all items that are required for proper engineering change management execution (Jarratt et Al, 2011), (Veldman & Alblas, 2012), (Huang & Mak, 2003), (Quintana et Al, 2011), (Terwiech & Loch, s.a.).

4.3.3 Evaluating the effectiveness of ECM implementations

Table 6: Effectiveness of engineering change management

Effectiveness of engineering change management	Percentage of respondents
Very effective	19, 23%
Effective	26, 92%
Neutral	15, 38%
Ineffective	26 92%
Very ineffective	11,54%

The Likert scale results indicated that 46, 15% rated their ECM effectiveness on the higher end of the scale and 38, 46% rated on the lower end of the scale. The rest was rated as neutral. It was found that the effectiveness of the ECMS was related to the company and also the industry the company was operating in (see Table 7 for comparison between the *petrochemical company*, *large steel manufacturing company* and *the specialised products company*).

Table 7: Effectiveness comparison

Company	Rated as effective to very effective	Rated as ineffective to very ineffective
Petrochemical company	88,33%	0%
Large steel manufacturing company	25%	66,67%
Specialised products company	60%	20%

The industry (which has inherent risk); and countries of operations affected the required (either by law or other standards) control and extent of application over change that is required. The bylaws in certain countries (e.g. USA) require certain operations such as hazardous chemical and oil companies to have more rigorous control over the changes that are implemented (U.S. Department of Labor, 2000), and thus as expected all the respondents from the *petrochemical company* indicated that their ECMS were fairly effective and inclusive (as it is governed by the Management of Change procedure in the Process Safety Manual (U.S. Department of Labor, 2000)). The respondents in the *petrochemical* company indicated via their understanding of ECM that they are well aware of ECM and the impact of non-conformance. The other respondents from the other two companies all had different opinions on the effectiveness of their engineering change management system. Follow up discussions with some of the respondents that gave the aforementioned answers revealed that their position, department they were working for, experience and usage of ECM depicted their view on the effectiveness of ECM. Some sub-departments within the service engineering department (e.g. process automation systems or instrumentation and control) adopted their own ECM system to

manage changes performed by the sub-department team. The management of changes were limited to their own changes and did not include information and inputs from other departments or affected equipment. The general purpose of their management system was to provide a change history in order to enable the sub-department to revert back to previous states with relative ease if needed.

The lack of an official implemented ECMS at a company would require individuals to devise an individualized procedure to manage the aspects of a change, however, it was found that, except for the *large steel manufacturing company*, the *petrochemical-* and *specialised product company* does have ECMS that is governed by company policy to ensure that changes are performed consistently the same by any employee at any time. The level of understanding and effectiveness of ECM varied in the other two companies that formed part of the survey. Seniority in the organization played a big role in the response. In general the more senior the respondent was the better the understanding was on ECM and also the priority engineering change management took by the individual performing the change: senior employees without a company specific ECMS listed more aspects (such as risk assessments, document reviews, training) that were required for a change . Follow up interviews gave insight into the response in the sense that a senior employee has, over the years, developed their own way or “system” to manage the changes they introduce.

4.3.4 Inclusion of different departments or processes in the ECM process

Table 8: Departments that make use of ECM

Departments that make use of ECM	Percentage of respondents that agreed
Maintenance	69, 23%
Operational changes	65, 38%
Documents (including drawing) changes	73, 08%
Projects	76, 92%
Risk assessments	46, 15%
Safety, Health and Environment	46, 15%

Quality	53, 85%
Incident investigations	34, 62%
None	3, 84%

The results from the survey indicated that the ECMS are used with Maintenance changes, Operational changes, Documents changes, Projects and Quality and to a lesser extent in Risk Assessments, Safety, Health and Environment and Incident Investigations.

This corresponds to literature that indicated that ECM is important from a safety aspect (U.S. Department of Labor, 2000), (Health and Safety Executive, 2013), and is often triggered by request and changes of clients or deficiencies or inadequacies of existing products – e.g. maintenance or operational needs (Balcerak, K.J. & Dale, B.G., 1992), (Jarratt *et Al*, 2011).

4.3.5 Accessibility of ECM data

Table 9: Type of ECM process

ECM process	Respondents that said
It is company specific	69, 23%
It is up to the individual performing the change	30, 77%

The data indicates that most companies have set procedures and systems to manage ECM. The subsequent questions would thus reveal how effective the systems are and what areas of their ECM requires additional work. The 30, 77% that indicated that their company does not have an ECM are all from the *large steel manufacturing company* although it was found from analysing the data that not all of the respondents from the *large steel manufacturing company* indicated that their ECM was company specific.

Table 10: ECM storage and accessibility

Capturing of ECM data on centralised, easily accessible location	Percentage that agreed it is
Very effective	11, 54%
Effective	26, 92%
Neutral	30, 77%
Ineffective	15, 38%
Very ineffective	15, 38%

Table 11: Accessibility of ECM data

Accessibility of ECM data	Respondents that agreed
Not at all	15, 38%
Limited to the employee working on the change	19, 23%
Accessible by only a few people	34, 62%
Accessible to a large extent	23, 08%
Fully accessible	7, 69%

The survey indicated fairly conclusive results on accessibility of ECM data, previously performed ECMS and cross-search functionality. Many of the respondents were unsure where the ECM data was stored and thus selected neutral on the Likert scale. The largest percentage of respondents (34, 62%) indicated that accessibility to ECM data was limited to only a few people in the organisation.

Table 12: ECM cross search capabilities

Cross Search capabilities	Respondents that said
Only administrators	42, 31%
Only stakeholders	15, 38%
Interested parties	30, 77%
Everyone	11, 54%

Records and information on previous changes were also not available to any employee who wished to do a similarity search. This indicates that the ECMS does not provide an archive where previous changes can be examined for similarity and applicability – it thus indicated that new or junior employees would not be able to gain access to knowledge captured in terms of changes.

4.3.6 Management of EC's

Table 13: Control and management of engineering changes

Control and management of engineering changes	Percentage of respondents that selected
Administrator	42, 31%
Manager of engineering change	30, 77%
Not implemented	26, 92%

73, 08% of the respondents indicated that EC is managed by some authority be it an ECM administrator or a manager of engineering changes. The results were once again based on the company and industry – the same was found in literature (Wright, 1997), Jarratt *et Al*, 2011), (Huang & Mak, 2003). 85, 71% of the 26, 92% of respondents that indicated that the control and management of engineering changes are not implemented were from the *large steel manufacturing company*. The industries (such

as the *petrochemical company*) where changes were highly managed and controlled indicated in follow up discussions that they had dedicated managers or administrators for engineering changes whose sole purpose was to manage progress and compliance on engineering changes. The other companies made use of line managers or seniors (most instances the engineering manager: 28%) that has dual responsibilities to manage engineering changes. The same was found in literature where it was found that it was common practice for the engineering department to handle engineering change requests (Balcerak, K.J. & Dale, B.G., 1992).

Table 14: Administration of EC

Administration of engineering changes	Percentage that said
General Machines Regulations: 2.1 or 2.7	19, 23%
Engineering Manager	30, 77%
Change Manager	11, 54%
Departmental Head	19, 23%
Other:	
Individual implementing the change	3, 84%
None	7, 69%
Specialist	3, 84%
Drawing office Manager	3, 84%

Limited responses (19%) indicated that changes are managed by the legal appointee from the Occupational Health and Safety Act (Act 83 of 1993) e.g. General Machines Regulations 2.1 or 2.7 – follow up discussions indicated that the legal appointee was however involved or consulted in many instances and has the authority to overrule decisions.

4.4 Aspects of engineering change

Table 15 shows the level of control required for a change before a change can be close-out at the specific company. From the table it is quite clear a limited amount of the respondents were required to have changes reviewed by some authority prior to implementation. There is also a lack of business case requirements and only a few of the respondents were required to do a cost vs. benefit analysis.

Table 15: Aspect of engineering change needed for an engineering change close-out

Aspects required for close-out of EC	Percentage
Basic description of change (e.g. problem statement and substantiation)	88, 46%
Business case: cost vs. benefits analysis	61, 54%
Risk assessment	76, 92%
Affected processes / plants / personnel	88, 46%
Reviews on the proposed change	57, 69%
Assign a senior employee to evaluate the change	46, 15%
Request document changes (drawings, operating procedures, commissioning procedures, maintenance procedures, etc.)	76, 92%
Verify changes reflected in documents	50, 00%

The data indicates that the ECMS of the three evaluated companies all follow the generic model of ECMS as found in literature (Jarratt *et Al*, 2011),(Veldman & Alblas,

2012), (Huang & Mak, 2003), (Quintana *et Al*, 2011), (Terwiech & Loch, s.a.) although senior evaluation and reviews could potentially be improved.

A verify important aspect of engineering change management is the review or auditing phase to ensure that what was identified to be performed was actually implemented and properly documented (Park, 2012). 50% of the respondents indicated that this was not done.

4.4.1 Communication and decisions

Table 16: Level of communication

Rating of communication send out during a change	Percentage respondents that selected
Excellent	4%
Good	20%
Neutral	36%
Fair	20%
Poor	20%

The survey results indicated that communication on engineering changes were limited in most instances. In general, most respondents indicated that the engineering department is mostly involved in changes, to a lesser extend stakeholders and affected departments are included. Most respondents indicated that the business unit managers and other commercial departments such as finance, legal, health and safety, etc. where not involved in the change management communication or decisions, similar to the findings of Huang & Mak (2003) who indicated that the case study companies he evaluated chose not to involve a committee of administrator for EC, even though Diprima (1982) and Wright (1997) determined that it is a good way to ensure consistency.

The respondents' results on how good communication in the company is are also limited. Most of the respondents remained neutral but others indicated that communication was poor and could be improved.

4.5 Measuring the effectiveness of implementations of ECM

76, 92% of the respondents indicated that documentation control is the biggest concern when it comes to the management of engineering change. As documents are the source of EC control (Quintana *et Al*, 2011) and maintenance and other functions are inherently reliant on correct data from the documents, it indicates that the current ECM process does not yet have adequate control of document changes. 69, 23% of the respondents also indicated that they were aware of changes that weren't closed out properly. Unfortunately, the question did not ask for more information but it still indicates that there is no adequate control or enforcement of engineering changes in some of the companies surveyed. The approval of ECs is thus still not done properly and the use of multi-disciplinary teams as indicated by literature for consistency is thus not currently being used (Diprima, 1982), (Wright, 1997). This was also the findings from the study of Huang & Mak (2003) who indicated that many companies chose not to involve a committee for the approval of ECs.

Table 17 shows results from the survey.

Table 17: Maladministration of changes

Awareness of mismanaged changes	Percentage perceived by respondents
Changes implemented hap hazardously – without communication	50%
Changes that were not documented properly	76, 92%
Changes that were not closed out properly	69,23%
Changes that did not adhere to common best practices on engineering change management	50%

Changes that were not stored on the company's servers: e.g. a centralised access point	46,15%
Changes that were performed without problems	15,38%

The results from the survey when the respondents were asked how well documentation control was based on a scenario was rather conclusive: 69,23% of the respondents indicated that documentation was either not kept up to date or was somehow not properly managed and resulted in the loss of information. The respondents were only sure of about 15,38% of changes that were performed without any problems.

Table 18: Document control

The ability to duplicate a plant based on existing drawings that are available	Respondents that said indicated
Yes	30,77%
No	69,23%

Most respondents found the initiation, implementation and risk assessments of EC aspects of their ECMS quite successful at their respective companies. However, a lack of control was found with the archiving of EC, and post-closure observation. Most respondents had neutral responses on their workflow and (or) approval process, communication and maintenance of ECS.

When asked to rate the capabilities of their ECM process. The following data was obtained:

Table 19: Capabilities of ECM

	1	2	3	4	5	6	7	8	9	10
	%									
The EC request to be evaluated during change implementation	19.23	0.00	3.85	3.85	11.54	26.92	11.54	3.85	11.54	7.69
The EC request to be evaluated post change implementation	19.23	0.00	3.85	7.69	15.38	19.23	11.54	7.69	11.54	3.85
Expanded (additional scope added)	7.69	3.85	7.69	0.00	23.08	30.77	0.00	7.69	11.54	7.69
Changed (deviate from the initial change scope)	11.54	3.85	0.00	3.85	11.54	30.77	7.69	7.69	19.23	3.85
Allow additional / other change requests to be opened from the original EC request	15.38	15.38	3.85	0.00	19.23	19.23	7.69	11.54	7.69	0.00
Weighted average	14.61	4.62	3.85	3.08	16.15	25.38	7.69	7.69	12.31	4.62
Sum of average (1 - 4; 5; 6 - 10)	26.16				16.15		57.69			

- 1 Most ECMS allowed a change to be evaluated to some extent throughout the change’s lifecycle.
- 2 Post change implementation was either possible to some extent or not at all possible on their ECMS.
- 3 Additional scope can be added to some extent.
- 4 The scope of most changes can be changed during the process of performing the change.
- 5 The respondents felt that some additional change requests can be initiated during the process of performing a change.

