Business optimization through automated signaling design

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(Minor – Dissertation Research)

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Abstract

Railway signaling has become pivotal in the development of railway systems over the years. There is a global demand for upgrading signaling systems for improved efficiency. Upgrading signaling systems requires new signaling designs and modifications to adjacent signaling systems. The purpose of this research is to compare manually produced designs with design automation by covering the framework of multiple aspects of railway signaling designs in view of business optimization using computer drawings, programming software language and management of signaling designs. The research focuses on design automation from the preliminary design stage to the detailed design stage with the intention of investigating and resolving a common project challenge of time management. Various autonomous methods are used to seek improvement on the detailed design phase of re-signaling projects. An analysis on the project's duration, resources and review cycles is conducted to demonstrate the challenges that are faced during the design of a project. Signaling designs are sophisticated and crucial in an ever-changing railway environment. As a result, there is a demand for efficiency and knowledge within railway signaling to achieve successful completion project target dates.

A quantitative approach is used to identify the gaps leading to delays and best practices are applied using a comparative analysis to remediate on any snags that may potentially extend the project duration. The results illustrate that the resources required when automating detailed designs are reduced by two thirds for cable plans and book of circuits and reduced by one third for source documents. Successively, the projects benefit with reduced organizational resources, reduced design durations and reduced design review cycles. This research concludes that software integration of the signaling designs due to the efficiency and innovation of the selected computer drawing software and programming software language such as AutoCAD required less resources for computer drawings that are generated using automation tools compared to computer drawings that are generated manually. The resources required when automating the generation of signaling detailed designs are reduced for cable plans, book of circuits and source documents. This means that the business is optimized by utilizing less resources and subsequently delays are reduced during the design stage

Keywords: Railway, Railway Signaling, Railway Automation, Signaling Design, Computer Drawing, Programming Software, Railway Standards

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Abbreviations

SDLC	Software System Development Life Cycle
ILS	Interlocking System
FAO	Fully Automatic Operation
MIMO	Multiple Input Multiple Output
CENELEC	Comité Européen de Normalisation Électrotechnique
SIL	Safety Integrity Level
CCF	Common Cause Failure
ICT	Information and Communication Technology
CFF	Contributing Factors Framework
SPAD	Signal Passed at Danger
SAFE-Net	Safety and Failure Event Network
DTO	Driverless Train Operation
ATO	Automatic Train Operation
CBTC	Communication Based Train Control
ATP	Automation Train Stop
PTC	Positive Train Control
RMTCC	Rail Management and Traffic Control Center
NGTC	Next Generation Train Control
ETCS	European Train Control System
SWOT	Strengths Weaknesses Opportunities and Threats
ERTMS	European Rail Traffic Management System
AHP	Analytical Hierarchy Process
UTP	Unattended Train Operation
WeFA	Weighted Factors Analyses
THR	Tolerable Hazard Rate
GSM-R	Global System for Mobile Communication – Railway
DCS	Data Communication System
RBC	Radio Block Center
EMI	Electromagnetic Interferences
GP	Generic Product
GA	Generic Application

SA	Specific Application
RSR	Rail Safety Regulator
ROC	Required Operational Capabilities
FR	Front Sheet
CS	Control Sheet
AS	Aspect Switching
ECD	Element Connection Diagram
BoC	Book of Circuits
TA	Technical Advisor
LP	Line Plan
CP	Cable Plan
CRP	Cable Route Plan
FEC	Field Element Controller
ACE	Axle Counter Evaluator
IDF	Intermediate Distribution Frame
DB	Distribution Board
IM	Interlocking Module
IFB	Interface Board
CPU	Central Processing Unit
EC	Element Controller

Chapter 1: Introduction to the Study

1.1. Summary

Railway signaling has become more important and is at the helm of affairs in thinking about design automation. This contrasts with the historical perspective of thoughts and business optimization approaches. The framework of continuous optimization focuses on the automation of systems and the optimization procedure feedback. Automation systems function on adaptive and dynamic optimization for generic framework purposes. (Tortonesi 2015). Design automation of railway signaling focuses on optimization of safety and efficient rail movements. The history and previous knowledge of automation have enabled managers and engineers to understand functions better and have a holistic view of automation, continuous improvement and the software system development life cycle (SDLC). With this knowledge, optimizing the business model can be achieved significantly by automating the conceptual designs to yield or produce detailed designs with minimal human input.

