NEW GENERATION INTEGRATED DIGITAL ENGINEERING TO EMBRACE DOCUMENT REVISION IDENTIFICATION

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SUMMARY

Engineering process embraces tools, methodologies and resources to make sure the outcome of engineering process is safe so far as is reasonably practical (SFAIRP) and that there is a clear and transparent translation of the document application that leads to efficiency.

Currently, significant focus is on integration. Digital engineering is just one aspect of integration. In our signalling discipline, there can be some challenges when delivering a project, for example: senior designers not having enough time to guide younger designers. Consequently this could lead inexperienced designers to apply outdated standards. Similarly, when approved drawing revisions are updated, there is potential for incorrect and outdated versions to be utilised by installation and test teams. These two examples will lead to significant rework and delivering poor project outcomes.

1 INTRODUCTION

Digital revolution (known as the Third Industrial Revolution, is the shift from mechanical and analogue electronic technology to digital electronics (Wikimedia Foundation, Inc., 2019)) offers technology to address those issues in an integration of digital engineering. One of the areas in engineering process that has been significantly progressed with the advent of digital technology is version control of documentation. Controlled documents have a version number, revision number, signatures of people that have made changes to the document and the history of changes through the life of the document.

To be able to implement such thorough engineering control, a number of tools that embrace digital technology have been developed. Functionality like:

- organising and locking documents into a management system
- checking documents in and out of the management system
- generating automatic allocation of document revision/version when the document is edited,

This technology is already out there and serves the purpose well.

In this paper, we propose to introduce and explain a revision identification problem within an integrated digital engineering theme. Moreover, we propose the identification to be a mandatory control measure before the Document User starts reading its content. The benefits from such application are as follows:

- work to the latest version/revision of approved document
- minimise safety risks
- limit wasted resources, time and technology.

2 DOCUMENT

Presently, the earliest known archaeological evidence of any form of writing or counting are scratch marks on a bone from 150,000 years ago. But the first really solid evidence of counting, in the form of the number one, is from a mere twenty-thousand years ago. A bone from the Ishango National Park found in the Congo with two identical markings of sixty scratches each and equally numbered groups on the back. These markings are a certain indication of counting (Osborne, 2019).

A document is an item of written, printed, or electronic matter that provides information or evidence or that serves as an official record (Oxford University Press, 2019).

When preparing a document, there may be quite a significant number of revisions especially when the document is created by a team of people. In such cases, version control of the document needs to be applied.

Version control (also known as revision control or source control) is a category of processes and tools designed to keep track of multiple different versions of software, content, documents, websites and other information in development (TechTarget, 2019).

Version control involves a process of naming and distinguishing between a series of draft documents which lead to a final (or approved) version, which in turn may be subject to further amendments. It provides an audit trail for the revision and update of draft and final versions (University of Leicester, 2019).

Today, “paperless” documentation is a reality. The trend is that it will be part of how we operate in society. An example of this exists in our major banks where home loans can be signed via a web browser and electronic signatures used with those contracts. However, all engineering disciplines printed documents are, and will be still in use for some time. Therefore, printing is still relevant.

The invention of the printing press in 1440 C.E. was a major step forward in literacy. Prior to Johannes Gutenberg's solution to the problem of molding movable type, books were hand written and hand copied. Thus, only the very wealthy could afford to have copies of books made. The development of printing presses that could produce hundreds of books in a short period of time stimulated intellectual life. Soon after it was no longer the exclusive domain of the churches and courts. The printing press helped to bring about an era of enlightenment (Wichita State University, 2019).

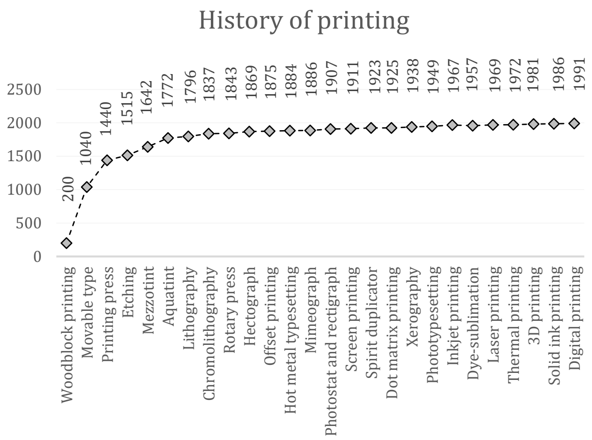

Figure 1 – History of printing (Wikimedia Foundation, Inc., 2019)

The history of printing has been presented on Figure 1.

Controlling versions of documents became even more critical when new, more efficient options of printing were developed. The amount of printed copies of documents influenced the need to recognise and to communicate the most recent versions of documents.

3 ENGINEERING PROCESS

Engineering process has existed since early days where more than one engineer was involved in inventing a new product, a group of products, a system, redesigning or implementing the product(s)/system.

3.1 Standards and guidelines

International standard on engineering process – ISO/IEC/IEEE 15288:2015 establishes a common framework of process descriptions for the life cycle of systems created by humans. It defines a set of processes and associated terminology from an engineering viewpoint (International Organization for Standardization, 2015).

For Australian railway organisations the Rail Industry Safety and Standards Board (RISSB) develops national standards that assist the rail industry. Two of the standards Signal Testing Process (RISSB, 2017) and Signal Design Process Management (RISSB, 25/01/2017) are particularly relevant to engineering process.

