Using an MBSE approach for automation control system selection in long steel products hot rolling plants

Ernest Mukuwari
ArcelorMittal South Africa
ernest.mukuwari@arcelormittal.com

Barend Botha
University of Johannesburg, Faculty of Engineering and the Built Environment,
School of Mechanical Engineering
bwbotha@uj.ac.za

Abstract: Automation systems in long steel products hot rolling plants are prone to performance failures with the potential of serious negative impact on the business. The selection process of these automation systems therefore requires careful consideration of various selection factors to maximize plant performance. The need was therefore identified to investigate the use of a suitable management approach to guide engineering automation teams in the long steel products hot rolling plants in the selection of automation systems. At the core is the need for an in-depth understanding of the issues surrounding distributed and hierarchical automation systems in long steel products plants. This includes identifying the challenges during the selection process, using sound engineering management principles. Current automation selection techniques were investigated through a survey, interviews and a case study. It was then decided to use a Model Based Systems Engineering (MBSE) approach, which utilises systems engineering principles together with digital technology to create models to simplify the understanding of complex problems and relationships. This was then used to develop a management framework for automation systems selection in support of the business case of long steel products hot rolling plants.

Keywords- Automation; Distributed and Hierarchical control systems; Systems engineering; Model Based Systems Engineering, Requirements analysis; Functional analysis and allocation; Synthesis; Systems analysis and control; Steel rolling plant

Introduction

Model Based Systems Engineering or MBSE integrates traditional systems engineering principles with digital technology to simplify understanding of complex problems, improve communication between stakeholders, improve decision making and reduce the time to reach a solution. It applies systems thinking in considering the problem to be part of a higher level problem and developing operational, system, and component models as required. It includes flow diagrams, architectures, mathematical models or any other models deemed necessary to ensure clarity of the problem and suitable solution. Simple mind mapping is a useful tool to start understanding the intricacies of a problem [1] by structuring the early thought process.

Long steel products hot rolling production plants are batch operations, occupying large geographical landscapes [2], [3], [4]. The various production systems involve the interaction of many elements as modelled in Figure 1.

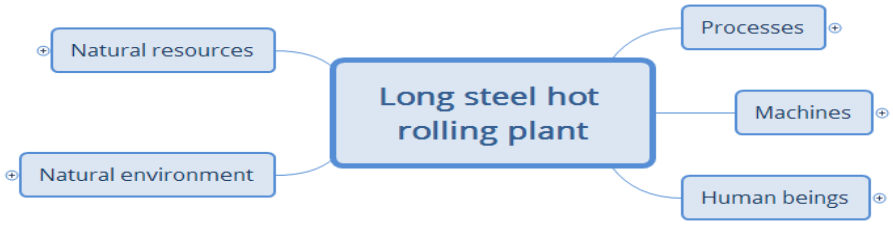

Figure 1: *Rolling plant interacting elements model*

Automation systems in the steel industry are strategically adopted to improve operational efficiency, enhance safety management, improve production planning and scheduling, and reduce manufacturing costs. Each production process, however, has its own distinct behavioural characteristics [3] requiring different automation solutions. Figure 2 shows the main process elements associated with a typical long steel products hot rolling plant.

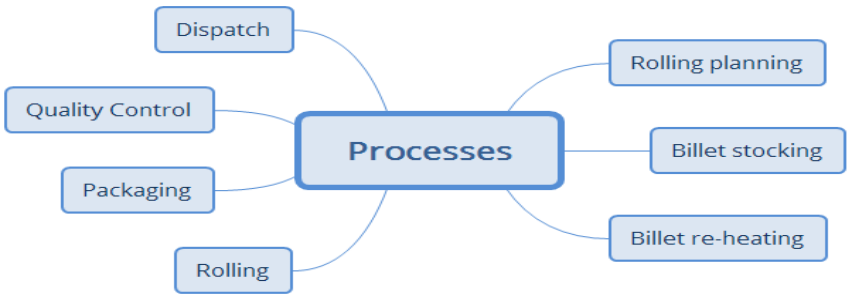

Figure 2: *Process elements.*

The different production processes need to interact with each other to meet the overall business objectives. In order to address these interacting elements, the requirements are categorised into functional and non-functional requirements [5], [6], [7]. It is the expectation of the customer that the selected system meets all the customer requirements. Unfortunately, requirements are often conflicting and as a result trade-off studies are required to balance the automation system [8].