The preliminary design consists of a line plan and a detailed design consists of cable plans, a book of circuits and source documents. The majority of re-signaling projects are delayed due to the design stage. The reason for this is that detailed designs require extensive time to ensure that the design is safe and compliant with the railway requirements. A large amount of the time is spent on updating and reviewing designs due to human error whilst producing the detail in the design (Yuguang, Hao et al. 2012). The lengthy review processes affect the next stage of a project significantly because the detailed designs are the predecessors of outside physical work and interlocking system (ILS) development such as installation and testing. This process has a detrimental effect from a business perspective due to the cost of penalties that are incurred from a delayed project (Quintero, Montenegro et al. 2016). For this reason, there is a challenge to mitigate any constraints that have the potential to delay signaling projects and affect the business negatively.

A possible solution is identified by automating the process of producing preliminary signaling designs into detailed designs with minimal human intervention to produce detailed designs (Tortonesi 2015). However, the detailed design automation process still requires a review process due to abnormal unique railway civil layouts and it needs to be modified by a human. Even with unique layouts, a tremendous amount of time and cost will be reduced in comparison to detailed designs being produced by humans. The production of designs is possible using automation because the design drawings are produced using computer-aided drawings Computer-aided drawings are readily compatible to be used in conjunction with programmable software as part of set instructions to achieve an objective.

There are numerous types of computer-aided drawings that can be used as a source to produce detailed design drawings using various programming languages through automation (Pintilie, Avram 2015). Another avenue that is considered is the use of a Microsoft Excel spreadsheet to produce a source document where the final file version will be a computer-aided drawing (CAD) file (Saha 2014). The data is exported from a Microsoft Excel spreadsheet to a CAD file that is compatible for the data preparation of the interlocking. The interlocking is a processing unit that is responsible for the safety and train movements of a railway section.

The source document is a detailed design that is used to generate the ILS. Previously, extensive design time was spent on perfecting a computer-aided drawing to produce a source document. Although this process is not automated, humans will spend less time designing a simple Microsoft Excel file as opposed to designing on a computer-aided drawing that requires a high level of skill. This is an additional minor measure with respect to business optimization as part of the mitigation of delays in signaling projects (Wang, Liu et al. 2015).

This research demonstrates an application of how a programming software is automated to generate detailed designs using various objects or elements from a computer drawing without human input (Amadori, Tarkian et al. 2012). Elements from a computer drawing are wayside equipment such as signals, point machines, axle counters (detection points) and tracks. This research takes a closer look at signaling design using Microsoft Excel to produce source documents as an additional measure for possible business optimization. As a result, the business internal processes become efficient with reduced human hours, thus saving business costs and time on any railway signaling project (Liu, Qiu 2014).

1.2. Background

Railway signaling was essentially introduced for driver control of train movements and has been developing to sophisticated stages, even as far as driverless trains. Nevertheless, signaling is still the backbone of ensuring safe controlled train movements (Pintilie, Avram 2015). This is achieved by using a method that prohibits a mechanism or system from executing a set-in motion instruction adjacent to an instruction that exists such that the two operating simultaneously have the potential to produce unsafe or undesirable results. This system was introduced as an interlocking system. Various interlocking systems such as Ebilock were later introduced from a company in South Africa. This system has been validated for its safe functionality and has been used in various global railway environments and projects.

There are currently 73 engineering and production facilities in over 28 countries with a worldwide network of service centres. With the population increasing, transportation demand is on the rise. A project from a particular company came into existence to increase the railway line capacity with new signaling systems to accommodate the infrastructure for modern trains (Yuguang, Hao et al. 2012). New signaling designs have to be produced and implemented within a set time frame. This means that the scope, time and budget are critical items for business optimization of any project (Tortonesi 2015).

1.3. Problem Statement

There is an emerging trend that reflects delays on railway re-signaling projects. The possible reason for the trend is that re-signaling projects are implemented with a delayed start due to the design stage consuming more time than anticipated according to the schedule of the project. The challenge is in the process of producing detailed designs from preliminary designs. This normally takes a significant amount of time due to human error and the general time needed to generate designs of such detail. This problem has a significant impact on a company in terms of business and signaling projects.

1.4. Research Questions

Railway signaling involves the integration of engineering and management driven by individuals of a project whose sole mandate is ultimately to propel the business and engineering strategy to achieve a successful project execution that is on time. The purpose of this research is to investigate, resolve and highlight the importance and challenges of time management during the design phase of a signaling project. This has a direct influence on the business optimization from the perspective of the project design timeframe. Furthermore, there are three key underlying research questions that arise with respect to achieving or overcoming the identified challenge on a signaling project:

1. Can the automation of the computer drawings for the signaling detailed designs from the preliminary designs be the solution for business optimization in railway signaling?