Table 20: Rating of ECM process

	1	2	3	4	5	6	7	8	9	10
	%									
Initiation	7.69	0.00	11.54	11.54	15.38	3.85	11.54	23.08	11.54	3.85
Approval Process / workflow	11.54	0.00	3.85	11.54	11.54	19.23	11.54	15.38	7.69	7.69
Risk assessment	0.00	3.85	11.54	15.38	11.54	11.54	19.23	11.54	7.69	7.69
Business case	3.85	11.54	7.69	11.54	15.38	11.54	15.38	15.38	3.85	3.85
Implementation	3.85	3.85	3.85	0.00	19.23	3.85	26.92	23.08	7.69	7.69
Archiving	19.23	7.69	11.54	11.54	7.69	3.85	19.23	3.85	7.69	7.69
Communication	7.69	3.85	11.54	15.38	23.08	11.54	7.69	11.54	0.00	7.69
Post-closure observation	23.08	11.54	7.69	7.69	11.54	11.54	7.69	3.85	7.69	7.69
Maintenance	7.69	7.69	19.23	7.69	23.08	3.85	15.38	0.00	7.69	7.79
Weighted average	9.40	5.56	9.83	10.26	15.38	8.98	14.96	11.97	6.84	6.85
Sum of average (1 - 4; 5; 6 - 10)	35.04				15.38		49.58			

4.6 Room for improvement

Table 21: Determining if existing ECMS require improvement

Respondents indicated	Percentage
Yes, I want an improved ECM	84, 62%
No, I do not want an improved ECM	15, 35%

84, 62% of the respondents indicated that they would like to have an improved ECMS at their company. This corresponds to what was found in literature (Jarratt *et Al*, 2011) that indicated that very little literature has been published on engineering change and the management thereof compared to other management systems although the limited published literature does indicate the great importance of ECM. Jarratt *et Al* (2011) further determined that regardless of the growth and improvement of engineering change management, it still remains a very real problem to organisations.

Results from the survey indicate that document control remains one of the greatest threats to proper engineering change management (see Table 22). This was also found from own personal experience and the follow up interviews with respondents. Many of the interviewees indicated that although their ECM system is quite comprehensive, enforced and controlled – unmanaged changes still occur and is not reflected in the “as-built” documentation. Post-closure audits is the only way to ensure that the change is adequately addressed (Jarratt *et Al*, 2011), (Huang & Mak, 2003) in all the necessary documents including drawings, reports and procedures.

Table 22: Aspects for improvement

Aspect that needs improvement	Percentage of respondents that would like improvement
Document control (incl. drawings and procedures)	69,2%
Approval levels	34,6%

Reviewers	34,6%
Change management administrator	34,6%
Change management committee	42,3%
Standardized procedure	56,7%
Risk assessments	42,3%
Request for information	50%
Workflow	57,7%
Other	<ul style="list-style-type: none"> ○ The ability to search reference documents of previous changes ○ An electronic system ○ Reduced paperwork ○ All of the abovementioned aspects in an electronic system following a standardized process as well as the ability to prematurely close out a change ○ Cost/benefit analysis ○ No paper based system with an enterprise sponsor within the company driving the implementation

4.7 ECM at the large steel manufacturing company

Table 23: Roles at large steel manufacturing company

Roles	Percentage of respondents
Service engineer	41,67%
Technical Manager	41,67%
Process Engineer	16,67%

The case study results are based on a representation of 12 highly technical employees either in engineering- or management of engineering positions. The specific department that the ECM is investigated for is very small: 7 technical managers and 14 engineers of different seniority. The sample size would thus give adequate representation of the department and the ECs that are performed.

Prior to the start of this research, my personal experience at the *large steel manufacturing company* initiated a study to determine why engineering changes lead to failures. The initial study identified a few key problems that are due to improper change management as identified in Chapter 2. The results of the survey provided conclusive evidence that indicated that *the large steel manufacturing company* did not have an ECMS implemented at their facility's service engineering department which ultimately lead to the failures described in Chapter 2. This significantly impacted the way changes were handled and seen in the company. The understanding of ECM varied between the respondents but the respondents had some (although somewhat limited to their individual experience or role at the company) knowledge on change management. When asked in which areas ECM is applied, the responses once again varied significantly and it can be concluded that this is due to the fact that the company does not see all changes as management items and does not have fully defined processes for each.

Table 24: Effectiveness of ECM at the large steel manufacturing company

Effectiveness of engineering change management	Percentage of respondents that agrees it is
Very effective	8,3%
Effective	16,67%
Neutral	8,33%
Ineffective	41.67%
Very ineffective	25%

The data indicates that 66, 67% of the respondents rated the ECMS between ineffective and very ineffective. Furthermore the respondents were unsure if changes were stored and archived centrally and that the availability of data on changes was rated between “not at all” available and “only accessible to a few people”.

Table 25: Accessibility of changes at the large steel manufacturing company

Availability of previously performed changes	Percentage that agree accessibility is
Not available at all	25%
Limited to the employee working on the change	25%
Available to only a few people	41,67%
Available to a large extent	8,33%
Fully accessible	0%

Knowledge transfer was thus not through investigation and research on previously implemented changes and could potentially lead to “reinvention of the wheel”. Jarratt *et Al* (2011) found literature that indicates that changes are a potential source of learning and provides a means to continuously improve and implement subsequent changes by learning from the experience and knowledge captured in the engineering change.

Risk assessments at the large steel manufacturing company were also not performed unsystematically. The answers from the study do not specifically indicate whether or not changes are performed with risk assessments as a pre-requisite. The fact that risk-assessments are only performed in “Some cases” indicate that it is mostly up to the individual(s) or line management whether or not risk assessment is seen as a necessity during a change.

Table 26: Extent of risk assessments at the large steel manufacturing company

Extent to which risk assessments are performed for any change to be implemented	Percentage that say
Regardless of size of change	0%
Some cases	41,67%
Most cases	16,67%
Only in certain predetermined cases	16,67%
Up to the employee(s) performing the change	25%

A lot of variability was also found on what constituted an engineering change process. The results indicate that the lack of a formal ECM system resulted in inconsistent engineering change management handling. The individualized change process eventually ended up in mismanagement of basic change close-out requirements. When asked to rate the ECM process, the results depicted in Table 27 was attained:

Table 27: Views on aspects of ECMS

	1	2	3	4	5	6	7	8	9	10
	%									
Initiation	16.70	0.00	16.67	25.00	8.33	8.33	8.33	16.67	0.00	0.00
Approval Process / workflow	25.00	0.00	8.33	16.67	8.33	16.67	8.33	8.33	0.00	8.33
Risk assessment	0.00	8.33	16.67	33.33	16.67	8.33	0.00	8.33	8.33	0.00
Business case	8.33	16.67	8.33	8.33	16.67	8.33	16.67	16.70	0.00	0.00
Implementation	8.33	8.33	8.33	0.00	16.67	8.33	33.33	16.70	0.00	0.00
Archiving	33.33	16.67	16.67	8.33	16.67	0.00	0.00	0.00	8.33	0.00
Communication	16.67	0.00	25.00	16.67	33.33	0.00	0.00	8.33	0.00	0.00
Post-closure observation	33.33	16.67	8.33	16.67	8.33	0.00	8.33	0.00	8.33	0.00
Maintenance	16.67	8.33	33.33	0.00	25.00	0.00	8.33	0.00	8.33	0.00
Weighted average	17.60	8.33	15.74	13.89	16.67	5.55	9.26	8.34	3.70	0.93
Sum of average (1 - 4; 5; 6 - 10)	55.56				16.67		27.78			

It is evident from Table 27 that the overall rating of the system is poor which indicates that the respondents have limited confidence in their ECMS process.

The responses to the extent of control of the ECMS resulted in Table 28

Table 28: Control of ECMS process

	1	2	3	4	5	6	7	8	9	10
	%									
The EC request to be evaluated during change implementation	33.33	0.00	8.33	8.33	25.00	8.33	8.33	0.00	8.33	0.00
The EC request to be evaluated post change implementation	33.33	0.00	0.00	16.67	16.67	16.67	16.67	0.00	0.00	0.00
Expanded (additional scope added)	16.67	8.33	0.00	0.00	25.00	0.00	0.00	8.33	0.00	16.67
Changed (deviate from the initial change scope)	16.67	8.33	0.00	0.00	25.00	8.33	8.33	16.67	0.00	8.33
Allow additional / other change requests to be opened from the original EC request	25.00	16.67	8.33	0.00	8.33	8.33	8.33	8.33	8.33	0.00
Weighted average	25.00	6.67	3.33	5.00	20.00	8.33	8.33	6.67	3.33	5.00
Sum of average (1 - 4; 5; 6 - 10)	40.00				20.00		31.66			

It is evident from Table 28 that their current ECMS was lacking in a few areas. In retrospect the question could have been rephrased better as certain sub questions can be interpreted wrongly (the question has both negative and positive aspects of engineering change management, however, the results seem to indicate that the negative aspects were viewed as neutral.

The respondent all had different views on what was required for a change to be closed-out and in most cases other departments such as commercial departments weren't included in the communications. This was further confirmed by the Likert scale rating on communication during a change and the awareness of changes that were performed without proper procedure.

The respondents all felt that definite improvements could be made to documentation control and a standardized procedure as (refer to Table 29). A relevant comment was made to the necessity of having an electronic ECMS to prevent ECM from being a paper system which ultimately prevents effective archiving, cross-searches and manageable control and progress evaluation of changes – similar comments were made by Jarratt *et Al* (2011) on the efficiency of out dated paper-based systems.

Table 29: Aspects of ECM that needs improvement

Aspects of ECMS that needs improvement	Percentage that agreed
Document control (incl. drawings and procedures)	100%
Approval levels	33%
Reviewers	58%
Change management administrator	50%
Change management committee	67%
Standardized procedure	92%
Risk assessments	58%
Request for information	58%
Workflow	75%
None	0%
Other	<p>A no paper system is a pre-requisite and a serious enterprise sponsor within the company to drive the implementation.</p> <p>There is also a great need for an automated ECM system that can</p>

incorporate all of the aforementioned aspects in this question. Some companies do have manual ECM systems, which results in the ECM process being a big paper exercise and as a result the stakeholders involved can still lose documentation or neglect (skip out) certain aspects of the process where there is no control to prevent the different phases of the ECM process to be closed out prematurely (e.g. change can be implemented before any quality assurance plan is readily available for the change at hand). In some cases the change can be closed out without any drawing updates being approved or submitted for archiving, this is especially true for manual ECM systems

All the respondents answered the scenario question with a 100% certainty that it would not be possible to rebuild a plant with their existing drawings of the plant. This result is a clear indication that engineering changes were performed over time without the necessary control. It was further established that all the respondents were aware of changes that were implemented but not closed out properly. Although generic ECM activities were used to which activities are necessary before a change closure the respondents did not all view engineering change management activities as requirements. This is supported by literature where Jarratt *et Al* (2011) and Pkosz & Malmqvist (1997) determined that the activities that constitute an engineering change differs from company to company as each company has their own requirements on engineering change.

4.8 Chapter summary

Although the sample size is admittedly small – the purpose of this study was not to determine a generalised conclusion of ECM at large but rather to determine what is deemed necessary, what limitations exist and how well ECM systems are applied as viewed by everyday users of ECM systems in order to for the *large steel manufacturing company* to develop a requirement specification.

The results from the survey provided insight into the three ECMS at the three surveyed companies. At first, the data seemed inconclusive, revealing a lot of variability in the results. However, when the data was individualized to a specific company it became apparent that the data from the *petrochemical company* and the *specialised product company* significantly differed from that of the *large steel manufacturing company*. Regardless of how well the implementations were at the *petrochemical company* or the *specialised products company* the results still proved that their ECMS were effectively allowing engineering changes to be managed. Compared to the data from the *large steel manufacturing company* it revealed that the lack of an ECM system at the company lead to individualized ECM which proved to be implemented significantly different from individual to individual.

In general, ECM at all three of the surveyed companies was not yet showing the expected results as indicated by literature. Various factors such as document control, approval and workflow by seniors and peers, communication and post-closure audits still needed to be improved in order for the ECM to be “fool proof”. The data showed that ECM was currently being implemented to manage projects, control and monitor configurations and update of documentation. In a sense, this is the bare minimum of an ECMS. It is worthy to note that the *petrochemical company* and the *specialised product manufacturing company* with effective ECMS had ECMS that were required by company policy. The companies also have sister plants in other countries such as the United States of America where ECM is a legislative requirement for safety and operability reasons for companies with hazardous operations. The changes that initiate ECM in the three surveyed companies were from maintenance, projects, documentation and configuration changes, operational changes and quality; to a lesser extent an EC was initiated from risk management-, safety, health and environmental studies or incident investigations. The ability of ECMS as a learning and knowledge tool was also fairly limited. In the three surveyed companies, all the respondents indicated that cross-

search functionality and accessibility to previously performed changes were limited. Similar to what was found in literature; engineering changes were managed by the engineering manager. It was expected but proven otherwise by the research that the legal appointee (General Machines Regulations: 2.1 or 2.7) would be involved in ECM.

The data also indicated that changes still occurred within the company that were implemented hap hazardously, undocumented and not closed out properly even though the ECMS should have prevented it. Most of the respondents also indicated that the currently available documentation would not be sufficient to address the changes that might arise – it was not clear if this was due to historical reasons or the inability of the ECMS to manage the documents, in retrospect the question should have asked the reason for the incorrect documentation.

The respondents all indicated that an improved ECMS would be beneficial and listed documentation control at the highest of priorities. Other aspects such as standardized procedures for engineering change, request for information, improved workflow and approval process, cross-search capabilities, reduced paper work and economic justification was further listed as areas of improvement.

Cross-comparison and individualization of the *large steel manufacturing company's* results resulted in valuable information and insight into the problems the company was facing. The high ineffectiveness of the company's ECM was mostly due to the fact that the ECM process was up to the individual performing the change and was not governed by any policy of the company. It was further evident that this resulted in a lack of comprehension and understanding of the ECM topic. Similar results were attained for areas of improvement and again documentation control came up as the highest priority, followed by a standardized procedure, improved workflow and approval process, the use of a change management committee and also use of reviewers.

In retrospect, some of the survey questions could have been extended to provide insight into the relationship between the significance of risk management and change management, however, not specifically asking the sample group questions regarding risk management also provided potential proof that the respondents were not aware of the connection. Additional research (see section 5.4) could potentially be conducted on this topic to create clarity.