Long steel products manufacturing processes occupy wide landscapes, with automation systems segmented into automation layers serving unique functions [2],[9],[10]. The International Society of Automation (ISA) hierarchical systems architecture as per ISA 95 [11] standard demands that the automation sub-systems integrate seamlessly with upper and lower sub-systems for satisfactory performance. However, understanding the ISA automation models is not sufficient. The requirements for automation systems selections are not only technical but much broader to include other business challenges. Figure 3 indicates the business models that also require careful consideration.

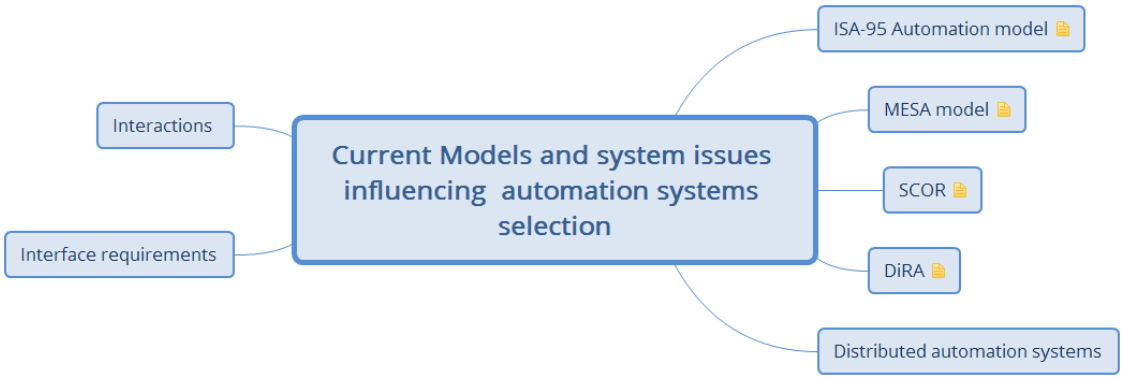

Figure 3: *Models influencing automation systems selection*

The ISA 95 model looks at plant to enterprise information systems. MESA (Manufacturing Enterprise Solutions Association) model looks at plant to enterprise processes. Meanwhile, SCOR (Supply Chain Operations Reference) model looks at the supply chain processes and the DiRA (Reference Architecture for Discrete Manufacturing Industries) architecture looks at systems capabilities of channelling data to empower business processes. Each model looks at the business with a different lens subject to what is being analysed. Complexity and lack of clarity on how to extract the systems requirements become evils of the systems selection process. An engineering management process that deals with complexities of systems engineering will aid in understanding the business systems requirements and interdisciplinary communication challenges.

The spatial process distribution and hierarchical architecture of automation systems tend to influence the automation systems design decisions. However, the driving factors for design decisions should be based on the customer requirements and environmental constraints. Robust automation systems have large operational locus of control and safety margins. By virtue of occupying large landscapes, related automation systems are expensive to acquire [12]. Consequently, failures of automated production systems due to poor design decisions cause huge business losses that are unacceptable [13],[14]. These impacts need to be understood during the selection process through proper system modelling techniques that takes advantage of the technology advancements and existing models as indicated in Figure 3.

Current technological developments have seen an explosion of intelligent electronic devices, implementation of customer requirements in software [4],[15],[16] and networked systems [17],[18],[19]. The newly developed software tends to change the customer perception of what

is possible leading to new requirements [20] during systems development. These new developments bring forth other management issues such as system security [21],[22], engineering training and development shortfalls [17], and change management. The increasing number of interfaces and interactions between processes, automation systems, multi-disciplinary engineering teams, intelligent electronic devices, customer requirements and distributed functions increases risks [23],[24].