Rail infrastructure managers, rail transport operators and any other authorities that invest in rail transport and are responsible for delivering major projects, may have developed standards and guidelines that are more specific than the international standard ISO/IEC/IEEE 15288:2015.

One of the interesting guidelines strictly related to engineering process is actually "Best Practices for Using Systems Engineering Standards (ISO/IEC/IEEE 15288, IEEE 15288.1 and IEEE 15288.2) on Contracts for Department of Defence (DoD) Acquisition Programs" (Office of the Deputy Assistant Secretary of Defense for Systems Engineering, 2017). The reason DoD adopted the standards is that the defence industry has found applying systems engineering (SE) processes and practices throughout the system life cycle could potentially improve project performance, as measured by the project's ability to satisfy technical requirements within cost and schedule constraints (Office of the Deputy Assistant Secretary of Defense for Systems Engineering, 2017). The guideline was issued to tailor the standards to the DoD environment.

Document version control that is highly relevant in engineering process also has a number of guidelines. Guidance Document: Version Control (Rochfort, 2015) simplistically describes and explains the basics of document version control.

3.2 Mathematics and important statements

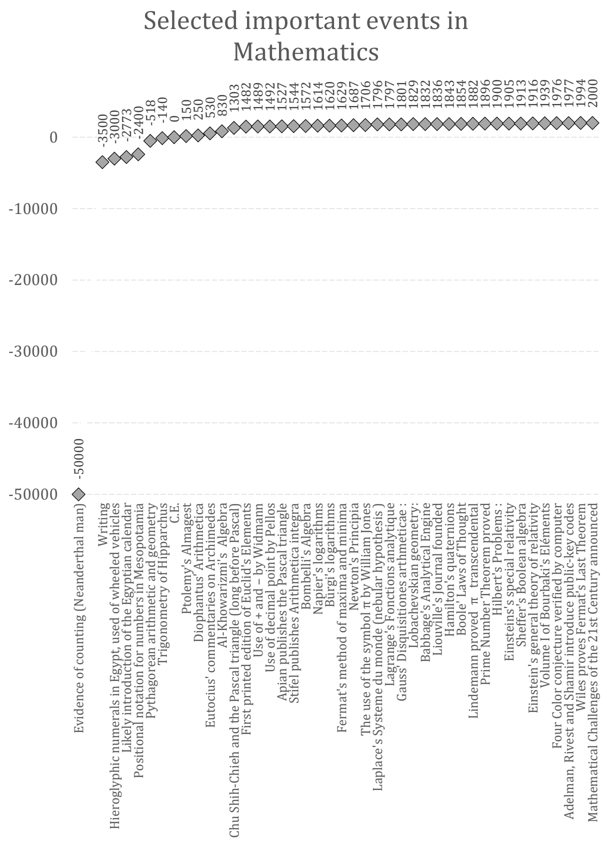

Figure 2 – Important events in Mathematics (Wichita State University, 2019)

The 20th century launched the "Information Age," in which computers, and the data they generate and manage, have come to influence all aspects of everyday life. Mathematics provides the basic theory on which all computers depend, and in turn, computer science is a source of new challenges to the field of mathematics.

What is more, the practical implementation of computers in solving problems arising in science, technology, commerce and other areas continually requires new infusions of mathematical ideas as the use of computers becomes ever more sophisticated (UCLA, 2019).

Mathematics is an integral part of engineering. There would be no engineering without mathematics. The chart in Figure 2 shows important dates in the history of mathematics. The dates are closely related to documentation, especially those dates highlighting inventions in numbering that introduced new opportunities in distinguishing versions of documents. The chart also gives us some perspective on when certain theories came about. This could probably be correlated with some important dates in engineering, e.g. the influence of Sheffer's Stroke in Boolean algebra (1913) became the building base in electronics and digital engineering later on. Boolean algebra gave a beginning for a number of specific computer languages. One of them – Common Algebraic Specification Language (CASL) (Donald Sannella, Andrzej Tarlecki, 2012) is being successfully used in an algebraic modelling software systems. CASL is often used when modelling a signalling relay logic.

There are some interesting statements by engineering experts quoted in the article on Interesting Engineering (Kerrigan, 2018):

- "I don't spend my time pontificating about high-concept things; I spend my time solving engineering and manufacturing problems." - Elon Musk (a technology entrepreneur, investor, and engineer)
- "Problem-solving is essential to engineering. Engineers are constantly on the lookout for a better way to do things." - Dinesh Paliwal (a businessman, CEO of Harman International Industries)
- "Engineers operate at the interface between science and society." - Gordon Stanley Brown (a professor of electrical engineering at Massachusetts Institute of Technology)
- "A good engineer thinks in reverse and asks himself about the stylistic consequences of the components and systems he proposes." - Helmut Jahn (an architect, known for designs such as the Sony Centre on the Potsdamer Platz in Berlin, Germany, the One Liberty Place in Philadelphia, Pennsylvania and the Suvarnabhumi Airport in Bangkok, Thailand).

Those statements given by successful and influential individuals provide a high level guidance and should be treated as an advice to the engineering industry, especially at the start of developing engineering process.