2. How will the signaling design automation of computer drawings resolve or improve the challenge of business optimization on railway re-signaling projects?

3. Who or what will benefit from business optimization of signaling projects in terms of resources, project duration and design review cycles?

Chapter 2: Literature Review

The basis of this research starts with a detailed literature review to gain insight into what has been said previously with regards to signaling within the railway environment and the engineering automation discipline. The literature review is used for an understanding of what railway signaling challenges exist and the approach used to remediate these challenges. Previous research with similar known findings assists with the approach of applying engineering management methods in accordance with railway engineering requirements.

The literature review finds instances of other research findings and identifies gaps in the knowledge that the research design then identifies. This helps to formulate the research questions within the railway signaling framework. The findings assist in identifying the unknown gaps and fulfilling the activities that are required for the research design of railway signaling using automation.

2.1. Railway Background

The background review assists in illustrating the transformation of railway systems within the signaling framework from the early times.

Railway signaling initiated through mechanical systems that use levers at stations. The controlling of train movements uses these mechanical levers and were the first form of signaling interlocking. The interlocking is a processing unit that is responsible for the safety and train movements of a railway section. The mechanical interlocking become more advanced over the years and evolved into electro-mechanical, relay and electronic interlocking. In recent years, the development of safety within interlocking has taken priority in terms of train movements. Railway projects are impacted by the emerging signalling requirements. As a result, there has been a trend of delays in completing railway signaling projects according to the projected time.

2.1.1. Introduction to Railway Use

The railway industry started to grow in popularity in the early 1800s when there was a demand for long distance travelling. Trains were the only reliable use of transport at that time. The railroad was becoming so large in certain countries that long-distance travel was possible without changing trains in that country.

Railway excursions were introduced and were return-trips with reduced fares (Major 2015). The working-class mobility escalated and the demand for railway transport increased. Subsequent to the increase in railway transportation, the impact of climate change was also noticed, which means that railroad networks need effective consideration on adaptation for efficient operation (Dawson, Shaw et al. 2016). Railway development and other factors such as economic development and urban planning have an overall direct influence on urban development.

Urban development produces a high growth in population. Economic development drives this growth and therefore creates employment (Chang 2017). Urban development is thus aligned with the development of the railway industry.

With the railway development and demand increasing, safety and reliability quickly became a priority in the railway environment. Railway signaling was introduced to cater for these requirements. As the development of signaling progressed, signaling buildings and sub-assemblies became obsolete as global modernization initiatives focused on computer-based railway signaling (Reeves 2016).

2.1.2. Railway Signaling

Signaling systems were first introduced using mechanical elements. These elements were controlled by an interlocking system. An interlocking system controls safe train movement by monitoring the element positions to ensure optimal reliability and safety. Blocks are used from the interlocking system to execute safe instructions and monitor the train movements (Stankaitis, Iliasov 2017). The fully automatic operation (FAO) is safer, more reliable, offers route flexibility and has a high efficiency in terms of transportation (Niu, Fang et al. 2018). A case study in Iran demonstrated that human error contributes substantially to undesired events in terms of costs (Khademi, Babaei et al. 2018).

The interlocking of the signaling equipment reduces the number of errors and risks leading to unsafe conditions. Disruptions caused by unsafe conditions are managed better when an evaluation of the impact of time on delays has been established (Sun, Wu et al. 2016). There is a high dependency on railway signaling for safety and reliability. The development of signaling safety is very important for this research and the railway industry as it forms part of the design automation stage (Carpitella, Certa et al. 2018).

2.2. Development of Signaling Safety

Safety and reliability within the railway signaling industry are of paramount importance. Historically safety has depended on interoperability that has not been tampered with by incapable technology but rather by unique approaches to safety and reliability (Jiang, Fan et al. 2018). Multiple input, multiple output (MIMO) techniques are used to improve the safety and reliability for signaling of high-speed communication (Zhou, Ai 2014). Also, technological and human factor frameworks have been investigated to define the risk tolerability criteria, risk assessment and a system definition using a quantitative and qualitative safety-oriented approach (Szmel, Wawrzyniak 2017). The technological and human factor frameworks must comply with the standards defined by railway signaling safety committees such as CENELEC.