To mitigate these risks and achieve the business requirements, an engineering management process that identifies all these vulnerabilities and requirements was required. In [4],[16],[20], [25] one such process is that of decomposing the customer requirements and allocating them to the relevant engineering disciplines. The identified solutions are then synthesised into a wholesome system solution. The MBSE framework developed serves as a guide to automation engineers during the selection process by providing logical steps that can easily be verified and validated.

Documentation of design decisions

Throughout the automation system selection process, historical and current documentation need to be reviewed and created. According to Müller and Hunter [26], formalisation of the documentation process aids decision makers in design analysis and design documentation. The design decisions are then used in future to help understand why those decisions were made and what their potential impacts on the business were.

A systems engineering approach

Automation systems engineering is a multi-disciplinary task [23] involving engineering disciplines such as mechanical, electrical, software, metallurgical and information technology [17], [23]. Multi-disciplinary engineering teams often need a common design modelling tool during the development of automation systems for better understanding. A typical modelling language is the Systems Modelling Language (SysML) which is common in MBSE environments. The idea is to simplify models such that engineering domain concerns are segregated. Each discipline is then able to understand the sub-discipline requirements and the semantics [27].

According to Ladiges et.al [12], automation systems changes impacts on electrical and mechanical equipment. As such, a formalized requirements evaluation process [14], is necessary to determine the impact of such changes on the non-functional requirements of a production facility before implementation. Designers and developers need to understand where the requirements are coming from. Not only is the traceability of decisions important [40], but formalized systems also make compliance to requests for changes easier.

System requirements are hierarchical according to Ladiges et.al [12]. However, the idea is not to decompose the system architecture to get the sub-system requirements, but to decompose the system requirements, Sparrius [20] argues. Formal engineering workflows assist with the decomposition of functional requirements and separation of functional requirements from non-

functional requirements. At the same time, hardware and software issues are separated [8]. In Figure 4 a formalised engineering process that can be followed is given.