3.3 Process is an algorithm

In earlier times the engineering process was in its infancy and informal. Since then, technology has to become more complicated. The research, development and implementation of the technology required more engineering and non-engineering resources to be involved. Engineering process became substantial and progressively formalised.

Figure 3 shows a signalling engineering process in a project lifecycle that contains two elements: I – engineering design process and II – engineering implementation process. Note, an outcome of the engineering design process gives some directions to and in the engineering implementation process. Processes related to the design updates in the engineering implementation process have been omitted for clarity.

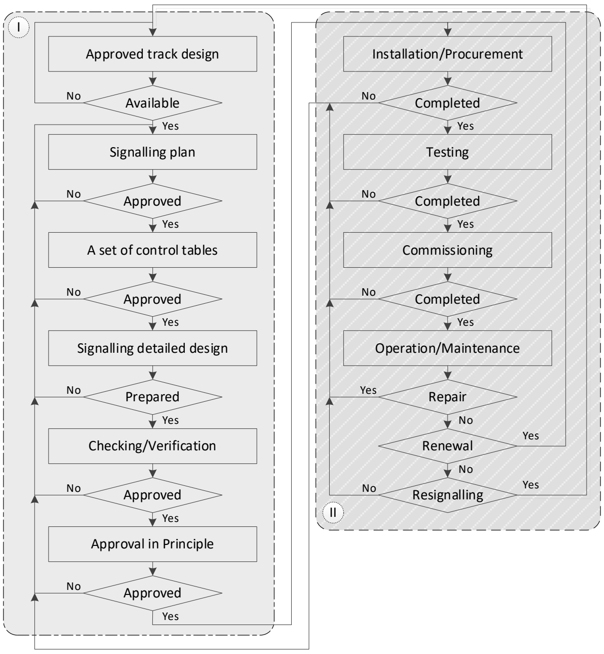

Figure 3 – A signalling engineering process of a project lifecycle

Engineering process is simply a methodical number of engineering steps to design, redesign or implement new product(s)/system. Very often it is an algorithm, i.e. a process or set of rules to be followed in calculations or other problem-solving operations that is strictly managed by engineering and project management.

Each product/system is different. Implementation of the product/system may be different too. Therefore, it is crucial to design and apply suitable engineering process to make the product design and implementation successful.

In signalling industry, each rail infrastructure manager has it's own processes of implementing a signalling system. Also, system suppliers have their own processes to engineer an implementation of the system. As part of engineering process, a number of documents are produced to support manufacturing, installation, test & commissioning as well as future operation and maintenance. With advent of Office of the National Rail Safety Regulator (ONRSR) in Australia, engineering processes are being enhanced by some adoption of system engineering practices (Office of the Deputy Assistant Secretary of Defense for Systems Engineering, 2017). System engineering practice looks into system requirements management and it's often called system safety assurance. That adoption provides additional sets of rules that require more documents to be used and produced to extract and manage system requirements defining the safety needs of future system implementation.

3.4 Sub-process

The step "Signalling detailed design" on Figure 3 includes a number of processes to complete a signalling system design, e.g. main cables design, power supply design or interlocking data design. They create sub-processes of "Signalling detailed design". In section 1.2 of (Jacek Mocki, Shane Curtin, Yulan Liu, 2017), interlocking data engineering process is discussed in greater details.

Steps in a sub-process are progressed sequentially while sub-processes can be processed in parallel with some delays due to dependancies between sub-processes. For example, until power calculations in power supply design are completed, the main cable sizes may be unknown, so the main cables design sub-process sequence will be held at this point until power calculations from power supply design sub-process are available.

3.5 Processing time and negative feedback

Processing time is effectively the time required during which all steps of the main process (algorithm) and dependant processes (sub-processes), necessary to complete a full cycle of the algorithm, are processed. The processing time depends on:

- the number of steps
- time of transition between steps
- the task complexity
- inputs availability
- resources
- inputs changes.

The number of steps seems to be self-explanatory, however, it is worth to mention that due to multiple transitions between steps, the algorithms may be entering negative feedback, i.e. the return of part of an output signal to the input, which is out of phase with it, so that amplifier gain is reduced and the output is improved (William Collins Sons & Co. Ltd., 2019). For example: a design has been already released to installation. A standard that has influence on that design, is updated. The designer needs to review the updated standard and the influence on the design. There is a potential that a new design will be released to installation teams while installation continues to be delivered to the old version of the design. As a result of the negative feedback, the output is improved, however, implications in the process can be quite substantial. Not only the algorithm will transit through the same step few times but also the time of managing the change in each of the affected steps increases.

Time of transition is a critical element of processing time, especially for documents. Practically, the documents are not changed in transition. Transition can be compared with a post office service where a box is being sent from a sender to a recipient for a fee. In the algorithm, a document is being sent from one step of the algorithm to the other through various recipients. The fee is replaced by a conditional step, for example: the signalling detailed design on Figure 3, can only be sent to checking/verification when it is prepared. Time of this transition has no influence on the design content and shall be minimal to allow checking/verification to begin efficiently.

In an algorithm step, there is a task undertaken. For example the task could be: Testing (a second step of engineering implementation process algorithm on Figure 3). Complexity of the task can be quite substantial. Testing, especially principle interlocking data testing, could be very time consuming. Algorithm processing time will heavily depend on the task complexity.