Summarizing the chapter can be concluded as follow:

- a. The views on ECM from the respondents were likened to project management, control and monitor of configurations and update of documentations. The respondents did not view the approval process, economic justification or reporting of significant importance.
- b. The respondents from the *petrochemical company* and the *specialised product manufacturing company* rated the effectiveness of their ECM's highly.
- c. The respondents from the *large steel manufacturing company* viewed their ECM's as very ineffective.
- d. The effectiveness was closely related to the industry the company operates in as well as the area of other operations: e.g. companies with operations in the United States of America require management of change in terms of a legal requirement.
- e. The changes that trigger ECM were Maintenance, Projects, Documentation and Configuration changes, Operational changes and Quality. ECM was applied to Risk management, Safety, Health and Environment and Incident investigations to a lesser extent.
- f. The *petrochemical company* and the *specialised product manufacturing company* had company specific policies that require ECM. The *large steel manufacturing company* did not require it from a company policy and it was implemented at the discretion of the individual engineer performing the change.
- g. The accessibility of data on changes in the system was rated neutral and was only available to a few employees or the employee performing the change.
- h. Cross-search for previous, similar engineering changes were limited, the highest rating was towards administrators that can perform cross-searches.
- i. Management of engineering changes was by an administrator or a dedicated manager of engineering changes and was usually the engineering manager.
- j. Aspects of engineering change management that was currently implemented on the existing ECMS of the companies were as follow:
 - a. Basic definition of change and problem statement;
 - b. Communication to affected personnel or plants;
 - c. Risk assessments;
 - d. Business case (e.g. Cost / Benefit analysis or economic justification);

- e. Documentation changes (incl. drawings, operational procedures and manuals).
- k. Aspects of engineering change management that was not currently implemented sufficiently:
 - a. Evaluation by seniors or peers;
 - b. Verification of implementation;
 - c. Communication to all affected employees were rated between neutral down to very ineffective;
 - d. The current ECMS at the three surveyed companies had limitations and the employees were aware of changes that were:
 - i. Implemented hap hazardously (e.g. did not go through the ECM process);
 - ii. Were undocumented;
 - iii. Not closed out properly.
- l. 69, 23% of the respondents believe that they did not have adequate or up to date drawings in place to successfully address changes that might arise.
- m. The current ECM did not prevent scope creep and can be changed during the process of performing an EC without being re-evaluated.
- n. 84, 62% of the respondents would have liked an improved ECMS. The respondents listed the following aspects that could be improved:
 - a. Documentation control
 - b. Standardized procedures for engineering change
 - c. Request for information
 - d. Workflow or the approval process
 - e. Cross-search capabilities
 - f. Reduced paper work (e.g. electronic system)
 - g. Cost / Benefit analysis to be part of the requirements.

The results also conclusively proved that the *large steel manufacturing company* requires an improved ECM process. The 66, 67% of the respondents of this company rated the effectiveness between ineffective or very ineffective. The ability to view changes by the employees of this company was rated the highest at “only a few employees”. Risk assessments only apply to some changes (41, 67%) or were up to the employee performing the change (25%). The rating of the aspects of the ECMS at the company was all on the lower end of the scale with a weighted average of 55, 56%

rating the system lower than 50% capable. The control of the ECMS was not conclusive and was either rated as 40, 00 % on the lower end of the scale or 31, 66% on the high end of the scale. Similar results were attained compared to the other two surveyed companies when asked which areas needed improvement:

- a. Document control was rated at 100% improvement needed;
- b. Reviewers 58%;
- c. A change committee 67%;
- d. Standardized procedure 92%;
- e. Workflow or approval 75%.

The data obtained from the survey provided significant insight into practical ECMS applications in industry. It was interesting to note how different industries drove different responses in the survey. In general it was quite clear that the *petrochemical company* had a fairly advanced and refined ECM system. A significant difference was found in the other two companies used in the case study but the results were mostly driven by experience of the individual (on both the system and change management over the years). The more senior an individual was the better the understanding and self-driven control was when an engineering change had to be performed.

The next chapter draw conclusions on the research and identifies areas for future work or research.

Chapter 5: Conclusion, Recommendations and the Way Forward

5.1 Introduction

The objective of this research study was to determine the applicability and hence, the level or quality of the application of ECM at *a large steel manufacturing company*. The current application and use of ECM in practical industrial engineering environments was investigated in order to determine the high level understanding, level- and sophistication of practical implementation and quality (identified problems with existing systems) of engineering change management.

In Chapter 1 the problem statement and research objectives were introduced providing insight into the various reasons for this research, Chapter 2 examined literature on topics relevant and related to engineering change management in industrial engineering environments. Fundamental theories and concepts were explored and critically examined. Chapter 3 devised an experiment to determine the “value” of ECM in the practical setting. The results and interpretations of the experiments were concluded in Chapter 4 from which key evidence was gathered. Combined, the results of the experiment (Chapter 4) and the literature review (Chapter 2) were used to gather evidence to support the reasons why ECM is required and specifically how ECM would benefit the *large steel manufacturing company*. This chapter aims to answer the research question and objectives in the following manner:

- a. Reviewing of the Research question and objectives – section 5.2.
- b. Answering the Research question and objectives – section 5.3.
- c. And lastly, paving the way forward by recommending future research into the subject – section 5.4.

The success of the study was determined by how well the research questions and objectives were answered in the following sections.

5.2 Review of the Research question and objectives

In Chapter 1, the research question was defined as the following:

The purpose of this study was to determine the applicability, high level understanding, the level- and sophistication of practical implementation and quality of application

(identified problems with existing, or the lack of existing systems) of the engineering change management procedures in the service engineering division of three different companies in order to draw a comparison with the service engineering division of the large steel manufacturing company that would ultimately assist and provide information to the large steel manufacturing company in order to develop a workable ECM system.

Three local companies with similar profiles (industrial manufacturing) were used to determine how well ECM was implemented at these companies, what aspects of control were common amongst the companies and what aspects of ECM needed improvement. The findings were compared to the views of the respondents in the *large steel manufacturing company*. Differences between views and similarities were searched for in order to determine if ECM can be generalised.

Furthermore, the research aimed to answer the following objectives in support of the research question:

1. How does the existing ECM at the three companies compare to each other and collectively compare to ECM as found in literature?
2. What aspects are deemed important by everyday users of ECM, and what aspects needed improvement?

5.3 Answering the research question

The results revealed that the general understanding and comprehension of engineering change management at all of the surveyed companies were lacking compared to the fundamentals and concepts as found in Chapter 2. It was found that the understanding and comprehension of engineering change management is vital for the success of engineering change management as a management system at any industrial engineering company. It is thus unlikely that success would be achieved with the engineering management system if users of the system do not fully comprehend the essence of such a system. It was also evaluated if the process of performing engineering change was according to a formalised system and it was found that the limited knowledge of the process of engineering changes prevented a formalised system to be implemented and resulted in unsuccessful implementations of engineering changes as indicated by the respondents. In a sense, this dissertation determined that the comprehension of engineering change was found to be dependent on personal

experience in engineering change management and the specific company policy wording and description on engineering change in the context of the organisation (and not in the context of an generalised engineering concepts). The comprehension was further accounted for by the quality of the system implementation at the individual companies (in a way, how well change management was enforced at a company and to what level buy-in was received by company management). The fact that engineering change management has grown in popularity in recent years as an engineering management concept in certain countries such as the United States of America and the United Kingdom and that such a management systems became of significant importance to organisations, was only indicated as important by one of the three surveyed companies (the petrochemical company). The research revealed that the full potential and benefits from a properly implemented engineering change management system was not yet grasped by the users and was vied only as a “necessary evil”.

The level of application of engineering change management in the three surveyed companies varied significantly, but at the time of this dissertation all three surveyed companies were still managing engineering changes on a paper-based system. Two of the surveyed companies, however, had plans to move to a fully electronic system. This in turn affected the usability and ultimately the quality of engineering change management in the organisations. It is thus a step in the right direction from the two previously mentioned companies to move from paper-based to electronic-based systems in order to improve quality and usability of their systems. The research indicated that the practical implementations of engineering change management were well established in the two companies with defined ECM company policies, but lacked significantly in the *large steel manufacturing company*- which was also due to the fact that it was not required by any of the company’s policies. In terms of quality, none of the researched ECMS implementations at the surveyed companies were yet at a level where all the changes were adequately addressed and required improvements in various aspects to realize the full potential of engineering change management. Although a lot of groundwork has been covered in the *petrochemical* and *specialised product company*, their systems still required continuous improvement initiatives to iron out the limitations of their systems. Engineering change management was still not implemented at the *large steel manufacturing company* at the time of this study, but the awareness on the benefits of a structured ECM was noticed by the respondents of the

company. The findings from this study can be used by the *large steel manufacturing company* to tailor and introduce their own ECM system.

This research evidently indicated that a formalized engineering change management is important to the *large steel manufacturing company* to manage the observations and effects that developed from previous uncontrolled engineering changes performed in the company. The information from the other two other surveyed companies: *the petrochemical company* and *the specialised product company*; indicated that change management can indeed be generalised and effectively implemented in an industrial manufacturing company but, even if implemented successfully, requires continuous improvement on the systems to properly address engineering changes effective and efficiently.

As a last comment: “a collective shift in the academic community to recognise that change is the predominant paradigm of engineering rather than ab initio design” (Jarratt et Al, 2011) has significant meaning in this instance and might be truer than ever as this research indicated the applicability of ECM in the service engineering division as well.

5.3.1 Answering the first research objective

Comparatively, the principles of how ECM is performed (officially or unofficially) at each of the three companies were found to be the similar. However, as with any management system, the smaller individual tasks and subsequent levels of ECM that were performed were governed by company policy as well as the industry the company operates in: It was found that the type of industry (e.g. petrochemical) and the countries where the companies operate in had an impact on the level of application on the management of engineering changes, e.g.: The *petrochemical company* required an ECM from a legislative health and safety requirement as they had operation in the United States of America where the process and priority of EC was driven by the risk to these requirements; the ECM of the *specialised product company* were driven from the company’s global quality perspective and requirements.

The fact that ECM was performed in two distinct processes: a formal process– the company official ECM process and; unofficial the informal ECM process that was used by employees as an attempt to “quickly” rectify a time constraint task was found in all three surveyed companies. However, the official process was found in two out of the

three surveyed companies as the leading method of implementing an engineering change and this was due to the company's official policies requiring so. The lack of ECM at the *large steel manufacturing company* clearly indicated that different needs by different individuals lead to different unofficial ECM processes and constituents of ECM being implemented. It was also found that ECM was performed in all three of the companies in most life-cycles of a product, process or project engineering being performed regardless of the size of the change.

Furthermore, it was found that the six step ECM process by Jarratt *et Al* (2011) was followed by the three companies but in different levels of quality and intensity at each of the levels. "Solution selections and approval by a change board" was not followed by any of the companies at the time of this study, but the step was implemented in some way by concurrent evaluations and approvals in the *petrochemical company*.

As it stands, it can be concluded that ECM at the three surveyed companies can be generalised and that the engineering change process followed the same generic process determined from literature.

5.3.2 Answering the second research objective

Practically, the understanding and comprehension of what initiates and constitutes an ECM system remained diverse and challenging in the three companies. This was expected as the literature also indicated that, although there was a clear understanding of what causes changes and the associated problems and concerns that come along with change, there was a lack of consensus on how to deal with changes. The information from the survey indicated that many employees viewed ECM as an extremely complex and difficult process and did not fully grasp the process, need and constituents of ECM. In many cases, ECM was only performed by an individual as it was required by company policy (boiling down to a "pointless paper-exercise" as indicated by one respondent) or as damage control rather than a continuous improvement opportunity or engineering best practice concept. .

However, as with any other system, ECM at the companies also needed to be constantly changed, adapted and evolved to ensure continuous improvement and proper applicability. As ECM form part of core systems and processes for health, safety, environment, quality, maintenance, operations, and to a large extent knowledge

sharing, which is important for succession planning and growth of employees- it is crucial for business success to have a fully functional, controlled and continuously improved ECMS to ensure successful engineering operations. The lack thereof leads to “information deficiencies” for other employees or future projects that solely base their decisions and designs on out-dated data that is no longer relevant. This effectively hampers any employees from working changes that are affected by previous uncontrolled change as sub-standard and insufficient data would ultimately exist on the previous change. ECM needs to be a compulsory requirement at any industrial manufacturing company and needs to be fully understood and captured in company policies. The *large steel manufacturing company* neglected ECM as an operational management system and thus did not achieve and managed engineering changes effectively. It should however be said that the ECMS evaluated at the three surveyed companies all required additional improvements in the following areas:

- Documentation control – especially drawings and operating procedures:
As engineering is reliant on data and document control is the legal process by which change is managed, recorded and controlled, it is of crucial importance that as minimum engineering changes are reflected in all the relevant documents. It is also important to identify the interconnectivity of components and objects during the early phases of the change.
- Workflow: The approval process needs to be implemented on an electronic workflow system to allow changes to be approved promptly. The use of an electronic workflow system allows tracking of changes; approvals and time spent on each and affectively eliminates the “authority complex” from affecting execution of work. An effective electronic approval workflow system effectively eliminates paper-based change requests and also provides effective means of auditing. It was found that many engineers left the structured, formalised company engineering change management procedure in order to implement the change in the required time.
- Economic justification: It was found that cost was one of the four fundamental pillars of proper engineering change management, thus, ensuring that the cost/benefit analysis of each EC is properly analysed ensures that the company achieves the full benefit of ECM eliminating the literature indicated “39% of all changes that are actually required and 40-60% that is technically necessary”.

Stemming from the research findings on the ECM at *large steel manufacturing company* the following additional improvements areas were identified by the respondents to the survey:

- The use of reviewers and the implementation of a change committee to review changes, approve timelines, costs, resources and tasks to ensure that the change request is adequately addressed. Literature indicated that the best results were achieved when the technical and commercial feasibility of an engineering change was reviewed by a cross-disciplined and cross-functional team of reviewers as it provides means for a consistent and standardised approval of changes.
- Implementation of a standardized procedure: The employees felt a need to have the ECM system captured in company policy in terms of procedures and instructions.
- The use of electronic workflow and approval: The employees identified a need to have the workflow of the system automated to ensure that changes are expedited through the process.