The CENELEC ("Comité Européen de Normalisation Électrotechnique" – the European Committee for Electrotechnical Standardization) standards and rules for signaling design are governed by the railway safety authority in accordance to the Safety Integrity Level (SIL) 4 that takes the lead and is at the forefront of safety, reliability and maintainability within the railway signaling industry (Wang, Guiochet et al. 2018).

Redundancy in the system architecture is vital for safety design to prevent function failure or dangerous failure modes. This approach to improving safety and reliability emanates from a concern of minimizing common cause failure (CCF) during operation of a signaling system (Durmuş, Takai et al. 2015). CCFs are categorized according to their severity to prioritize the risk mitigation that is associated with it (Du, Ma et al. 2018).

Signaling systems are fundamental to any railway operations as they form the centre of safety, stability, traffic control, communication between adjacent dispatchers and the detection of wayside disasters. A method of using fast developing information and communication technology (ICT) as a remedial solution to improve communication reliability of radio networks on a closed communication for each sector is applied (Wang, Ma et al. 2016). It can be observed that there are benefits with using this approach such as introducing an onboard moving block, continuous train monitoring for determining track or section occupation, and the speed of the train can be monitored. With much awareness, the data on train movements are used to improve operations, safety, and reliability (Hiraguri 2017).

2.3. Signaling Awareness

Through technological advances in time, signaling has become elite in the railway environment. It can be seen from various research papers that there is a vast transition from obsolete mechanical signaling to the revolutionizing electro-mechanical signaling, followed by modern electronic signaling (Crawford, Kift 2018). However, some awareness must be acknowledged around the potential health and safety risks associated with progressive integration efforts and human-automation design.

In 2009, a contributing factors framework (CFF) tool was introduced in Australia. It consists of data from a manual with set systematic factors that contribute to the rail safety occurrences (Filtness, Naweed 2017). The manual assists in alleviating risks such as signals passed at danger (SPAD), derailments, collisions, and safe working rules. The manual raises the concern for signaling awareness to greater levels, to the extent of introducing a methodology for modelling accident occurrences. It is called the Safety and Failure Event Network (SAFE-Net). SAFE-Net methodology clearly assists in identifying the bridge between practice and theory for a socio-technical system (Klockner, Toft 2017). This is an important factor to consider when working with driverless trains within the signaling environment.

2.4. Driverless Operation

The first driverless trains are dated to as far back as 1960. Most people currently believe that driverless trains are something new within the railway environment. There is a significant dependence of a driverless train on a signaling system. All signaling systems are designed to monitor and control safe train movements. A driverless train operation (DTO) is controlled using a sophisticated signaling system (Wang, Zhang et al. 2016). It is of importance to note that the signaling system requires input source documents for safe and reliable DTO.

There is a benefit that advantages the DTO such as increasing the capacity of trains on a line simultaneously. Again, this highlights the dependence on a signaling system, especially where there are numerous trains with complex layouts. However, in circumstances where there is low adhesion, the line capacity and autonomous operation are compromised (Powell, Fraszczyk et al. 2016).

2.4.1. Autonomous Operation

The development of driverless trains has increased at various levels due to autonomous railway environment demands. The reasons vary from industrialization requirements, demographical evolution, railway governance, higher urbanization, fleet operators and even safety requirements (Chakraborty, Nurain et al. 2019). The challenge at hand is that the DTO function is a closed controlled environment in contrast to an open uncontrolled environment. At the moment, signaling systems are limited due to this functionality and are experiencing a challenge for implementation (Trentesaux, Dahyot et al. 2018). Automatic train operation (ATO) is being introduced to minimize the driver control handle and replace traditional manual driving. The ATO is trusted due to its theoretical background and the implementation is practical due to the communication-based train control (CBTC). This is high-resolution signaling that continuously monitors train location and occupancy (Yin, Tang et al. 2017). CBTC uses wayside equipment such as detection points to determine train locations and therefore drives the signaling equipment to control the traffic on the railway lines. The autonomous operation needs to be considered for research as it contributes to the signaling designs and the impact of the evolution of train controls. There is a gap in previous research papers on this point with regards to the automation of signaling designs.