Another aspect of processing time concerns the availability of inputs. An input can be a document (e.g. standard, scope of work, requirements, specification, concept design, etc.), it could be a task completed (e.g. a fitted-out signalling hut that is ready for bell testing) or/and it could be mobilisation of resources (e.g. design team to undertake a detailed design of main cables). Availability of the inputs can significantly slow down or improve the processing time.

So far, the number of steps, time of transition between steps, the task complexity, and input availability have been described. Resources can decrease the processing time for all those, however, they can significantly improve the time as well:

- if a task is processed quickly and the outcome of the steps is satisfactory to transit between steps without any necessity to remain in a step to satisfy safety and quality
- if a transition is a bottleneck in a process, a dedicated resource to manage the transition can focus on decreasing the transition time
- if adequately qualified and experienced resources are employed throughout the process and sub-processes to decompose the task complexity and deliver safe and good quality outcome
- if input availability is a bottleneck in a process, a dedicated resource to manage inputs can support their availability. In some cases an input may not exist, and the appointment of a highly qualified and experienced resource may significantly reduce input preparation to ensure the input is available.

Sometimes, due to an undividable task, it is impossible to decrease processing time by employing more resources. In this case, the task must be identified up front as it requires special attention to the management of the resources.

One of the unpleasant surprises in engineering process is negative feedback described above. The negative feedback due to a change of inputs to which the subsequent work has been undertaken or/and completed is a source of significant delays as the change must be assessed, corrective actions have to be undertaken, additional budget may need to be established, resources may need to be re-employed, additional equipment may be needed, etc. There is no golden bullet to reduce negative feedback, however, there are strategies to limit negative feedback through employing professional, educated and experienced resources, ensuring transparency of process and clearly defining the investment process and tasks within the process, sub-processes and steps.

3.6 Railway is not just signalling

Railways are a network of tracks (infrastructure) with trains (rolling stock), organisation, and personnel required for its working. Often, rail professionals refer to railway elements as disciplines. We continue following the nomenclature. Therefore, signalling is a railway discipline that interfaces with other disciplines like: track, telecommunication, civil/structures, stations, overhead line electrification, power supply and rolling stock. Those disciplines deliver a physical outcome (i.e. a construction that is visible) and are referred to as functional. Through the time, other, non-physical, disciplines have been created to support railway and railway operations, e.g. environmental discipline that interfaces or have an impact on structures or track alignment. They are also known as non-functional. One of the most important non-functional disciplines is an investment that drives processes of functional and non-functional disciplines. Some of those are not engineering disciplines, however, they follow some kind of processes that engineering processes or investment process trigger or require an input from.

An example of processes in an investment process are reflected on Figure 4. The signalling engineering process (shown in greater details on Figure 3) is connected with telecommunication engineering process, power supply engineering process and overhead line electrification engineering process. It heavily relies on track engineering process that requires input from environmental process. Apart from overhead line electrification engineering process, the signalling process also gives input to telecommunication engineering process and power supply engineering process. There are other processes that signalling gives input into or receives output from, however, the intention is to consistently demonstrate process mechanisms, rather than defining exact relationships in each individual process.

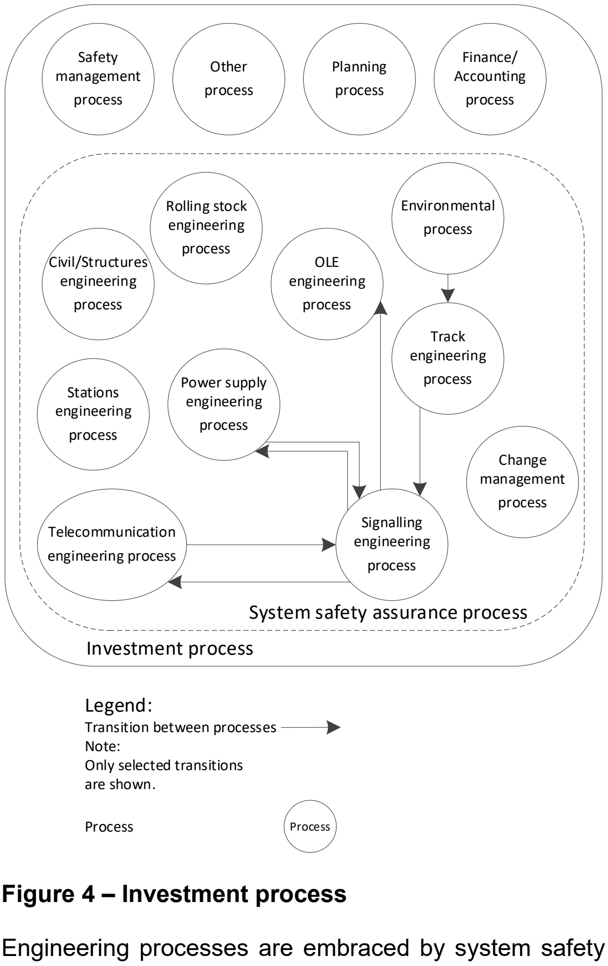

Figure 4 – Investment process

Engineering processes are embraced by system safety assurance process. All the processes are closed by and depend on the investment process.

Having said that, all disciplines and processes require inputs (standards, guidelines, procedures) and generate outputs (reports, plans, requirement documents, drawings, manuals, instructions, certificates and procedures). Taking into consideration the complication and size of a rail project, the number of documents involved in an investment process can be counted in their thousands.