5.4 Recommendations for future research

Based on the research into ECM for *the large steel manufacturing company* the following recommendations can be presented:

1. The study was refined and included limited scope into the full industrial engineering sector. It did however; reveal crucial aspects of ECM that warrants further investigation. Risk management is a key principal of engineering change and various literature related engineering change management to risk-based management – especially in process safety and case study literature. It can thus be recommended that additional research should be conducted on risk management in the context of engineering change management. Determining the best approach to use risk management as a decision-support tool for engineering change management can be recommended for future research. As the *large steel manufacturing company* is in the process of developing a tailored ECM, the study could assist in the development of a more refined risk management system that would improve the results that would be obtained from their ECMS.

2. Engineering change management as a knowledge retention tool unintentionally stemmed from the research. ECM as a tool to manage knowledge transfer; succession planning and knowledge retention in *the large steel manufacturing company* could be determined in order to understand if it would lead to better continuity of business operations. The information gap which hinders future changes to be implemented successfully was identified throughout this research. Knowledge retained in engineering change management documents could thus potentially ensure that contingency is built into the company to prevent the so-called “reinvention of the wheel”. Additional research to determine the link between engineering change management and knowledge-retention could potentially unveil how ECM could assist to ensure that critical business and engineering know-how is retained and captured in the system.
3. Additional research into the software for ECM could also be conducted that could lead to the development of a model for an electronic ECMS that incorporates all the aspects of engineering change management such as document control, workflow (approval of items), communication and collaboration. It was determined that “off-the-shelf” systems are not presently available that enables the users to configure and tailor the system to their needs. “Off-the-shelf” packages can thus be evaluated against the requirements that were determined from literature in this study.
4. The literature indicated that ECM should be applied to any change regardless of size and type except where the replacement is “in-kind”. The effects of frequent maintenance and replacements of parts (due to some or the other re-occurring problem) are thus not managed with the engineering change management system. Further studies can be performed to evaluate alternative options to capture the re-occurring problems in the ECMS in order to continuously improve the maintenance efficiency.
5. Finally, one might also argue why engineering change management in South Africa has not yet shifted towards a legislative requirement for engineering changes as found in other countries such as the United States of America and the United Kingdom. The implementation thereof as a requirement might change the face of safety, operability and maintainability of plants in South Africa and could potentially decrease incidents that lead to injuries, fatalities, environmental

damage or equipment damage – further research into this matter can be conducted.

5.5 Overall conclusion

The primary objective of this study was to determine the applicability and level of application of ECM in *the large steel manufacturing* company. The research evidently indicated the applicability of ECM to the company and the current improper level of application that evidently lead to various engineering management problems. Various reasons why ECM would be beneficial to the company was also substantiated. Although it is believed that a management system such as ECM cannot change or rectify historical problems at the company, it could assist the company to ensure that future changes are properly managed that would result in a reduction of the predetermined problems that were constantly experienced by the company. ECM is a management system that fully interlinks with other management systems such as configuration management, operation management, maintenance management, quality management and most importantly health-, safety and environmental management and should thus be viewed in the same light of importance. Literature indicated that improper change management was at the heart of many severe and tragic incidents at industrial companies in the past. ECM should thus be seen as a business development management strategy that assists a company to continuous improvement, innovate; ensure competitiveness in the market and most importantly safety of their process and employees.

Finally, it can be concluded that the research was found to be successful when critically evaluated against the objectives of this study and conclusively answered the research question that was presented.

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Appendix A: Academic data collection survey



PLEASE NOTE THAT THE SURVEY DATA WILL NOT BE USED TO PERSONALLY IDENTIFY ANY INDIVIDUAL OR COMPANY. THE DATA CAPTURED IN THIS SURVEY WILL REMAIN CONFIDENTIAL AT ALL TIMES AND IS SOLELY FOR ACADEMICAL PURPOSES

* What is your role at the company?

- Artisan
- Technician
- Service Engineer (e.g. Maintenance, Improvement, etc.)
- Process Engineer
- Design / Project Engineer
- Production / Line Engineer
- Manager – technical
- Manager – commercial
- Other (please specify)

[Reset](#)

* In which area of engineering do you work?

- Product development
- Services (e.g. maintenance, supply and management of energy)
- Products
- Research and Development
- Quality
- Health, Safety and Environment
- Production
- Other (Please specify)

[Reset](#)

* Please indicate your level of experience

- Graduate
- In practical training
- Junior
- Senior
- Specialist

Other (Please specify)

[Reset](#)

* Are you professionally registered at ECSA?

Yes, registered as Candidate

Yes, registered as professional (e.g. Pr.Eng)

No

Other (please specify)

[Reset](#)

* Please describe your understanding of engineering change management in a few short sentences?

* To what extent do you apply ECM in your company?
(Engineering change management is the process of planning, controlling and recording changes that affect the original form, fit and function of the original engineered design (and thereby controlling the risks associated with the change). These changes can be any hardware, software, plant inputs, material specifications, operating procedures, drawings and other documentation)

Very Effective

Effective

Neutral

Ineffective

Very Ineffective

[Reset](#)

* In which of the following areas is ECM applied?

Maintenance

Operational changes

Document (incl. drawing) changes

Projects

Risk assessments

Safety, Health and Environment

Quality

Incident investigations

None

[Reset](#)

Other

* Is your ECM:

- Company specific
- Individual specific (e.g. do you use your own developed system from your own wits and integrity)?

[Reset](#)

* How effectively is the data of engineering change management captured on a centralised business location?

Very Effective

Effective

Neutral

Ineffective

Very Ineffective

[Reset](#)

* How accessible is your data on ECM's by any employee?

Not at all

Limited to the employee working on the change

- Accessible by only a few people
- Accessible to a large extent
- Fully accessible

[Reset](#)

* Can a cross-search be performed to determine if similar changes were performed previously?

- Only Administrators
- Only stakeholders
- Interested parties
- Everyone

[Reset](#)

* Are ECMs managed by an administrator or manager?

- Administrator
- Manager of engineering change
- Not implemented

[Reset](#)

* To what extent is risk assessments (e.g. HAZOP study) performed for any change to be implemented?

- Regardless of size of change
- Some cases
- Most cases
- Only in certain predetermined cases
- Up to the employee(s) performing the change

[Reset](#)

* Are engineering changes administrated by some internal authority?

- General Machines Regulations: 2.1 or 2.7
- Engineering Manager
- Change Manager
- Departmental Head
- Other (please specify)

[Reset](#)

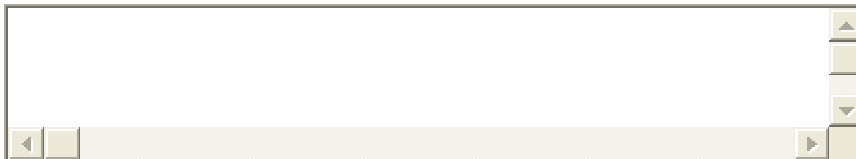
* Which of the following is applicable before an engineering change order can be closed out?

- Basic description of change

- Business case: Cost vs. Benefit analysis
- Risk assessment
- Affected processes / plants / personnel
- Reviews on the proposed change
- Assign a senior employee to evaluate the change
- Request document changes (drawings, operating procedures, commissioning procedures, maintenance procedures, etc.)
- Verify changes reflected in documents

[Reset](#)

Other - please specify



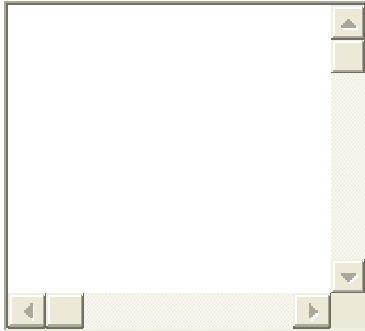
* Which of the following is included in the change management processes?

- Stakeholders
- Engineering department
- Affected departments
- All business unit managers
- Commercial departments (finance, HR, communications, Risk, Legal, Health Safety

and Environment)

[Reset](#)

Other please specify per line



* How effective would you rate the communication sent out to all employees (or all employees affected by the change)?

Excellent

Good

Neutral

Fair

Poor

[Reset](#)

* Are you aware of any engineering changes that were performed that

Were implemented hap hazardously

Were not properly documented

- Were not closed out properly
- Did not adhere to common best practices on engineering change management
- Were not stored on a centralised, easily accessible location for future use by other employees
- None

[Reset](#)

Other (please specify)

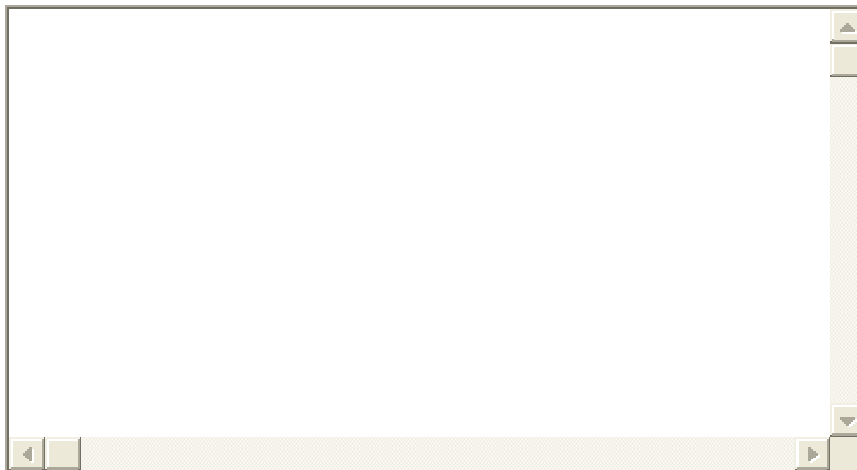
* If for example your plant were to be duplicated, would you be able to use the existing available documents to exactly replicate a working plant?

Yes

No

[Reset](#)

Please provide reasons



the original EC request?



* Would you like an improved ECM system at your company?

Yes

No

[Reset](#)

* Which of the following aspects of an ECM would you be interested in to be improved?

- | | |
|---|--|
| <input type="checkbox"/> Document control (incl. drawings and procedures) | <input type="checkbox"/> Approval levels |
| <input type="checkbox"/> Reviewers | <input type="checkbox"/> Change management administrator |
| <input type="checkbox"/> Change management committee | <input type="checkbox"/> Standardized procedure |
| <input type="checkbox"/> Risk assessment | <input type="checkbox"/> Request for information |
| <input type="checkbox"/> Workflow | <input type="checkbox"/> None |

[Reset](#)

Other (please specify)

A large empty text input field with a scroll bar on the right side, intended for specifying other aspects of ECM to be improved.

The following information is needed to establish the level of implementation and quality of ECM. None of the information disclosed below will be used to identify an individual or company and will be kept in utmost confidentiality

* Please provide your name and surname

* Please provide an email address by which we can contact you

* Please state the company you work for

Thank you for your time and effort spent in order to complete this survey to the best of your knowledge at the time.

Thank you for your time and effort to fill in this survey. Your response is appreciated!

Appendix B: Survey results

Results for: Engineering change management

Academic data collection survey

PLEASE NOTE THAT THE SURVEY DATA WILL NOT BE USED TO PERSONALLY IDENTIFY ANY INDIVIDUAL OR COMPANY. THE DATA CAPTURED IN THIS SURVEY WILL REMAIN CONFIDENTIAL AT ALL TIMES AND IS SOLELY FOR ACADEMICAL PURPOSES

*1) What is your role at the company?

		Response (%)	Responses
Artisan		0.00	0
Technician		0.00	0
Service Engineer (e.g. Maintenance, Improvement, etc.)		28.00	7
Process Engineer		24.00	6
Design / Project Engineer		12.00	3
Production / Line Engineer		0.00	0
Manager - technical		28.00	7
Manager - commercial		4.00	1
Other (please specify)		4.00	1
		Answered Question	25
		Skipped Question	0

Other (please specify)

Process Safety Engineer

*2) In which area of engineering do you work?

		Response (%)	Responses
Product development		0.00	0
Services (e.g. maintenance, supply and management of energy)		60.00	15
Products		0.00	0
Research and Development		8.00	2
Quality		8.00	2
Health, Safety and Environment		4.00	1
Production		16.00	4
Other (Please specify)		4.00	1
		Answered Question	25
		Skipped Question	0

Other (Please specify)

Commissioning

*3) Please indicate your level of experience

		Response (%)	Responses
Graduate		16.67	4
In practical training		8.33	2
Junior		12.50	3
Senior		45.83	11
Specialist		16.67	4
		Answered Question	24
		Skipped Question	1

*4) Are you professionally registered at ECSA?

	Response (%)	Responses
Yes, registered as Candidate	29.17	7
Yes, registered as professional (e.g. Pr.Eng)	12.50	3
No	50.00	12
Other (please specify)	8.33	2
	Answered Question	24
	Skipped Question	1

Other (please specify)
Eligible for ECSA Registration
Registered as Pr.Eng in Europe

*5) Please describe your understanding of engineering change management in a few short sentences?