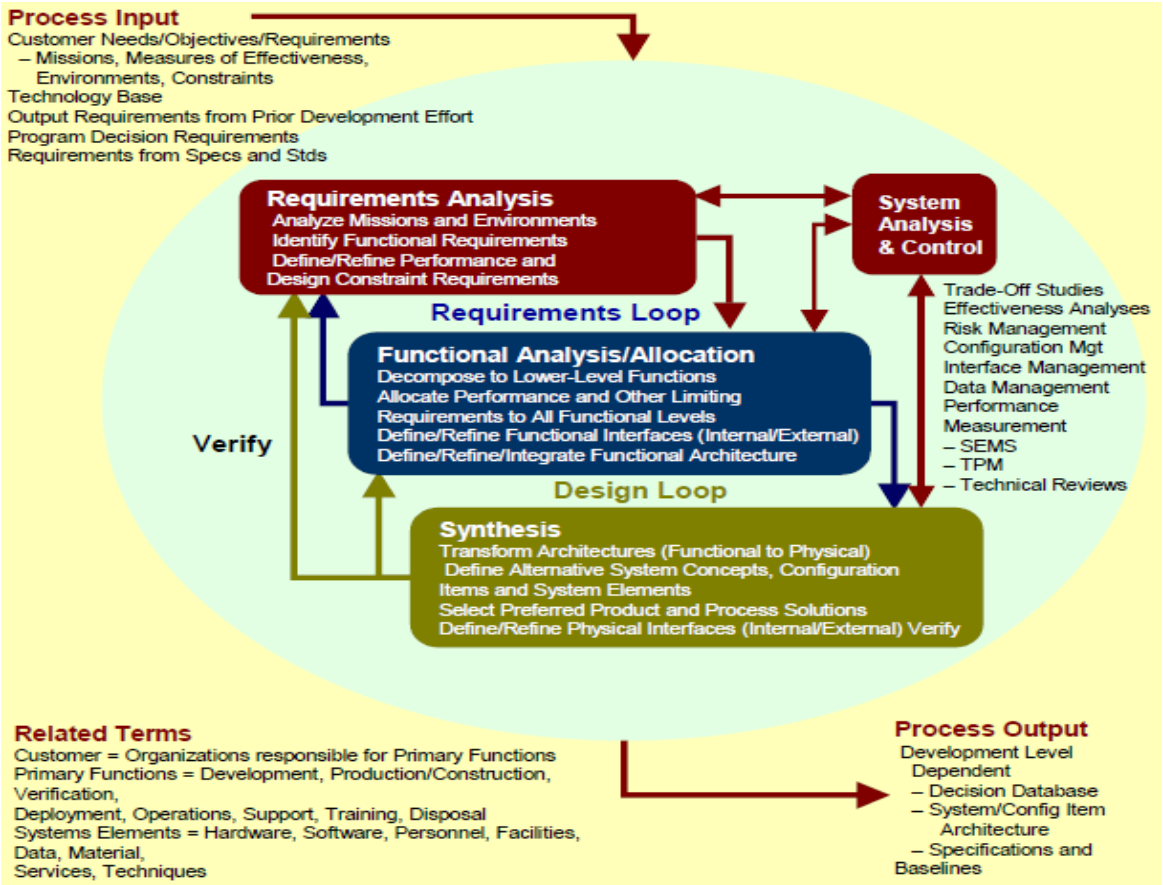

Figure 4: *System engineering method and approach* [28], [29]

Materials and Methods

The research used various data sources, analysis methods and modelling techniques to gain an in-depth understanding of the field of study as shown in Figure 5.

Figure 5: *Materials and methods used*

During the literature study relevant and current, academic and industry literature was reviewed. Figure 6 shows the fields and/or topics studied representing the major areas of interest.

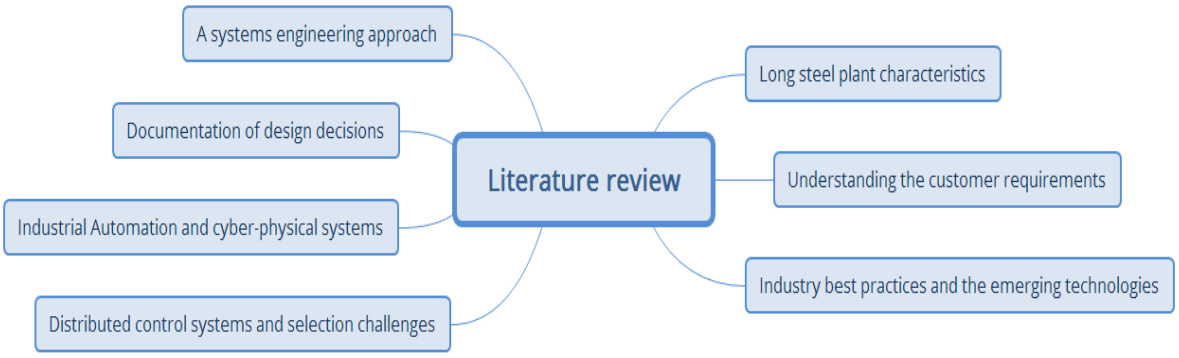

Figure 6: *Literature review*

A research questionnaire was developed and distributed to fifteen purposively selected engineers and engineering managers in a long steel products hot rolling company. Meanwhile, whilst waiting for the anonymous questionnaire responses, a draft framework was developed using ArisExpress software based on the reviewed literature.

During the analysis of the research questionnaire feedback, it became obvious that more clarity was required on some of the responses. Follow-up interviews were then arranged and conducted with two engineers and two engineering managers from the purposively selected respondents. The interviews were conducted with one interviewee at a time. During these interviews, the draft framework was presented for comments and valuable inputs were submitted by the respondents. Adjustment to the draft framework was made to accommodate the questionnaire and interview feedback.

In order to assess the validity of the preliminary selection framework in a real plant environment, the framework was applied to a case study investigation on a reheating furnace for the rolling plant. The case study outcomes and the preliminary selection framework were then compared and relevant adjustments were once again made to the selection framework. The relevant framework was then submitted to the engineering teams in the long steel products product plants for comments.

Results and discussion

Automation control systems in long steel products hot rolling plants are hierarchical and distributed. Figure 7 gives an overview of the automation levels applicable to this industry.