So far, engineering, non-engineering and investment processes have been mentioned. In this paper, those processes are treated as being very generic with simplified steps wherever possible, so that processing mechanisms can be shown and discussed.

4 DIGITAL REVOLUTION

At the beginning, computers like ZX Spectrum, COMMODORE or ATARI were used to play games or learn basic programming codes and languages. In the background, while business headed the personal computer (PC) or Apple way, which was available at $10,000 in 1983 (Knight, 2014), the personal use of those machines was still too expensive for the general public. In late 80's computers became more accessible to everyone.

Microsoft first shipped Windows 1.0 in 1985, and this DOS shell was content to run even on old 4.77 MHz PCs, albeit slowly. That was also the year Aldus invented the fourth major productivity software category – after word processing, spreadsheets, and databases – by releasing PageMaker. Desktop publishing was born, and Apple found a strong niche market for the Macintosh and LaserWriter (Knight, 2014).

At that time, the most critical aspects in a wider application of the personal computer were the processing time and the functionality of programs (software) installed on PCs. Later, with the development of microprocessors and other electronic components of PCs, the initial obstacles became obsolescent.

The computer has changed the practice of engineering forever. In the simplest terms it has taken the drudgery out of the design process (Weisberg, 2008).

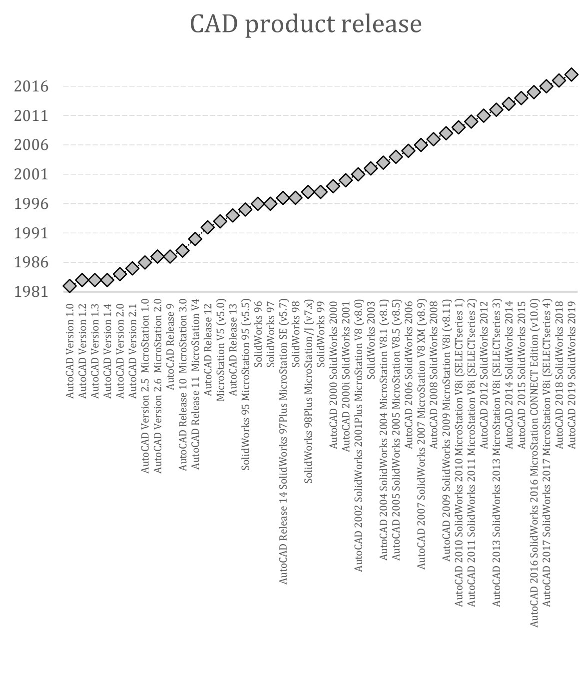

Figure 5 – CAD product history

As an example, the computer aided design (CAD) software developed for over 30 years (Figure 5) revolutionised engineering to the extent that not only are the drawings prepared on computers but also engineering processes are being conducted in three dimensions (3D). Some of the designs are even automatically generated by specific computer packages developed by means of programming languages available within CAD packages.

According to (Meyer, 2017), there are five filters of digital revolution:

- ethical – that discusses ethical limits of new technologies
- social – that is a social resistance against technological change
- corporate governance – that reflects corporate decision-making models to produce different end results due to the different focuses and the variety of interests in the process
- legal – moderates what is possible and what is applied in the real world
- productivity – that discusses the viability of new technological applications to increase productivity.

The fact is digital revolution is happening, slowly in some areas of engineering, faster in others. Australian railway engineering has also entered the digital revolution and is progressing with a processing time influenced by the five filters mentioned above.

The productivity filter of developing or implementing new technology in rail engineering looks back to the days of manual engineering. The best innovators, entrepreneurs and implementers are often those who have in depth experience and understand railways.

4.1 Manual engineering

Manual – means operated by hand, rather than by electricity or a motor (William Collins Sons & Co. Ltd., 2019). Manual engineering – engineering conducted by hand.

Figure 6 – Work before CAD (L.Rokas, 2019)

Following the CAD example given, before 1982 engineers were preparing documents manually. Drawings were developed in design offices where drafting desks occupied most of the office space (Figure 6).

All calculations were conducted manually, often with the assistance of a slide-rule. Reports, instructions, manuals and books were prepared using a typewriter. Techniques reflected on Figure 1 were utilised when copying the documents. Version control was already heavily implemented to support engineering process.

4.2 Digital engineering

Digital – performed using electronic devices such as computers and mobile phones (William Collins Sons & Co. Ltd., 2019).

Digital engineering – may be defined as the convergence of emerging technologies such as Building Information Modelling (BIM), Geographic Information Systems (GIS) and related systems to derive better business, project and asset management outcomes. Digital Engineering enables a collaborative way of working using digital processes to enable more productive methods of planning, designing, constructing, operating and maintaining assets through their life-cycle (Australian Government - Department of Infrastructure and Regional Development, 2016).

Today, drawing boards are no longer used by engineers. The CAD industry is a multi-billion dollar business with literally millions of engineers, architects, and drafters using these computer systems on a daily basis (Weisberg, 2008). It plays a major role in 2D, 3D modelling and design, BIM and an integrated digital engineering.