Text Answers (15)
Change management is a process; many companies have set procedures that need to be followed. This starts with needs, feasibility studies, costing, budget requesting. All these stages get the involvement of the customer, HSE&EP and other affected departments. From here the project planning starts followed by tendering or bidding, finalizing technical designs and getting the necessary approvals should they be required. Orders and contracts are put in place. During the construction phase, nothing starts before the legal issues are in place (as per the construction regulations). All inspections are documented and progress reports to be issued as per the plan. Budget control, critical path control and all safety issues are to be managed. On completion commissioning with tests are to be recorded and performance is to meet original design requirements. Safety inspections are to be conducted and all hazards are to be rated and addressed. All Instruction, Technical, Training, Calibration, Operating manuals together with all approved drawings, part lists and maintenance schedule cards and structural, electrical and vessel certificates are to be completed. SCADA programs together with their function specifications and backups are to be stored. Thereafter the process is put into production with specific attention given to Safe work procedures, product performance, process stability and set-up procedures. Fixed Asset documentation for accounting purposed together with performance against budget reports are to be submitted.
It is a system (program, guidelines) which you follow for completing your projects. It keeps you informed on which stage of the project you currently are and what your next step should be. It has all the required phases of the project, necessary information and templates to make any engineering change easy and fast. It also keeps records of all the projects (including all used documentation drawings, letters etc.) for archiving and easy future access if necessary. It can also be used for reporting and feedback purposes.
Keeping track of changes to control software in control systems and other control devices.
ECM is the process of managing changes made to a process/system. This includes managing all aspects a change which includes requesting the change, planning, implementation, evaluation of the "new" process. Thus all changes should be recorded and should be traceable.
Changes must be recorded for a future reference. It must also be approved/discussed by/with management and colleagues.
Process of planning controlling and recording changes to plant and equipment for reference purposes.
Document any change during testing and after implementation as well as updating all relevant manuals and procedures after acceptance testing is completed. Back-up file creation also form part of change management, although no change were made but an audit of the actual and saved image was done.
It is the process of keeping equipmnet drawings, diagrams, data sheets up to date (as built) in order to facilitate the correct and speedy finding of faults, repair/remanufacturing and specification of equipment.
Change management ensures that any changes to plant or equipment are carried out in safe and responsible manner and that all systems and documentation are updated to reflect the change.
System to track changes that are made. To assist in the planning of change. Capturing of data for future use. controlling Quality.
The systematic and logical risk based approach to initiating, plannig, developing and implementing any change in an engineering environment, being process, structure, personnell or otherwise
It is a system to control configurations brought about in an industry. The system should bring about changes in a systematic and controlled manner, where changes need to go through a process to assure that the minimum quality, best practice, company policies, financial management and regulatory requirements have been met and controlled and implemented throughout the change life-cycle. Change management also provides a means of traceability, which can assist in bringing about similar changes in future.
Consider impact of change on other systems/processes Update all relevant documentation. Communicate to and train relevant personnel. Monitor the change vs intent.
Engineering change management is the process of documenting every change to a process or system and updating any relevant information or data relating to the change. The process also includes training of personnel and communication that everyone is aware of the change. ECM is vital in keeping information about a system or process up to date.
The main aim of ECM is to manage the risks associated with changes. Engineering change management is critical to keep all operations supporting systems up to date. With supporting systems I mean training, specification documents, equipment install base, operating procedures/parameters, ect. With updated documentation engineering time spent on improvement designing and fault finding will be significantly decreased. From a safety side it is to ensure all relevant safety checks were followed and equipment is safe to operate by trained personnel. The legal implications are to ensure that ownership of changes / equipment are placed in the care of the party that is most responsible for activities on the equipment. And that the facility legal appointed person is made aware of the changes on his / her facility.

*6) To what extent do you apply ECM in your company? (Engineering change management is the process of planning, controlling

and recording changes that affect the original form, fit and function of the original engineered design (and thereby controlling the risks associated with the change). These changes can be any hardware, software, plant inputs, material specifications, operating procedures, drawings and other documentation)

		Response (%)	Responses
Very Effective		20.00	5
Effective		28.00	7
Neutral		16.00	4
Ineffective		24.00	6
Very Ineffective		12.00	3
Answered Question			25
Skipped Question			0

*7) In which of the following areas is ECM applied?

		Response (%)	Responses
Maintenance		15.00	18
Operational changes		14.17	17
Document (incl. drawing) changes		15.83	19
Projects		16.67	20
Risk assessments		9.17	11
Safety, Health and Environment		10.00	12
Quality		11.67	14
Incident investigations		6.67	8
None		0.83	1
Answered Question			120
Skipped Question			95

Other

Any change which is not like for like which is not typical maintenance or normal operation

Some level of ECM is applied at our I.T. and process automation services

*8) Is your ECM:

		Response (%)	Responses
Company specific		72.00	18
Individual specific (e.g. do you use your own developed system from your own wits and integrity)?		28.00	7
Answered Question			25
Skipped Question			0

*9) How effectively is the data of engineering change management captured on a centralised business location?

		Response (%)	Responses
Very Effective		12.00	3
Effective		28.00	7
Neutral		32.00	8
Ineffective		16.00	4
Very Ineffective		12.00	3
Answered Question			25
Skipped Question			0

*10) How accessible is your data on ECM's by any employee?

		Response (%)	Responses
Not at all		16.00	4
Limited to the employee working on the change		16.00	4
Accessible by only a few people		36.00	9
Accessible to a large extent		24.00	6

Fully accessible		8.00	2
		Answered Question	25
		Skipped Question	0

*11) Can a cross-search be performed to determine if similar changes were performed previously?

		Response (%)	Responses
Only Administrators		44.00	11
Only stakeholders		16.00	4
Interested parties		28.00	7
Everyone		12.00	3
		Answered Question	25
		Skipped Question	0

*12) Are ECMs managed by an administrator or manager?

		Response (%)	Responses
Administrator		44.00	11
Manager of engineering change		32.00	8
Not implemented		24.00	6
		Answered Question	25
		Skipped Question	0

*13) To what extent is risk assessments (e.g. HAZOP study) performed for any change to be implemented?

		Response (%)	Responses
Regardless of size of change		24.00	6
Some cases		20.00	5
Most cases		32.00	8
Only in certain predetermined cases		8.00	2
Up to the employee(s) performing the change		16.00	4
		Answered Question	25
		Skipped Question	0

*14) Are engineering changes administrated by some internal authority?

		Response (%)	Responses
General Machines Regulations: 2.1 or 2.7		20.00	5
Engineering Manager		28.00	7
Change Manager		12.00	3
Departmental Head		20.00	5
Other (please specify)		20.00	5
		Answered Question	25
		Skipped Question	0

Other (please specify)

Individual implementing the change

none, limited

by the specialist

Not sure

Drawing office mahager

*15) Which of the following is applicable before an engineering change order can be closed out?

		Response (%)	Responses
Basic description of change		15.71	22
Business case: Cost vs Benefit analysis		11.43	16
Risk assessment		14.29	20

Affected processes / plants / personnel		15.71	22
Reviews on the proposed change		10.71	15
Assign a senior employee to evaluate the change		8.57	12
Request document changes (drawings, operating procedures, commissioning procedures, maintenance procedures, etc.)		14.29	20
Verify changes reflected in documents		9.29	13
		Answered Question	140
		Skipped Question	-115

Other - please specify	
Most changes occur due to a request from the plant and are executed without approval	
Not sure	
Training and RFC	
PSSR,RFC,RFO,BO	
Verification of beneficial use	
All the above are applicable but are not always done	
There are no formal close-out requirements in our company. No questions are asked if the process is functioning correctly.	

*16) Which of the following is included in the change management processes?

		Response (%)	Responses
Stakeholders		21.21	14
Engineering department		27.27	18
Affected departments		25.76	17
All business unit managers		13.64	9
Commercial departments (finance, HR, communications, Risk, Legal, Health Safety and Environment)		12.12	8
		Answered Question	66
		Skipped Question	-41

Other please specify per line	
There is no check-box for the "other option". Just omit the option selected No formal change management process is implemented at our company	
Some stakeholders, sometimes	

*17) How effective would you rate the communication send out to all employees (or all employees affected by the change)?

		Response (%)	Responses
Excellent		4.00	1
Good		20.00	5
Neutral		36.00	9
Fair		20.00	5
Poor		20.00	5
		Answered Question	25
		Skipped Question	0

*18) Are you aware of any engineering changes that were performed that:

		Response (%)	Responses
Were implemented haphazardously		16.88	13
Were not properly documented		24.68	19
Were not closed out properly		22.08	17
Did not adhere to common best practices on engineering change management		16.88	13
Were not stored on a centralised, easily accessible location for future use by other employees		14.29	11

None	5.19	4
Answered Question		77
Skipped Question		-52

*19) If for example your plant were to be duplicated, would you be able to use the existing available documents to exactly replicate a working plant?

	Response (%)	Responses
Yes	32.00	8
No	68.00	17
Answered Question		25
Skipped Question		0

Please provide reasons
No formal change management process is implemented at our company, which has the effect that the latest and most up-to-date designs and operating philosophies are re-traceable for quick and accurate perusal.
Drawings and documentation is not complete and well kept
Documents are old and misplaced.
documentation incomplete and out of date
This may be possible only if the replication is performed within the first two years of the first plant commissioning. Changes are implemented and no Hazop study performed or documentation verified. The loss of knowledge through high staff turnover and many managerial movements does allow for very limited change management. Multi environment responsibilities and silo/distributed management allow for this laps in documentation management.
High percentage of documentations more than 30 years old and not readable. Plants build later than 1980 can be duplicated. On some plants project documentation was not correctly transferred from original contractor to company and resulted in loss of information.
Some maintenacne changes are not always recorded properly
Provisional yes, experienced individuals, with both system and plant knowledge must be available.
Lots of documentation has been lost or never properly stored.
Detailed drawings are kept together with specifications primarily for maintenance / replacement reasons and they could be used to duplicate the equipment.

*20) How would you rate your ECM process (where 1 star means very ineffective and 10 stars more than effective)?

	1	2	3	4	5	6	7	8	9	10	Responses	Total
Initiation	8.00%	0%	12.00%	8.00%	16.00%	4.00%	12.00%	24.00%	12.00%	4.00%	25	151
Approval process / Workflow	12.00%	0%	4.00%	8.00%	12.00%	20.00%	12.00%	16.00%	8.00%	8.00%	25	150
Risk assessment	0%	4.00%	12.00%	12.00%	12.00%	12.00%	20.00%	12.00%	8.00%	8.00%	25	153
Business case	4.00%	12.00%	8.00%	8.00%	16.00%	12.00%	16.00%	16.00%	4.00%	4.00%	25	138
Implementation	4.00%	4.00%	4.00%	0%	16.00%	4.00%	28.00%	24.00%	8.00%	8.00%	25	167
Archiving	20.00%	4.00%	12.00%	12.00%	8.00%	4.00%	20.00%	4.00%	8.00%	8.00%	25	125
Communication	8.00%	4.00%	8.00%	16.00%	24.00%	12.00%	8.00%	12.00%	0%	8.00%	25	132
Post-closure observation	24.00%	8.00%	8.00%	8.00%	12.00%	12.00%	8.00%	4.00%	8.00%	8.00%	25	117
Maintenance	8.00%	8.00%	16.00%	8.00%	24.00%	4.00%	16.00%	0%	8.00%	8.00%	25	128

*21) To what extent does your ECM process allow:

	1	2	3	4	5	6	7	8	9	10	Responses	Total
The EC request to be evaluated during change implementation?	20.00%	0%	0%	4.00%	12.00%	28.00%	12.00%	4.00%	12.00%	8.00%	25	142
The EC request to be evaluated post change implementation?	16.00%	0%	4.00%	8.00%	16.00%	20.00%	12.00%	8.00%	12.00%	4.00%	25	139
Expanded (additional scope added)?	8.00%	0%	8.00%	0%	24.00%	32.00%	0%	8.00%	12.00%	8.00%	25	149
Changed (deviate from the initial change scope)?	12.00%	0%	0%	4.00%	12.00%	32.00%	8.00%	8.00%	20.00%	4.00%	25	155
Allow additional / other change requests to be opened from the original EC request?	16.00%	12.00%	4.00%	0%	20.00%	20.00%	8.00%	12.00%	8.00%	0%	25	124

*22) Would you like an improved ECM system at your company?

	Response (%)	Responses
Yes	84.00	21
No	16.00	4
	Answered Question	25
	Skipped Question	0

*23) Which of the following aspects of an ECM would you be interested to be improved?

	Response (%)	Responses
Document control (incl. drawings and procedures)	15.60	17
Approval levels	8.26	9
Reviewers	8.26	9
Change management administrator	8.26	9
Change management committee	10.09	11
Standardized procedure	12.84	14
Risk assessment	9.17	10
Request for information	11.01	12
Workflow	12.84	14
None	3.67	4
	Answered Question	109
	Skipped Question	-84

Other (please specify)

The ability to reference documents of previous changes through a search function.

The ideal scenario will be to have an electronic based system.