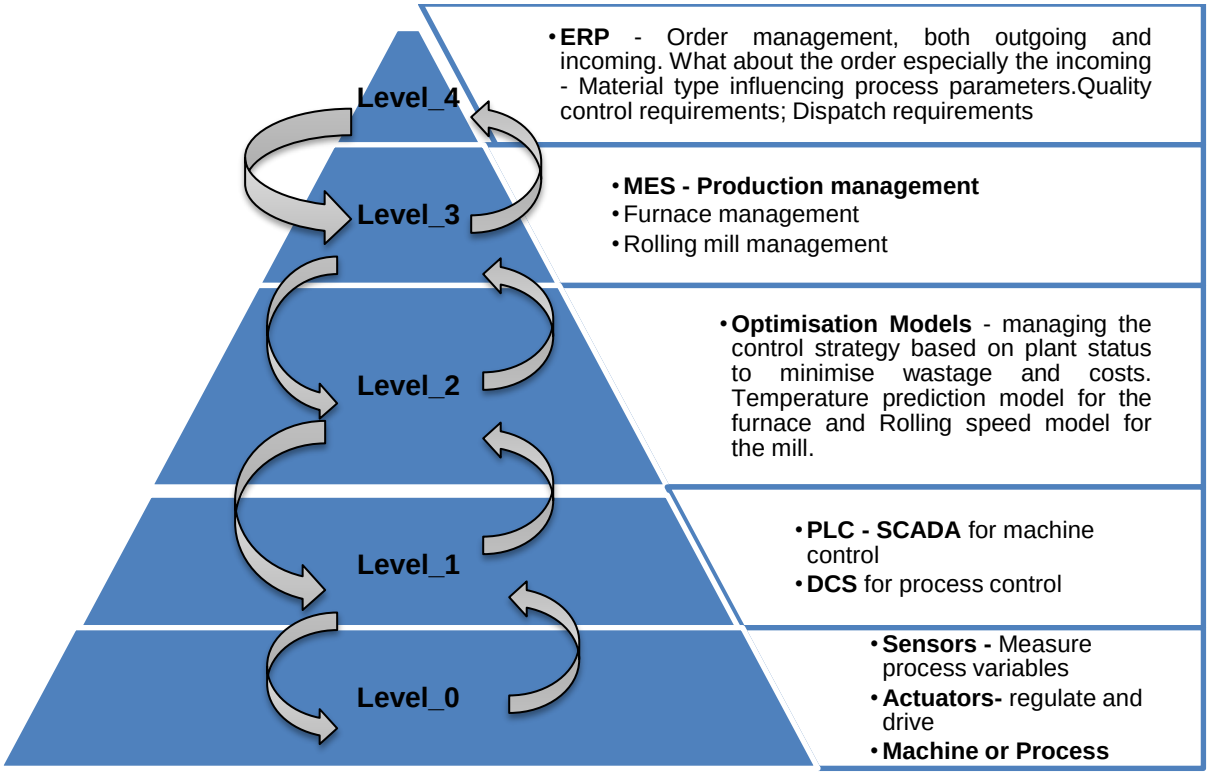

Figure 7: *Rolling plants automation model*

Identification of what constitutes an automation system during project initiation is very important for identification of interfaces and possible interactions. The survey, as shown in Figure 7, showed that only 9% view the entire automation model as given in Figure 4 as an automation system. The rest of the respondents grouped the levels into different clusters. The cause for the sharp contrast is attributable to the organisational project structure which is more of functional structures along engineering disciplines than matrix structures. This difference in opinion causes important interfaces to be missed during the selection process leading to misalignment during design and consequently poor performance when in production.

The case study identified that a number of automation projects in the case study plant were implemented due to various issues related to technology and process deficiency. However, the failure to identify important interfaces resulted in some (sub)-systems failing to satisfy the customer requirements leading to manual operation being preferred over automatic operation. The consequence of the design decisions was that huge energy losses were experienced due to human reliability issues. It is difficult for operators to handle the controls manually when process conditions change. Further investigations into the possible business impact revealed huge potential quality losses due to the interface management failures.