The digital engineering main goals, written in National Digital Engineering Policy Principles (Australian Government - Department of Infrastructure and Regional Development, 2016), are as follows:

- to provide a framework that promotes a greater uptake of digital engineering by the building and infrastructure sectors nationally and to encourage innovation and efficiencies in their delivery and management of public infrastructure
- to promote consistency and openness in the data requirements for major public building and infrastructure assets to facilitate a more harmonised approach to industry in the application of digital engineering
- to increase capacity and capability across both the public and private sectors to optimise the benefits of digital engineering in building and infrastructure development, delivery and management.

Digital engineering produces even more documentation than manual engineering. As it can be imagined, version control and release control of documentation have major impacts on negative feedback in engineering process. The aim of digital engineering is to reduce paper print, therefore, terms like: paperless engineering process is being introduced. Documentation version control in a paperless engineering process is even more important to assure correct version of the document is implemented.

4.3 Integration

Integration has a number of definitions. To understand the word, we use the most practical definition:

Integration – the act of combining or adding parts to make a unified whole (William Collins Sons & Co. Ltd., 2019).

The word integration can be applied into many contexts. For example:

- assurance – when preparing a project requirement (An integrated CAD environment shall be delivered for CAD operator working on signalling plan)
- psychological – when developing a team (an integration event will break the ice to unify the unitised the team)
- engineering – when developing an engineering process (the investment process includes all the rail disciplines so that a framework for integration is set).

4.4 Integrated digital engineering

As part of the National Digital Engineering Policy Principles (Australian Government - Department of Infrastructure and Regional Development, 2016), there are seven major principles set out for digital engineering. Four of the principles are particularly relevant to integrated digital engineering. They are as follows:

- a more consistent application of digital engineering in public infrastructure
- digital engineering data formats, standards, protocols, systems and tools should be open and harmonised, where possible
- digital engineering data formats, standards, protocols, systems and tools should be harmonised across whole of asset life-cycle management processes, where possible, to ensure data built up through the design and construction phases of a project is fully utilised in the asset management and operations phases
- digital engineering approaches complement existing project design and development systems and interface with Geographic Information Systems (GIS) to graphically display and visualise relevant information captured as part of the Digital Engineering process.

To explain the integrated digital engineering in a practical way, the Bew and Richards BIM maturity levels model is presented on Figure 7. It shows levels of BIM and the development directions toward integrated BIM (iBIM).

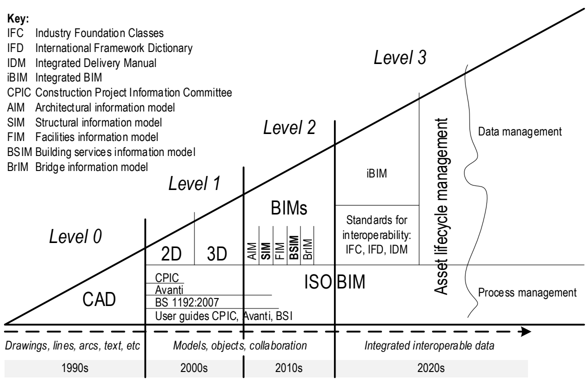

Figure 7 – The Bew and Richards BIM maturity levels model (Bew-Richards, 2008)

The levels of BIM are explained in (Mordue, 2019). According to (Mordue, 2019), Level 2 of BIM (known as collaborative BIM) is mandated in the UK. Federated model information is shared within a Common Data Environment. More about BIM Level 2 can be found on the website https://bim-level2.org/en/.

BIM and GIS are being adopted in rail civil and structural applications, however, rail systems are still left behind between Level 0 and Level 1 of the Bew and Richards BIM maturity levels model. Some of the digital system designs are still prepared at Level 0, where a CAD operator is using drawings, lines, arcs and text to manually build schematics showing rail systems. Others have progressed to Level 1, where basic components are modelled and information about those components is kept in a database. The modelled components are like building blocks from which the system design can be built without major considerations for each of the individual components that had already been designed.

Even when moving forward to a new generation of engineers, the challenge will remain to organise, process and combine all rail disciplines within an integrated digital engineering structure, so that the outcome of the investment process is integrated for the entire life-cycle of the investment.

Many strategies need to be developed and applied for each infrastructure investment to define and achieve an integrated digital engineering outcome that is social, ethical, accords with corporate governance, is legal, and productive.

5 DOCUMENT REVISION IDENTIFICATION

The process of naming and distinguishing between the series of draft rail documents in an engineering process may be disintegrated. It means rail disciplines may have their own way to name and control the documents. Some names could follow a coded nomenclature specific to a discipline, others may be named by the Document Originator with some phrases that are meaningful for the team that takes part in the sub-process of this document production.

5.1 Disintegration

This disintegration has significant impact on processing time in engineering process:

- A Document User works to an approved version of the design that may not be in its latest revision. This situation can cause a delayed negative feedback in the engineering process. Consequences of such scenario may be expensive and sometimes difficult to rectify.
- A Document User works to the latest version of approved design. The design office may prepare another version of the design that is under approval. The Document User (could be an installer or tester of the design) wouldn't know that the later version of design is coming.

Negative feedback in engineering process could be prevented if installation teams knew the exact status of their design, such as when a drawing is being updated. This ability to know its status would result in the installation teams putting that component of work on hold until the update is complete.

5.2 Numbering rail documents

In terms of numbering rail documents, Arabic digits, Roman numerals or letters are applied, however, a variety of conventions (dependent on the rail disciplines) are used in numbering, for example: Version 1 Issue 1; Revision 2.1; v1.2; Revision A Issue 2; etc.