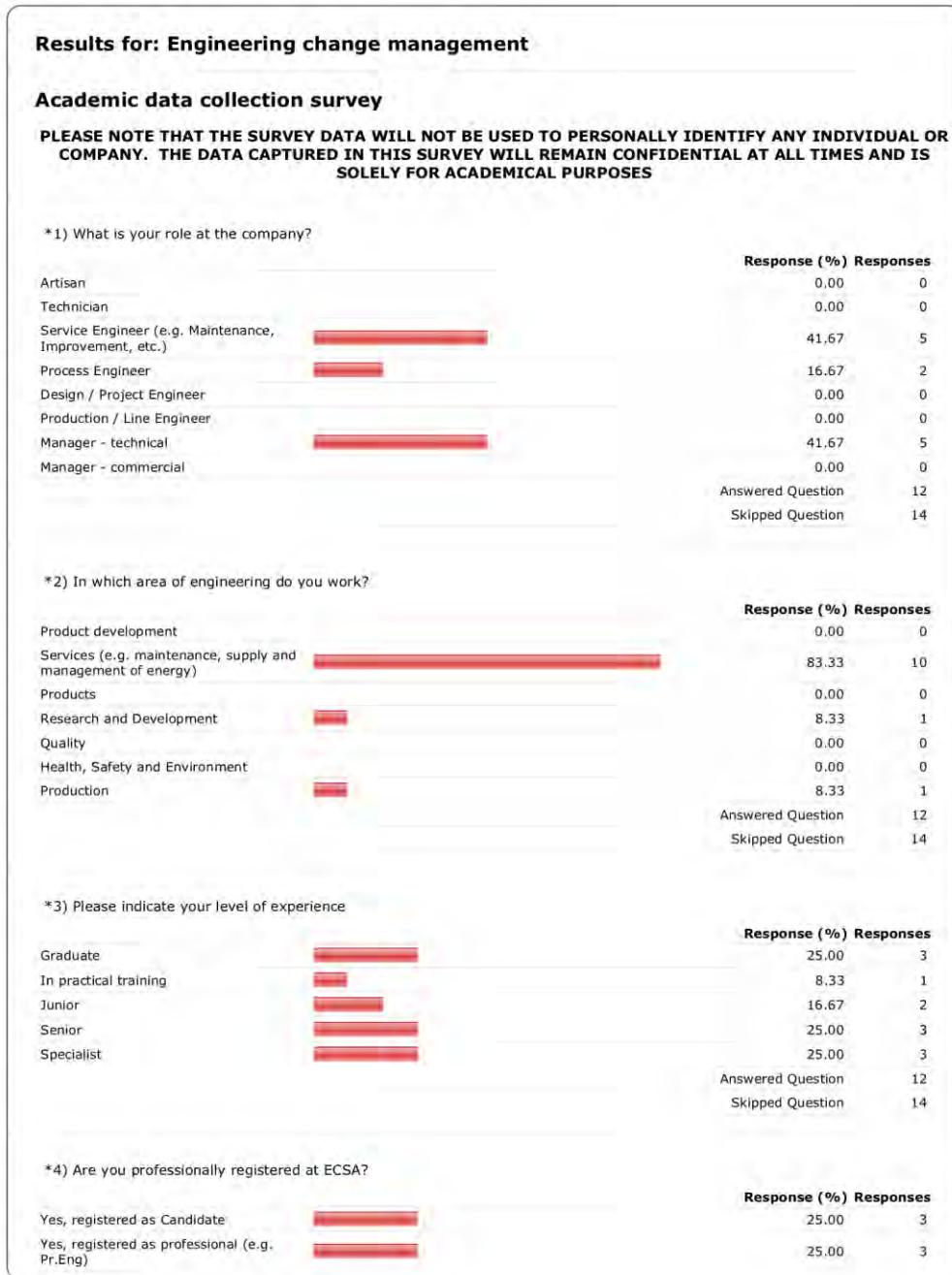
Amount of paper work

There is also a great need for an automated ECM system that can incorporate all the aforementioned aspects in this question. Some companies do have manual ECM systems, which results in the ECM process being a big paper exercise and as result the stakeholders involved can still lose documentation or neglect (skip out) certain aspect of the process as there is no control to prevent the different phases of the ECM process to be closed out prematurely (eg. the change can be implemented before any quality assurance plan is readily available for the change at hand). In some cases the change can be closed out without any drawing updates being approved or submitted for archiving, this is especially true for manual ECM systems.

Cost/benefit analysis

An no paper system are a pre-requisite and a serious enterprise sponsor within the company need to drive the implementation.

Appendix C: Large steel manufacturing company



No		41.67	5
Other (please specify)		8.33	1
		Answered Question	12
		Skipped Question	14

Respondent ID	View Survey	Email	First Name	Last Name	Other (please specify)
9928519	View	-	-	-	Eligible for ECSA Registration

*5) Please describe your understanding of engineering change management in a few short sentences?

ID	Email	First Name	Last Name	Text Answers (12)	View
9935128	-	-	-	The methods used to track and implement all necessary changes due to a plant modification. These changes can range from technical drawings to a safe operating procedure.	View
9934514	-	-	-	It is a system (program, guidelines) which you follow for completing your projects. It keeps you informed on which stage of the project you currently are and what your next step should be. It has all the required phases of the project, necessary information and templates to make any engineering change easy and fast. It also keeps records of all the projects (including all used documentation drawings, letters etc.) for archiving and easy future access if necessary. It can also be used for reporting and feedback purposes.	View
9934511	-	-	-	Keeping track of changes to control software in control systems and other control devices.	View
9931825	-	-	-	ECM is the process of managing changes made to a process/system. This includes managing all aspects a change which includes requesting the change, planning, implementation, evaluation of the "new" process. Thus all changes should be recorded and should be traceable.	View
9931240	-	-	-	Changes must be recorded for a future reference. It must also be approved/discussed by/with management and colleagues.	View
9930107	-	-	-	Process of planning controlling and recording changes to plant and equipment for reference purposes.	View
9930083	-	-	-	Document any change during testing and after implementation as well as updating all relevant manuals and procedures after acceptance testing is completed. Back-up file creation also form part of change management, although no change were made but an audit of the actual and saved image was done.	View
9930080	-	-	-	It is the process of keeping equipment drawings, diagrams, data sheets up to date (as built) in order to facilitate the correct and speedy finding of faults, repair/remanufacturing and specification of equipment.	View
9928519	-	-	-	It is a system to control configurations brought about in an industry. The system should bring about changes in a systematic and controlled manner, where changes need to go through a process to assure that the minimum quality, best practice, company policies, financial management and regulatory requirements have been met and controlled and implemented throughout the change life-cycle. Change management also provides a means of traceability, which can assist in bringing about similar changes in future.	View
9927284	-	-	-	A system that force you to do minimum requirement for any change made in the workplace.	View
9927204	-	-	-	Evaluation of the aspects, impacts and consequences of engineering change. Utilisation of collected data, experience and knowledge to optimise the process of change, including people management, technical decision making process, and defining the process of change within a industrial or similar environment	View
9926831	-	-	-	To systematically resolve an engineering need so that the request is adequately understood, all options are considered and the task is completed in terms of SHERQ, cost, resource utilisation and documentation control. All documentation pertaining to the design, operations and maintenance are clearly defined, approved and executed.	View

*6) To what extent do you apply ECM in your company? (Engineering change management is the process of planning, controlling and recording changes that affect the original form, fit and function of the original engineered design (and thereby controlling the risks associated with the change). These changes can be any hardware, software, plant inputs, material specifications, operating procedures, drawings and other documentation)

		Response (%)	Responses
Very Effective		8.33	1
Effective		16.67	2
Neutral		8.33	1
Ineffective		41.67	5
Very Ineffective		25.00	3

Answered Question 12
Skipped Question 14

*7) In which of the following areas is ECM applied?

		Response (%)	Responses
Maintenance		12.20	5
Operational changes		12.20	5
Document (incl. drawing) changes		19.51	8
Projects		17.07	7
Risk assessments		9.76	4
Safety, Health and Environment		7.32	3
Quality		12.20	5
Incident investigations		7.32	3
None		2.44	1
		Answered Question	41
		Skipped Question	-15

Respondent ID	View Survey	Email	First Name	Last Name	Other
9928519	View	-	-	-	Some level of ECM is applied at our I.T. and process automation services

*8) Is your ECM:

		Response (%)	Responses
Company specific		33.33	4
Individual specific (e.g. do you use your own developed system from your own wits and integrity)?		66.67	8
		Answered Question	12
		Skipped Question	14

*9) How effectively is the data of engineering change management captured on a centralised business location?

		Response (%)	Responses
Very Effective		0.00	0
Effective		8.33	1
Neutral		33.33	4
Ineffective		25.00	3
Very Ineffective		33.33	4
		Answered Question	12
		Skipped Question	14

*10) How accessible is your data on ECM's by any employee?

		Response (%)	Responses
Not at all		25.00	3
Limited to the employee working on the change		25.00	3
Accessible by only a few people		41.67	5
Accessible to a large extent		8.33	1
Fully accessible		0.00	0
		Answered Question	12
		Skipped Question	14

*11) Can a cross-search be performed to determine if similar changes were performed previously?

		Response (%)	Responses
Only Administrators		41.67	5
Only stakeholders		25.00	3
Interested parties		33.33	4
Everyone		0.00	0
		Answered Question	12
		Skipped Question	14

*12) Are ECMs managed by an administrator or manager?

		Response (%)	Responses
Administrator		25.00	3
Manager of engineering change		25.00	3
Not implemented		50.00	6
		Answered Question	12
		Skipped Question	14

*13) To what extent is risk assessments (e.g. HAZOP study) performed for any change to be implemented?

		Response (%)	Responses
Regardless of size of change		0.00	0
Some cases		41.67	5
Most cases		16.67	2
Only in certain predetermined cases		16.67	2
Up to the employee(s) performing the change		25.00	3
		Answered Question	12
		Skipped Question	14

*14) Are engineering changes administrated by some internal authority?

		Response (%)	Responses
General Machines Regulations: 2.1 or 2.7		16.67	2
Engineering Manager		25.00	3
Change Manager		8.33	1
Departmental Head		16.67	2
Other (please specify)		33.33	4
		Answered Question	12
		Skipped Question	14

Respondent ID	View Survey	Email	First Name	Last Name	Other (please specify)
9926831	View	-	-	-	Individual implementing the change
9927284	View	-	-	-	by the specialist
9930107	View	-	-	-	Drawing office manager
9927204	View	-	-	-	none, limited

*15) Which of the following is applicable before an engineering change order can be closed out?

		Response (%)	Responses
Basic description of change		18.87	10
Business case: Cost vs Benefit analysis		11.32	6
Risk assessment		13.21	7

Affected processes / plants / personnel		20.75	11
Reviews on the proposed change		5.66	3
Assign a senior employee to evaluate the change		7.55	4
Request document changes (drawings, operating procedures, commissioning procedures, maintenance procedures, etc.)		15.09	8
Verify changes reflected in documents		7.55	4
		Answered Question	53
		Skipped Question	-27

Respondent ID	View Survey	Email	First Name	Last Name	Other - please specify
9926831	View	-	-	-	Most changes occur due to a request from the plant and are executed without approval
9928519	View	-	-	-	There are no formal close-out requirements in our company. No questions are asked if the process is functioning correctly

*16) Which of the following is included in the change management processes?

		Response (%)	Responses
Stakeholders		28.00	7
Engineering department		28.00	7
Affected departments		24.00	6
All business unit managers		8.00	2
Commercial departments (finance, HR, communications, Risk, Legal, Health Safety and Environment)		12.00	3
		Answered Question	25
		Skipped Question	1

Respondent ID	View Survey	Email	First Name	Last Name	Other please specify per line
9930083	View	-	-	-	Some stakeholders, sometimes
9928519	View	-	-	-	There is no check-box for the "other option". Just omit the option selected No formal change management process is implemented at our company

*17) How effective would you rate the communication send out to all employees (or all employees affected by the change)?

		Response (%)	Responses
Excellent		0.00	0
Good		0.00	0
Neutral		33.33	4
Fair		25.00	3
Poor		41.67	5
		Answered Question	12
		Skipped Question	14

*18) Are you aware of any engineering changes that were performed that:

		Response (%)	Responses
Were implemented haphazardously		15.22	7
Were not properly documented		23.91	11
Were not closed out properly		26.09	12
Did not adhere to common best practices on engineering change management		15.22	7

Were not stored on a centralised, easily accessible location for future use by other employees.	19.57	9
None	0.00	0
	Answered Question	46
	Skipped Question	-20

*19) If for example your plant were to be duplicated, would you be able to use the existing available documents to exactly replicate a working plant?

	Response (%) Responses
Yes	16.67 2
No	83.33 10
	Answered Question 12
	Skipped Question 14

Respondent ID	View Survey	Email	First Name	Last Name	Please provide reasons
9926831	View	-	-	-	Most plant designs are not verified or professionally approved. Some plants do not have drawings nor documentation.
9927284	View	-	-	-	Not yet on this level
9930083	View	-	-	-	This may be possible only if the replication is performed within the first two years of the first plant commissioning. Changes are implemented and no Hazop study performed or documentation verified. The loss of knowledge through high staff turnover and many managerial movements does allow for very limited change management. Multi environment responsibilities and silo/distributed management allow for this laps in documentation management.
9930107	View	-	-	-	High percentage of documentations more than 30 years old and not readable. Plants build later than 1980 can be duplicated. On some plants project documentation was not correctly transferred from original contractor to company and resulted in loss of information.
9934514	View	-	-	-	Lots of documentation has been lost or never properly stored.
9928519	View	-	-	-	No formal change management process is implemented at our company, which has the effect that the latest and most up-to-date designs and operating philosophies are re-traceable for quick and accurate perusal.
9931825	View	-	-	-	Some maintenance changes are not always recorded properly
9934511	View	-	-	-	Provisional yes, experienced individuals, with both system and plant knowledge must be available.

*20) How would you rate your ECM process (where 1 star means very ineffective and 10 stars more than effective)?