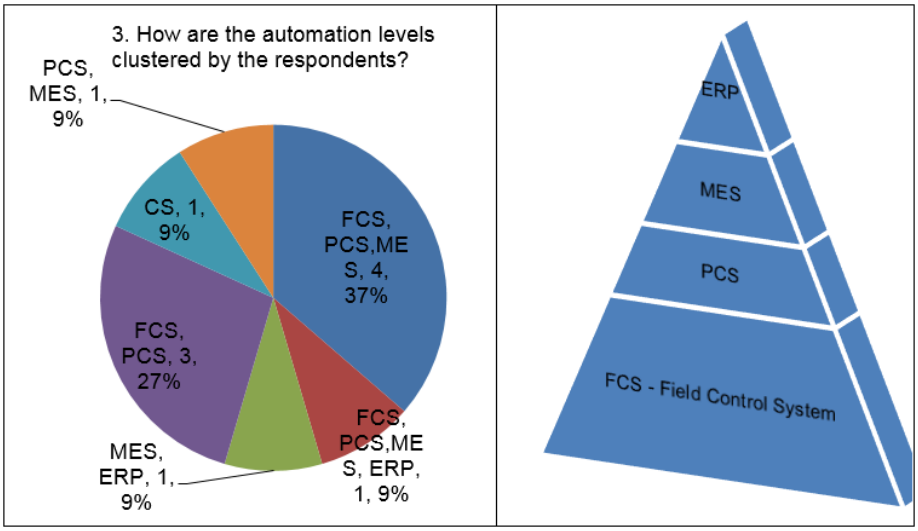

Figure 8: *What constitutes an automation system?*

The upper automation levels are predominantly Information Technology based whereas the lower levels are dominated by Electrical and Electronic Engineers who are operationally focused. A new fusion of the three disciplines is required to come up with the relevant skills set and a multi-disciplinary team capable of handling the automation requirements. In Figure 9 the migration path from the current integration status to a new desired position is given.

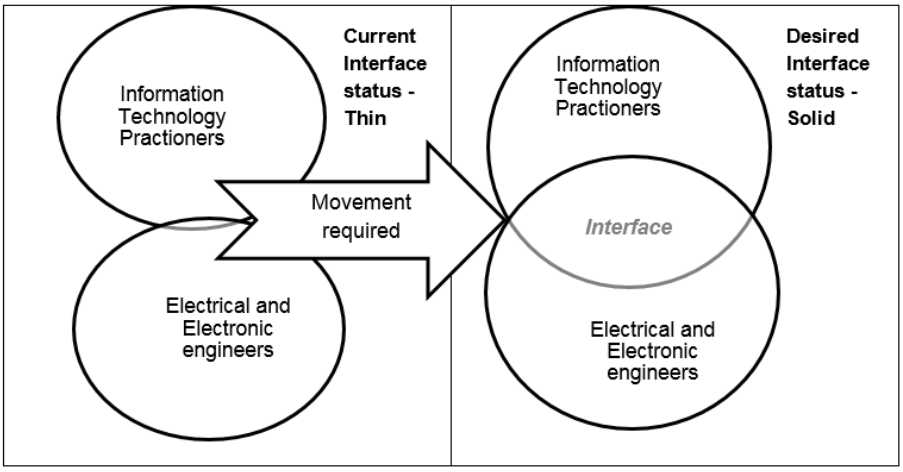

Figure 9: *Engineering technologies interface*

The distributed system architecture influences the interaction between processes. These interactions are important for the intelligent application of emerging technologies. A typical application of new technology is the use of artificial intelligence to effect automatic electronic controller process parameter changes as mechanical components fail.

Automation systems selection methodology

Integration of design engineering disciplines is very important to identify all possible operational concerns. However, to be able to identify these concerns, a structured engineering process is required. During the case study investigation, the system engineering process as given in Figure 11 was developed and applied.

The system analysis and control is the heart of all documentation systems to include templates for procedures, testing, evaluation, and management plans. This system process was found to be non-existent and it was difficult to come up with information regarding why certain decisions were taken.