There is usually a lack of consistency in version control of the older revision and latest revision of documents. One of the examples identified was: an old version of a drawing was numbered – version 1 001, while the new version of the same drawing was numbered – issue 2.

5.3 Integration

There are some examples on how rail documents can be integrated:

- power supply design will be different to signalling design as it shows a different level of details, however, they can be integrated by a drawing border with the same version control convention
- some of the civil drawings are produced in AutoCAD while others are produced in MicroStation or SolidWorks. All files would have different electronic file extensions. Apart from using the same standard of drawing border, the integration can happen at the level of electronic print (portable document format – pdf) from the source file. One of the technique is to use metadata – information that is held as a description of stored data (William Collins Sons & Co. Ltd., 2019) to include information about the source file, its revision, authors, etc.
- documents from all rail disciplines printed to pdf format can be revision controlled. To integrate the documents around the users, a quick response (QR) code technique can be implemented. QR code is manually or automatically inserted into the pdf-ed documents in the place defined as safe (an empty space in a document, so that the QR code insert will not hide any document content). When distributed, the user scans the QR code visible in the document to identify its latest revision
- input documents in engineering process have different origins. Usually, the design is being produced by new generation designers to the input documents. Due to lack of resources, senior engineers that may know the documents' origin as well as check the latest version may not be available to guide the new generation. The QR code technique to check latest revision of input documentation would be an advantage to limit negative feedback and processing time in the engineering process.

The QR code technique (i.e. document revision identification) is successfully used to limit negative feedback in a investment processes and its sub-processes. It is an example of ethical, social, legal and productive application of digital revolution that can be in line with corporate governance.

6 HUMAN ERRORS

Documents and document applications are heavily exposed to human errors.

Reducing human error involves far more than taking disciplinary action against an individual. There are a range of measures which are more effective controls including the design of the equipment, job, procedures and training (Disaster Management Institute, 2019)

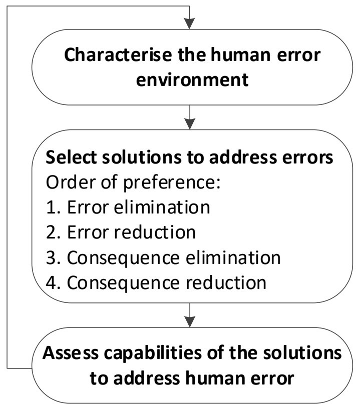

Figure 8 – Strategies for reducing human error (Disaster Management Institute, 2019)

(Disaster Management Institute, 2019) provides some comprehensive guideline on Strategies for reducing human error. We refer to Addressing human error in the design process (Disaster Management Institute, 2019) to show and apply the strategies relevant to eliminate or/and reduce errors or/and consequences in application of documents in engineering process.

- Characterise the human error environment

  Environment: All steps and transitions in investment process (i.e. engineering process, system safety assurance process and non-functional discipline process with all sub-processes and procedures)

  Human error: Working on outdated documentation

- Select solutions to address errors

  (a) No human involved in the investment process
  (b) Application of additional resources to control version of documents released to resources employed in the investment process before releasing the documents
  (c) Automate document production if possible
  (d) Provide adequate training to humans in the investment process
  (e) Automating document release procedure
  (f) Apply tool to send a document out of date message to humans who are using the document in the investment process
  (g) Develop a procedure of checking version of document with an originator
  (h) Apply a revision checking tool (such as document revision identification) to allow humans in the investment process checking versions of documents they are using
  (i) Develop a procedure of using the revision checking tool

(j) Others

- Assess capabilities of the solutions to address human error

Rail investment is unique due to geographical, financial, engineering, technological and other characteristics and no examples of identical rail investment have been identified. Having said that, capability assessments of a solution must take those specifics and differences in an investment process into consideration each time. The risks related to human errors in documents and document applications are repeatable in an investment process.

7 MANDATORY CONTROL MEASURE

We propose document revision identification to be available to the end Document User, so that the end user can identify if the document being applied is in its latest revision.

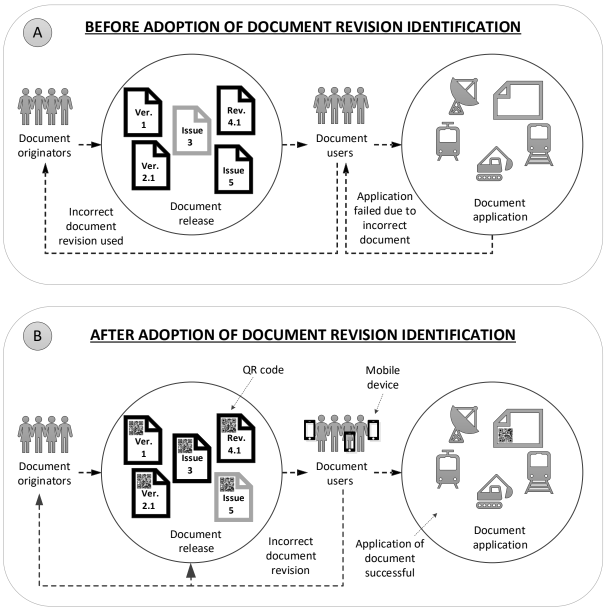

Figure 9 – Comparison of engineering implementation process before and after an adoption of the document revision identification

An example of a documentation flow in an engineering implementation process has been presented on Figure 9 (A – before an implementation of the document revision identification, B – after the implementation of the document revision identification).