	1	2	3	4	5	6	7	8	9	10	Responses	Total
Initiation	16.67%	0%	16.67%	25.00%	8.33%	8.33%	8.33%	16.67%	0%	0%	12	54
Approval process / Workflow	25.00%	0%	8.33%	16.67%	8.33%	16.67%	8.33%	8.33%	0%	8.33%	12	56
Risk assessment	0%	8.33%	16.67%	33.33%	16.67%	8.33%	0%	8.33%	8.33%	0%	12	57
Business case	8.33%	16.67%	8.33%	8.33%	16.67%	8.33%	16.67%	16.67%	0%	0%	12	58
Implementation	8.33%	8.33%	8.33%	0%	16.67%	8.33%	33.33%	16.67%	0%	0%	12	66
Archiving	33.33%	16.67%	16.67%	8.33%	16.67%	0%	0%	0%	8.33%	0%	12	37
Communication	16.67%	0%	25.00%	16.67%	33.33%	0%	0%	8.33%	0%	0%	12	47
Post-closure observation	33.33%	16.67%	8.33%	16.67%	8.33%	0%	8.33%	0%	8.33%	0%	12	40
Maintenance	16.67%	8.33%	33.33%	0%	25.00%	0%	8.33%	0%	8.33%	0%	12	47

Show values

***21) To what extent does your ECM process allow:**

	1	2	3	4	5	6	7	8	9	10	Responses	Total
The EC request to be evaluated during change implementation?	33.33%	0%	8.33%	8.33%	8.33%	25.00%	8.33%	0%	8.33%	0%	12	50
The EC request to be evaluated post change implementation?	33.33%	0%	0%	16.67%	16.67%	16.67%	16.67%	0%	0%	0%	12	48
Expanded (additional scope added)?	16.67%	8.33%	0%	0%	25.00%	25.00%	0%	8.33%	0%	16.67%	12	65
Changed (deviate from the initial change scope)?	16.67%	8.33%	0%	0%	16.67%	25.00%	8.33%	16.67%	0%	8.33%	12	65
Allow additional / other change requests to be opened from the original EC request?	25.00%	16.67%	8.33%	0%	16.67%	8.33%	8.33%	8.33%	8.33%	0%	12	50

Show values

***22) Would you like an Improved ECM system at your company?**



***23) Which of the following aspects of an ECM would you be interested to be improved?**



Respondent ID	View Survey	Email	First Name	Last Name	Other (please specify)
9930083	View	-	-	-	An no paper system are a pre-requisite and a serious enterprise sponsor within the company need to drive the implementation.
9928519	View	-	-	-	There is also a great need for an automated ECM system that can incorporate all the aforementioned aspects in this question. Some companies do have manual ECM systems, which results in the ECM

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process being a big paper exercise and as result the stakeholders involved can still lose documentation or neglect (skip out) certain aspect of the process as there is no control to prevent the different phases of the ECM process to be closed out prematurely (eg. the change can be implemented before any quality assurance plan is readily available for the change at hand). In some cases the change can be closed out without any drawing updates being approved or submitted for archiving, this is especially true for manual ECM systems.

Appendix D: Petrochemical company

Results for: Engineering change management

Academic data collection survey

PLEASE NOTE THAT THE SURVEY DATA WILL NOT BE USED TO PERSONALLY IDENTIFY ANY INDIVIDUAL OR COMPANY. THE DATA CAPTURED IN THIS SURVEY WILL REMAIN CONFIDENTIAL AT ALL TIMES AND IS SOLELY FOR ACADEMICAL PURPOSES

*1) What is your role at the company?

	Response (%)	Responses
Artisan	0.00	0
Technician	0.00	0
Service Engineer (e.g. Maintenance, Improvement, etc.)	33.33	2
Process Engineer	16.67	1
Design / Project Engineer	50.00	3
Production / Line Engineer	0.00	0
Manager - technical	0.00	0
Manager - commercial	0.00	0
Answered Question		6
Skipped Question		20

*2) In which area of engineering do you work?

	Response (%)	Responses
Product development	0.00	0
Services (e.g. maintenance, supply and management of energy)	50.00	3
Products	0.00	0
Research and Development	16.67	1
Quality	0.00	0
Health, Safety and Environment	0.00	0
Production	16.67	1
Other (Please specify)	16.67	1
Answered Question		6
Skipped Question		20

Respondent ID	View Survey	Email	First Name	Last Name	Other (Please specify)
9927304	View	-	-	-	Commissioning

*3) Please indicate your level of experience

	Response (%)	Responses
Graduate	0.00	0
In practical training	0.00	0
Junior	33.33	2
Senior	66.67	4
Specialist	0.00	0
Answered Question		6
Skipped Question		20

*4) Are you professionally registered at ECSA?

	Response (%)	Responses
Yes, registered as Candidate	66.67	4
Yes, registered as professional (e.g. Pr.Eng)	0.00	0
No	33.33	2
Answered Question		6
Skipped Question		20

*5) Please describe your understanding of engineering change management in a few short sentences?

ID	Email	First Name	Last Name	Text Answers (6)	View
9929527	-	-	-	Change management ensures that any changes to plant or equipment are carried out in safe and responsible manner and that all systems and documentation are updated to reflect the change.	View
9927960	-	-	-	Engineering change management is the process of documenting every change to a process or system and updating any relevant information or data relating to the change. The process also includes training of personnel and communication that everyone is aware of the change. ECM is vital in keeping information about a system or process up to date.	View
9927592	-	-	-	The main aim of ECM is to manage the risks associated with changes. Engineering change management is critical to keep all operations supporting systems up to date. With supporting systems I mean training, specification documents, equipment install base, operating procedures/parameters, ect. With updated documentation engineering time spent on improvement designing and fault finding will be significantly decreased. From a safety side it is to ensure all relevant safety checks were followed and equipment is safe to operate by trained personnel. The legal implications are to ensure that ownership of changes / equipment are placed in the care of the party that is most responsible for activities on the equipment. And that the facility legal appointed person is made aware of the changes on his / her facility.	View
9927304	-	-	-	Engineering change management is the process of planning, controlling and recording changes that affect the original form, fit and function of the original engineered design (and thereby controlling the risks associated with the change	View
9927301	-	-	-	A procedure or process which is followed to document change. This would typically include approvals by responsible people in terms of accountability and acceptance of the change. The main components are design, risk studies, Training and commissioning. The approvals referred to imply actual signing off. These change documents must then be referenced and archived.	View
9927293	-	-	-	It is a system which is used to identify any hazards or risks which might emerge as a result of a change in the process, personnel or procedures. The risks and hazards can then be communicated, mitigated and training given to the relevant parties.	View

*6) To what extent do you apply ECM in your company? (Engineering change management is the process of planning, controlling and recording changes that affect the original form, fit and function of the original engineered design (and thereby controlling the risks associated with the change). These changes can be any hardware, software, plant inputs, material specifications, operating procedures, drawings and other documentation)

	Response (%)	Responses
Very Effective	33.33	2
Effective	50.00	3
Neutral	16.67	1
Ineffective	0.00	0
Very Ineffective	0.00	0
Answered Question		6
Skipped Question		20

*7) In which of the following areas is ECM applied?

	Response (%)	Responses
Maintenance	18.18	6
Operational changes	15.15	5
Document (incl. drawing) changes	15.15	5

Projects		18.18	6
Risk assessments		9.09	3
Safety, Health and Environment		9.09	3
Quality		9.09	3
Incident investigations		6.06	2
None		0.00	0
		Answered Question	33
		Skipped Question	-7

Respondent ID	View Survey	Email	First Name	Last Name	Other
9927301	View	-	-	-	Any change which is not like for like which is not typical maintenance or normal operation

*8) Is your ECM:

	Response (%)	Responses
Company specific		100.00 6
Individual specific (e.g. do you use your own developed system from your own wits and integrity)?		0.00 0
		Answered Question 6
		Skipped Question 20

*9) How effectively is the data of engineering change management captured on a centralised business location?

	Response (%)	Responses
Very Effective		33.33 2
Effective		50.00 3
Neutral		16.67 1
Ineffective		0.00 0
Very Ineffective		0.00 0
		Answered Question 6
		Skipped Question 20

*10) How accessible is your data on ECM's by any employee?

	Response (%)	Responses
Not at all		0.00 0
Limited to the employee working on the change		16.67 1
Accessible by only a few people		16.67 1
Accessible to a large extent		66.67 4
Fully accessible		0.00 0
		Answered Question 6
		Skipped Question 20

*11) Can a cross-search be performed to determine if similar changes were performed previously?

	Response (%)	Responses
Only Administrators		50.00 3
Only stakeholders		0.00 0
Interested parties		33.33 2
Everyone		16.67 1
		Answered Question 6

Skipped Question 20

*12) Are ECMs managed by an administrator or manager?

	Response (%)	Responses
Administrator	66.67	4
Manager of engineering change	33.33	2
Not implemented	0.00	0
Answered Question		6
Skipped Question		20

*13) To what extent is risk assessments (e.g. HAZOP study) performed for any change to be implemented?

	Response (%)	Responses
Regardless of size of change	16.67	1
Some cases	0.00	0
Most cases	83.33	5
Only in certain predetermined cases	0.00	0
Up to the employee(s) performing the change	0.00	0
Answered Question		6
Skipped Question		20

*14) Are engineering changes administrated by some internal authority?

	Response (%)	Responses
General Machines Regulations: 2.1 or 2.7	16.67	1
Engineering Manager	16.67	1
Change Manager	33.33	2
Departmental Head	16.67	1
Other (please specify)	16.67	1
Answered Question		6
Skipped Question		20

Respondent ID	View Survey	Email	First Name	Last Name	Other (please specify)
9927293	View	-	-	-	Not sure

*15) Which of the following is applicable before an engineering change order can be closed out?

	Response (%)	Responses
Basic description of change	15.38	6
Business case: Cost vs Benefit analysis	12.82	5
Risk assessment	12.82	5
Affected processes / plants / personnel	12.82	5
Reviews on the proposed change	12.82	5
Assign a senior employee to evaluate the change	10.26	4
Request document changes (drawings, operating procedures, commissioning procedures, maintenance procedures, etc.)	12.82	5
Verify changes reflected in documents	10.26	4
Answered Question		39
Skipped Question		-13

Respondent ID	View Survey	Email	First Name	Last Name	Other - please specify
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9927301	View	-	-	-	Training and RfC
9927293	View	-	-	-	Not sure
9927960	View	-	-	-	Verification of beneficial use

*16) Which of the following is included in the change management processes?

		Response (%)	Responses
Stakeholders		18.18	4
Engineering department		22.73	5
Affected departments		22.73	5
All business unit managers		22.73	5
Commercial departments (finance, HR, communications, Risk, Legal, Health Safety and Environment)		13.64	3
Answered Question			22
Skipped Question			4

*17) How effective would you rate the communication send out to all employees (or all employees affected by the change)?

		Response (%)	Responses
Excellent		0.00	0
Good		33.33	2
Neutral		66.67	4
Fair		0.00	0
Poor		0.00	0
Answered Question			6
Skipped Question			20

*18) Are you aware of any engineering changes that were performed that:

		Response (%)	Responses
Were implemented haphazardously		18.75	3
Were not properly documented		31.25	5
Were not closed out properly		25.00	4
Did not adhere to common best practices on engineering change management		18.75	3
Were not stored on a centralised, easily accessible location for future use by other employees		0.00	0
None		6.25	1
Answered Question			16
Skipped Question			10

*19) If for example your plant were to be duplicated, would you be able to use the existing available documents to exactly replicate a working plant?

		Response (%)	Responses
Yes		33.33	2
No		66.67	4
Answered Question			6
Skipped Question			20

Respondent ID	View Survey	Email	First Name	Last Name	Please provide reasons
9927301	View	-	-	-	Even if all documents were perfectly updated, rebuilding the plant exactly is not likely. The management of change system is well managed and non-negotiable. Although these systems also rely

					on a culture change (of understanding the need) some avoid change to avoid doing documentation. Similarly, people take short-cuts. Some slip through.
9927592	View	-	-	-	Our ECM processes were introduced approximately 10 years ago and the plant is already 40 years old. This there is still a lot of documentation that needs to be updated. It seem and have been economically un-viable to spent the large amount of money that will not directly improve profitability for the plant. Thus updating of documentation happens on a adhoc bases as new project work is being done on specific equipment.
9929527	View	-	-	-	documentation incomplete and out of date
9927293	View	-	-	-	Drawings not up to date.
9927960	View	-	-	-	No changes to the process or systems are done without a engineering change management document. All paper work is updated before any changes are implemented.

***20) How would you rate your ECM process (where 1 star means very ineffective and 10 stars more than effective)?**

	1	2	3	4	5	6	7	8	9	10	Responses	Total
Initiation	0%	0%	0%	0%	0%	0%	16.67%	50.00%	33.33%	0%	6	49
Approval process / Workflow	0%	0%	0%	0%	16.67%	33.33%	16.67%	16.67%	16.67%	0%	6	41
Risk assessment	0%	0%	0%	0%	0%	0%	50.00%	16.67%	16.67%	16.67%	6	48
Business case	0%	0%	16.67%	16.67%	0%	16.67%	16.67%	16.67%	16.67%	0%	6	37
Implementation	0%	0%	0%	0%	0%	0%	33.33%	33.33%	16.67%	16.67%	6	49
Archiving	0%	0%	0%	16.67%	0%	0%	50.00%	16.67%	16.67%	0%	6	43
Communication	0%	0%	0%	0%	16.67%	33.33%	16.67%	16.67%	0%	16.67%	6	42
Post-closure observation	0%	16.67%	0%	0%	16.67%	16.67%	0%	16.67%	16.67%	16.67%	6	40
Maintenance	0%	16.67%	0%	16.67%	16.67%	0%	16.67%	0%	16.67%	16.67%	6	37

Show values

***21) To what extent does your ECM process allow:**

	1	2	3	4	5	6	7	8	9	10	Responses	Total
The EC request to be evaluated during change implementation?	0%	0%	0%	0%	0%	33.33%	33.33%	16.67%	16.67%	0%	6	43
The EC request to be evaluated post change implementation?	0%	0%	16.67%	0%	16.67%	0%	16.67%	0%	50.00%	0%	6	42
Expanded (additional scope added)?	0%	0%	0%	0%	16.67%	50.00%	0%	16.67%	16.67%	0%	6	40
Changed (deviate from the initial change scope)?	0%	0%	0%	16.67%	0%	50.00%	0%	0%	33.33%	0%	6	40
Allow additional / other change requests to be opened from the original EC request?	0%	0%	0%	0%	16.67%	33.33%	0%	33.33%	16.67%	0%	6	42

Show values

***22) Would you like an improved ECM system at your company?**

	Response (%)	Responses
Yes	66.67	4
No	33.33	2

Answered Question 6
 Skipped Question 20

*23) Which of the following aspects of an ECM would you be interested to be improved?