The systems engineering processes of requirements analysis, functional analysis and allocation, and physical analysis and allocation were then developed into graphical selection models that automation engineers could use as guides during the automation systems selection processes.

During the case study investigation, plant personnel were encouraged to apply and access the validity of the framework to actual plant conditions. Valuable comments and suggestions were submitted. The framework was found to contribute positively to the business. To quote one engineer; “this document is the missing link to a process that needs to be followed in a few easy steps. With this framework as a guide a number of disastrous decisions could have been avoided.”

The study also indicated that automation systems selection decisions are influenced by many variables. Figure 10 gives a summary of the driving factors as identified during the study.

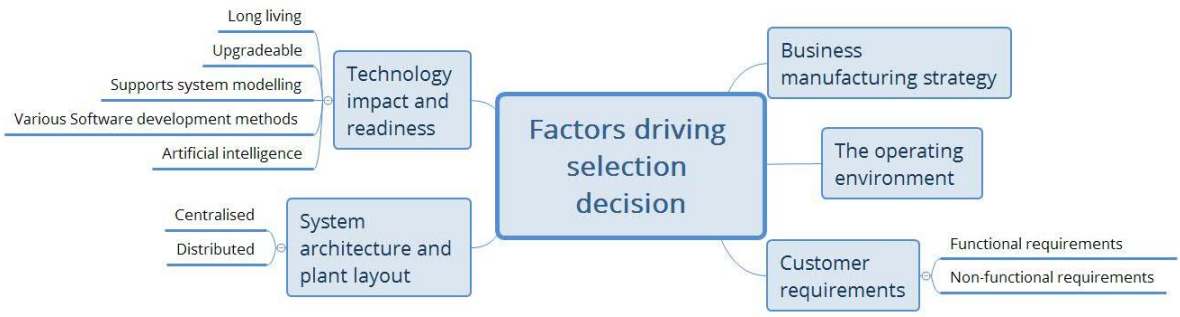

Figure 10: *Factors driving selection decision*

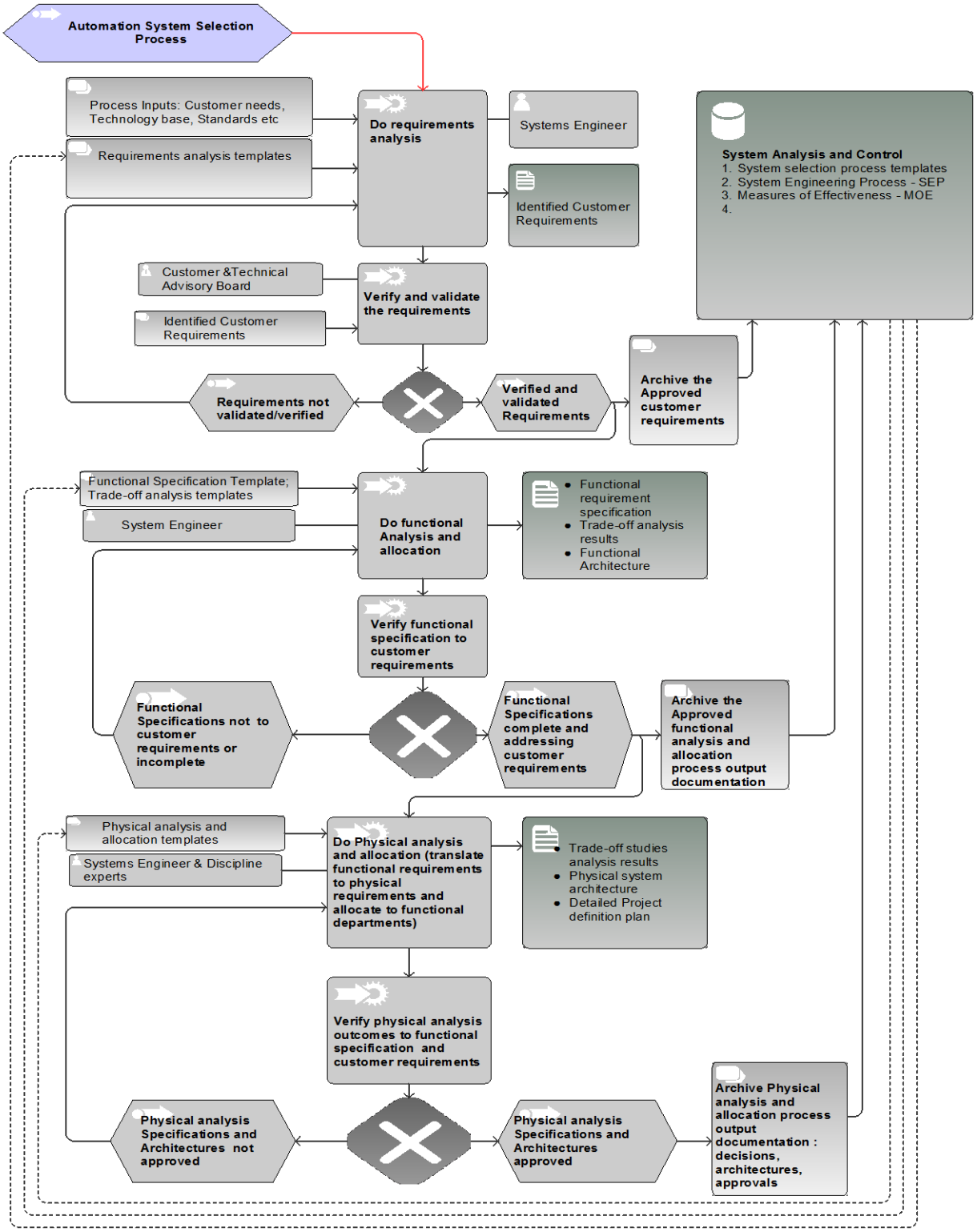

Figure 11: *Selection process framework*

Conclusion and further work

Model Based System Engineering tools were used to develop an automation system selection framework in the long steel products rolling environment. The digital technologies such as

Mind and ArisExpress were used during the development of the MBSE tools. The framework is used as a guide by automation engineers using easy to follow and validated visual steps. However, this framework should never be considered a stagnant document. It needs to be assessed continuously and adapted as the organisational culture develops and matures, and as technology evolves as new modelling techniques develop. A detailed selection framework for automation control systems in long steel products using mature systems engineering and management principles will be required. The framework will have to provide templates, guidelines, and procedures for guiding the automation engineers.