Let's explain the Figure 9. The Document Originators produced a number of documents. Some (five) documents were approved and released. The document version control's naming convention in those documents differs from each other (i.e. Ver. 1, Ver. 2.1, Issue 3, Rev. 4.1 and Issue 5). The first two documents (Ver. 1 and Ver. 2.1) were produced in an engineering process where version control was identified in the convention: "Ver. version number". Third document was created in a modified engineering process where the convention changed to the following pattern: "Issue issue number". The same scenario of engineering process modification applied to the fourth document ("Rev. revision number"). Later on, the version control in the engineering process returned to the pattern used in the third document and the Document Originators released Issue 5.

The challenge exists for the current and new generation of Document Users working in an integrated digital engineering environment to identify which revision is the latest one and to keep up with the document changes so that the latest revision is always used.

Figure 9 A shows an example where Document Users applied document in Issue 3 to design, to procure and to construct a rail system. Later on during testing, it was discovered the document – Issue 3 wasn't in its latest revision when applied to construction. As a result, two negative feedbacks were sent in the engineering process: "Application failed due to incorrect document" (sent to Document Users) and "Incorrect document revision used" (sent from Document Users to Document Originators). The scenario dictated a significant rework that cost the project millions of dollars.

The engineering implementation process flow on Figure 9 B is enhanced by the adoption of a document revision identification method.

In example B, Quick Respond (QR) codes (Wikimedia Foundation, Inc., 2019) have been added by Document Originators to each of the five documents. The QR codes had been generated by a revision identification administration tool. Those codes are unique, contain unique serial numbers and link to revision identification information.

The administration tool simply keeps a record of the document name, originator, revision release, the document versions needed to produce the QR codes.

Document Users can now access information from the QR codes in two ways:

- by scanning the code on a mobile device
- by inserting a unique serial number of the QR code into a website.

As of June 2018, 55.1% of the World population has access to and uses the internet. In Australia, the rate is higher – 68.9% (Miniwatts Marketing Group., 2019). The increase of the internet popularity and availability of mobile devices made the QR code technology accessible to the general public.

The concept of document revision identification is that Document Users take a released document and use a mobile device to scan the QR code. With a speed of the internet, a form will display on the mobile device to inform the user if the document in question is the latest one to be used in further steps of the engineering process.

This step significantly reduces the risk of negative feedback coming from the Document application. There still may be some potential for a negative feedback coming from the Document Users. This situation may happen if the Document Originator has an intention to stop engineering process due to eliminate a serious document error in the released documentation.

The document revision identification administration should lie with the responsibility of Document Originator or document controller to make the management component of document revision identification efficient.

Document revision identification management can be automated if the document metadata accurately reflects the content of the document, its name, author, publishing date and version control.

In the new generation integrated digital engineering, each document in the engineering process should be equipped with the document revision identification capability.

8 CONCLUSION

The following concluding remarks can be drawn from this paper:

In the era of digital revolution, it's a human responsibility to deliver ethical, social, legal and productive technology application in an integrated environment. Digital engineering has a bright future in this integration.

- Ethical, social, legal and productivity filters are critical to successful application of digital revolution products.
- Integrate the corporate governance filter to not be an obstacle.

There will be more and more technology accessible as a result of the digital revolution. New generation of engineers will have no time to understanding the physic's basics of each piece of rail technology. They will start taking existing rail devices and systems as granted components of the next generation technology.

- Make the technology simple and accessible.
- Ensure new generation has the right tools in the engineering, non-engineering and investment processes.

Processing time can be significantly reduced by proper algorithm organisation and a limitation of negative feedback in the engineering process.

- Plan processes and sub-processes so that the number of steps, time of transition between steps, the task complexity, inputs availability, resources and inputs changes are optimised and efficient.
- Limit negative feedback by implementing optimisation and efficiency and apply new generation digital revolution technologies.

Human errors in application of documents have negative consequences that may prevent further integration in a process.

- Apply strategies for reducing human errors.
- Eliminate and reduce errors and consequences.

Application of techniques to reduce negative feedback in investment, non-engineering, engineering processes and their sub-processes significantly reduces their processing times.

- "Don't spend time pontificating about high-concept things; spend your time solving engineering and manufacturing problems."
- Use document revision identification to limit and avoid negative feedback.

Metadata is an integral part of electronic document. It's application supports integrated digital engineering.

- Always fill up metadata to provide file name, document name, author name, version control and publication date.

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Jacek is a qualified, chartered, transport engineer, highly experienced as demonstrated through his career spanning:

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Between 2000 and 2005, Jacek was heavily involved in some key European Union projects in the UK and in Poland.

First time, he worked on Australian railway infrastructure in Victoria in 2004, taking part in a review of the Metropolitan Melbourne Railway Infrastructure. Since then he was involved in a number of projects in Australia.

Currently, he works for MOTZKY Pty Ltd addressing the customer's needs in three major categories: innovation, optimisation and efficiency. At MOTZKY, Jacek developed an innovative delivery and project control/reporting methodologies that are successfully utilised in customers' and MOTZKY's projects to achieve predictable outcome. He is actively promoting innovative, locally produced, operated and maintained technology in Australia as well as overseas.