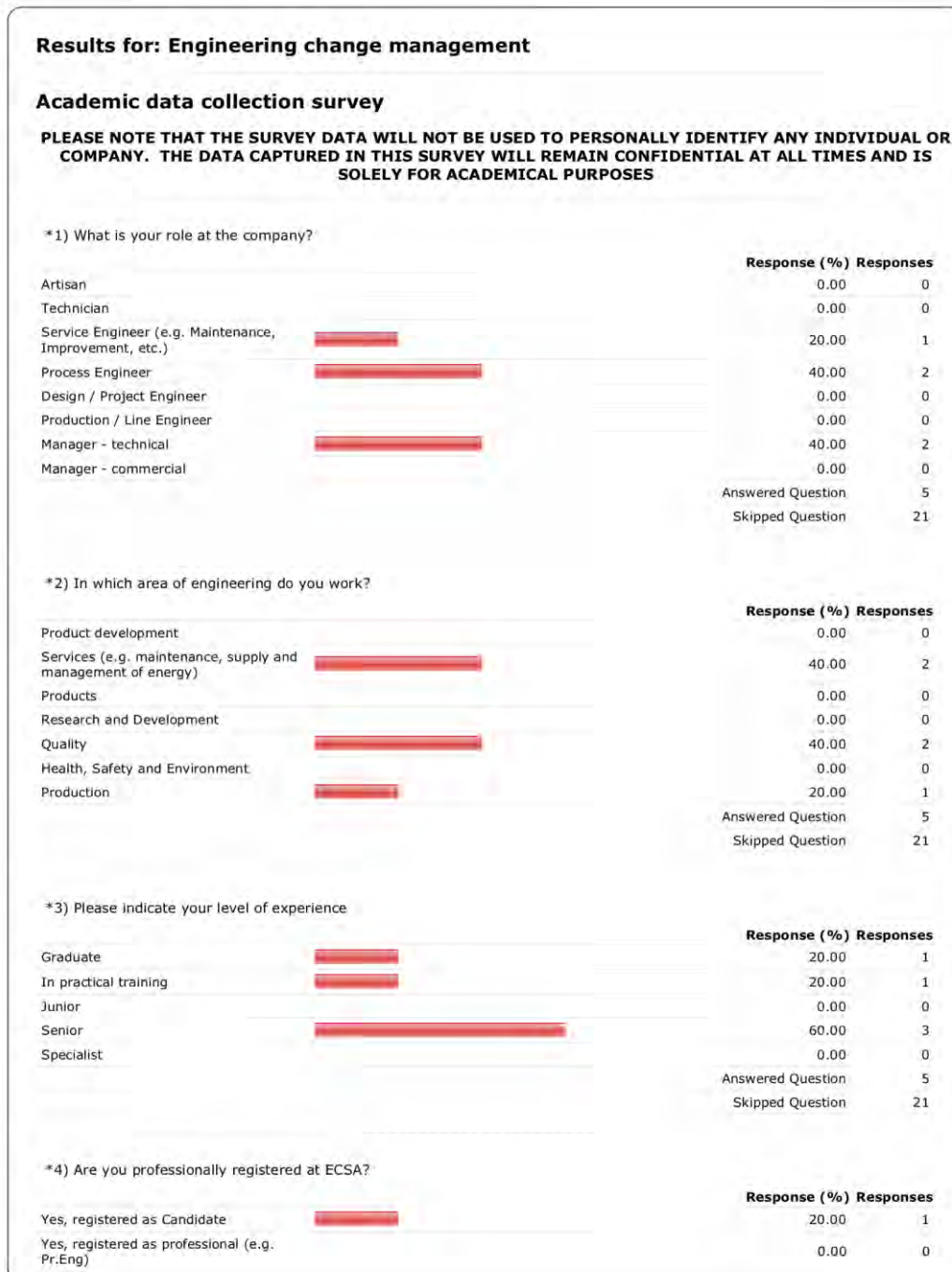
		Response (%)	Responses
Document control (incl. drawings and procedures)		10.00	1
Approval levels		20.00	2
Reviewers		0.00	0
Change management administrator		0.00	0
Change management committee		0.00	0
Standardized procedure		10.00	1
Risk assessment		0.00	0
Request for information		20.00	2
Workflow		20.00	2
None		20.00	2

Answered Question 10
 Skipped Question 16

Respondent ID	View Survey	Email	First Name	Last Name	Other (please specify)
9927301	View	-	-	-	The ability to reference documents of previous changes through a search function.
9927592	View	-	-	-	The ideal scenario will be to have a electronic based system.
9927960	View	-	-	-	Amount of paper work

No answers required.

Appendix E: Specialised products company



No		60.00	3
Other (please specify)		20.00	1
		Answered Question	5
		Skipped Question	21

Respondent ID	View Survey	Email	First Name	Last Name	Other (please specify)
9928740	View	-	-	-	Registered as Pr.Eng in Europe

*5) Please describe your understanding of engineering change management in a few short sentences?

















ID	Email	First Name	Last Name	Text Answers (5)	View
9934534	-	-	-	Change management is a process; many companies have set procedures that need to be followed. This starts with needs, feasibility studies, costing, budget requesting. All these stages get the involvement of the customer, HS&EP and other affected departments From here the project planning starts followed by tendering or bidding, finalizing technical designs and getting the necessary approvals should they be required. Orders and contracts are put in place. During the construction phase, nothing starts before the legal issues are in place (as per the construction regulations). All inspections are documented and progress reports to be issued as per the plan. Budget control, critical path control and all safety issues are to be managed. On completion commissioning with tests are to be recorded and performance is to meet original design requirements. Safety inspections are to be conducted and all hazards are to be rated and addressed. All Instruction, Technical, Training, Calibration, Operating manuals together with all approved drawings, part lists and maintenance schedule cards and structural, electrical and vessel certificates are to be completed. SCADA programs together with their function specifications and backups are to be stored Thereafter the process is put into production with specific attention given to Safe work procedures, product performance, process stability and set-up procedures. Fixed Asset documentation for accounting purposed together with performance against budget reports are to be submitted.	View
9928740	-	-	-	System to track changes that are made. To assist in the planning of change, Capturing of data for future use, controlling Quality.	View
9928655	-	-	-	The systematic and logical risk based approach to initiating, plannig, developing and implementing any change in an engineering environment, being process, structure, personnell or otherwise	View
9927434	-	-	-	d,mcnllhfst,kfjperhnrfyr90485l;n frtg;ujtv54pw jtuui	View
9927296	-	-	-	To effectively manage the re-design of a project already in operation to improve the effectiveness/efficiency of the output of that project.	View

*6) To what extent do you apply ECM in your company? (Engineering change management is the process of planning, controlling and recording changes that affect the original form, fit and function of the original engineered design (and thereby controlling the risks associated with the change). These changes can be any hardware, software, plant inputs, material specifications, operating procedures, drawings and other documentation)

		Response (%)	Responses
Very Effective		20.00	1
Effective		40.00	2
Neutral		20.00	1
Ineffective		20.00	1
Very Ineffective		0.00	0
		Answered Question	5
		Skipped Question	21

*7) In which of the following areas is ECM applied?

		Response (%)	Responses
Maintenance		12.90	4
Operational changes		12.90	4
Document (incl. drawing) changes		12.90	4
Projects		16.13	5
Risk assessments		9.68	3

Safety, Health and Environment		12.90	4
Quality		12.90	4
Incident investigations		9.68	3
None		0.00	0
		Answered Question	31
		Skipped Question	-5
*8) Is your ECM:			
		Response (%) Responses	
Company specific		100.00	5
Individual specific (e.g. do you use your own developed system from your own wits and integrity)?		0.00	0
		Answered Question	5
		Skipped Question	21
*9) How effectively is the data of engineering change management captured on a centralised business location?			
		Response (%) Responses	
Very Effective		0.00	0
Effective		60.00	3
Neutral		40.00	2
Ineffective		0.00	0
Very Ineffective		0.00	0
		Answered Question	5
		Skipped Question	21
*10) How accessible is your data on ECM's by any employee?			
		Response (%) Responses	
Not at all		0.00	0
Limited to the employee working on the change		20.00	1
Accessible by only a few people		40.00	2
Accessible to a large extent		20.00	1
Fully accessible		20.00	1
		Answered Question	5
		Skipped Question	21
*11) Can a cross-search be performed to determine if similar changes were performed previously?			
		Response (%) Responses	
Only Administrators		20.00	1
Only stakeholders		20.00	1
Interested parties		40.00	2
Everyone		20.00	1
		Answered Question	5
		Skipped Question	21
*12) Are ECMs managed by an administrator or manager?			
		Response (%) Responses	
Administrator		60.00	3
Manager of engineering change		40.00	2
Not implemented		0.00	0

Answered Question 5
Skipped Question 21

*13) To what extent is risk assessments (e.g. HAZOP study) performed for any change to be implemented?

	Response (%)	Responses
Regardless of size of change	60.00	3
Some cases	20.00	1
Most cases	20.00	1
Only in certain predetermined cases	0.00	0
Up to the employee(s) performing the change	0.00	0

Answered Question 5
Skipped Question 21

*14) Are engineering changes administrated by some internal authority?

	Response (%)	Responses
General Machines Regulations: 2.1 or 2.7	20.00	1
Engineering Manager	80.00	4
Change Manager	0.00	0
Departmental Head	0.00	0

Answered Question 5
Skipped Question 21

*15) Which of the following is applicable before an engineering change order can be closed out?

	Response (%)	Responses
Basic description of change	13.33	4
Business case: Cost vs Benefit analysis	6.67	2
Risk assessment	16.67	5
Affected processes / plants / personnel	16.67	5
Reviews on the proposed change	16.67	5
Assign a senior employee to evaluate the change	3.33	1
Request document changes (drawings, operating procedures, commissioning procedures, maintenance procedures, etc.)	16.67	5
Verify changes reflected in documents	10.00	3

Answered Question 30
Skipped Question -4

*16) Which of the following is included in the change management processes?

	Response (%)	Responses
Stakeholders	7.69	1
Engineering department	38.46	5
Affected departments	30.77	4
All business unit managers	7.69	1
Commercial departments (finance, HR, communications, Risk, Legal, Health Safety and Environment)	15.38	2

Answered Question 13
Skipped Question 13

*17) How effective would you rate the communication send out to all employees (or all employees affected by the change)?

		Response (%)	Responses
Excellent		0.00	0
Good		60.00	3
Neutral		0.00	0
Fair		40.00	2
Poor		0.00	0
		Answered Question	5
		Skipped Question	21

*18) Are you aware of any engineering changes that were performed that:

		Response (%)	Responses
Were implemented haphazardously		11.11	1
Were not properly documented		22.22	2
Were not closed out properly		22.22	2
Did not adhere to common best practices on engineering change management		11.11	1
Were not stored on a centralised, easily accessible location for future use by other employees		11.11	1
None		22.22	2
		Answered Question	9
		Skipped Question	17

*19) If for example your plant were to be duplicated, would you be able to use the existing available documents to exactly replicate a working plant?

		Response (%)	Responses
Yes		60.00	3
No		40.00	2
		Answered Question	5
		Skipped Question	21

Respondent ID	View Survey	Email	First Name	Last Name	Please provide reasons.
9928655	View	-	-	-	Drawings and documentation is not complete and well kept
9928740	View	-	-	-	Documents are old and misplaced.
9934534	View	-	-	-	Detailed drawings are kept together with specifications primarily for maintenance / replacement reasons and they could be used to duplicate the equipment.

*20) How would you rate your ECM process (where 1 star means very ineffective and 10 stars more than effective)?

	1	2	3	4	5	6	7	8	9	10	Responses	Total
Initiation	0%	0%	20.00%	0%	40.00%	0%	20.00%	20.00%	0%	0%	5	28
Approval process / Workflow	0%	0%	0%	0%	20.00%	20.00%	20.00%	20.00%	20.00%	0%	5	35
Risk assessment	0%	0%	0%	0%	20.00%	20.00%	40.00%	20.00%	0%	0%	5	33
Business case	0%	20.00%	0%	20.00%	0%	20.00%	20.00%	20.00%	0%	0%	5	27
Implementation	0%	0%	0%	0%	20.00%	0%	20.00%	40.00%	20.00%	0%	5	37
Archiving	0%	0%	20.00%	20.00%	0%	20.00%	40.00%	0%	0%	0%	5	27
Communication	0%	0%	0%	40.00%	20.00%	0%	20.00%	20.00%	0%	0%	5	28
Post-closure observation	0%	0%	20.00%	0%	20.00%	40.00%	20.00%	0%	0%	0%	5	27
Maintenance	0%	0%	0%	20.00%	40.00%	20.00%	20.00%	0%	0%	0%	5	27

Show values

*21) To what extent does your ECM process allow:

	1	2	3	4	5	6	7	8	9	10	Responses	Total
The EC request to be evaluated during change implementation?	0%	0%	0%	0%	40.00%	40.00%	0%	0%	20.00%	0%	5	31
The EC request to be evaluated post change implementation?	0%	0%	0%	0%	0%	60.00%	0%	40.00%	0%	0%	5	34
Expanded (additional scope added)?	0%	0%	20.00%	0%	0%	40.00%	0%	0%	40.00%	0%	5	33
Changed (deviate from the initial change scope)?	0%	0%	0%	0%	0%	40.00%	20.00%	0%	40.00%	0%	5	37
Allow additional / other change requests to be opened from the original EC request?	0%	20.00%	0%	0%	20.00%	40.00%	20.00%	0%	0%	0%	5	26

Show values

*22) Would you like an improved ECM system at your company?

	Response (%)	Responses
Yes	80.00	4
No	20.00	1
Answered Question		5
Skipped Question		21

*23) Which of the following aspects of an ECM would you be interested to be improved?

	Response (%)	Responses
Document control (incl. drawings and procedures)	18.18	4
Approval levels	9.09	2
Reviewers	9.09	2
Change management administrator	9.09	2
Change management committee	9.09	2
Standardized procedure	9.09	2
Risk assessment	9.09	2
Request for information	9.09	2

Workflow					13.64	3
None					4.55	1
					Answered Question	22
					Skipped Question	4
Respondent ID	View Survey	Email	First Name	Last Name	Other (please specify)	
9928655	View	-	-	-	Cost/benefit analysis	