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Bibliography

Dr Botha started his engineering career as systems engineer at Denel in 1992 and registered as professional engineer with ECSA in 1994. He joined Potchefstroom University in 1995 where he lectured at both under and post graduate level till 2008. In parallel he acted as consultant to PBMR and quality manager to M-Tech Industrial. He completed his Ph.D. in Engineering in 2003 at the North-West University. In 2008 he joined PBMR full-time as Senior Systems Engineer. After the closing of PBMR in 2010 he joined the University of Pretoria lecturing in Reliability Engineering, Reliability Based Maintenance and Mechanical Design as part of the Maintenance Engineering programme. He then joined SNC-Lavalin as Design Manager until SNC-Lavalin closed their South African office due to the slump in the mining industry. He is currently a lecturer in Mechanical Engineering Sciences at UJ where he lectures in Design and provides study guidance at postgraduate level in both Mechanical Engineering and the Postgraduate School of Engineering Management. Further information can be obtained from Dr Botha at bwbotha@uj.ac.za or from the website of the Department of Mechanical Engineering Sciences at the University of Johannesburg.

Ernest Mukuwari started his career in 2002 as an Instrumentation and Control Technician with Delta Corporation in Zimbabwe. In 2004 he joined the Zimbabwe Power Company as a senior Control and Instrumentation technician. Ernest then joined ArcelorMittal South Africa in 2008 and served in various capacities as a technologist, engineer and manager. He obtained a Bachelor of Technology in 2010 with the University of South Africa. In 2018 He completed his MPhil in Engineering Management with the Postgraduate School of Engineering

Management at the University of Johannesburg. He is currently employed as a maintenance manager with ArcelorMittal South Africa. Further information can be obtained from Ernest Mukuwari at ernest.mukuwari@arcelormittal.com.