2.5. Train Control Evolution

Various signaling systems are being designed, tested and implemented globally to achieve the safest and most reliable train controls. Japan uses a signaling system that has the functionality of an automation train stop (ATP). This is the revolutionized benchmark for ATOs in the sense that the control of the train movements within the signaling system has an embedded functionality that prioritizes the driver's brake operation within the signaling design layouts when the circumstances are of high danger and lead the train to a forced stop (Nakamura 2016). This is an additional measure in comparison to the usual automatic train control (ATC) that prevents accidents from occurring due to driver negligence (Wang, Li et al. 2016). The ATP functionality is introduced during the design phase and forms part of the source documents for the signaling system due to train movements.

Train control movements are set to have limitations to mitigate and avoid any possible derailments. These limitations minimize the risks that compromise the safety of train movements by using the evolutionary positive train control (PTC) system. The functionality is categorized according to various levels that determine different methods of preventing possible incidents from occurring using enforced speed restrictions and wayside monitoring within the Rail Management and Traffic Control Centre (RMTCC) (Hartong, Goel et al. 2011).

2.5.1. Next Generation Train Control

The evolution of signaling train control systems is developing at a steady rate. The Next Generation Train Control (NGTC) functionality is a convergence of the CBTC and the European Train Control System (ETCS) for the urban and main lines (Nakamura 2016). The ETCS is designed in isolation solely for application to urban lines whilst the CBTC is designed for main lines. Both systems are designed by world leaders in the European industry. The ETCS specifications development started in the early 1980s with the intention to standardize the system requirements to cater for CBTC (Gurník 2016). The NGTC functions are to be designed and implemented as NGTC-core functions in future as indicated in Figure 1.

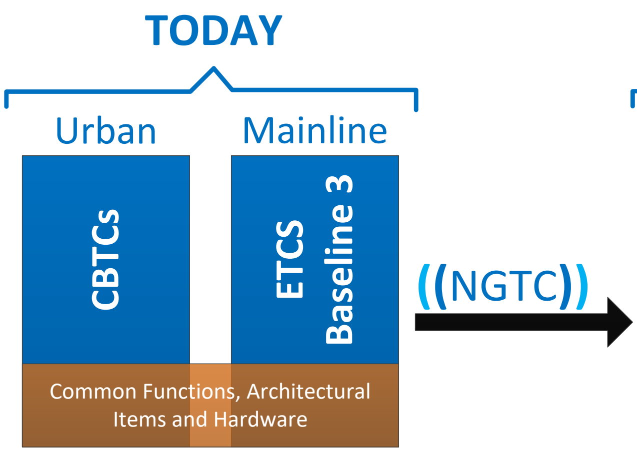


Figure 1: NGTC Convergence (Gurník 2016)

With the NGTC progression, it is seen through the European rail sector that a process decision analysis is to be conducted using a strengths, weaknesses, opportunities and threats (SWOT) approach (Krmac, Djordjević 2019). A dilemma surfaced during the development phase of the implementation of the European Rail Traffic Management System (ERTMS) of new findings for external and internal factors which required a decision-making framework such as the SWOT analysis.

Through research findings (Carpitella, Certa et al. 2018), it is important to note that the analytical hierarchy process (AHP) identifies the crucial factors that influence or criticize signaling designs and implementation. Using the AHP approach, some findings of the ATP are two-fold. The first scenario gives the operator control to drive the train at full speed but compromises the maximum train flexibility that is embedded within the source documents during the design stage (Krmac, Djordjević 2019). The second finding is that, even though the operator is given full speed deceleration supervision, the SPADs are increasing (Nachtigall, Ouředníček 2018). There are perceptions around the world with regards to ERTMS and ETCS implementation.

2.5.2. ETCS Perceptions

The perceptions around ETCS and ERTMS and railway signaling are crucial and beneficial to this research as they form the basis of understanding signaling designs and systems. This is essential because the implementation of railway signaling designs has a direct influence on businesses or projects and has a significant impact on the business optimization initiative.

Railway technology is ever-changing but the railway signaling systems are still at the heart of controlling train movements. Passengers are dependent on the reliability and safety of the signaling system and at the same time, headways are equally important to them (Fraszczyk, Brown et al. 2015). Headway simply means the amount of time it takes for a section to be clear with a follow-up train. This is important because it affects the design phase and influences and contributes to the economic benefits. There are different types of signaling systems and are differentiated by the number of aspects that influence the headway (Williams 2016). A formula derived in the UK is used to calculate the sequence for each of the following aspects:

- Two (2) aspect signaling: (braking distance + overlap + sighting distance) * 2 + train length
- Three (3) aspect signaling: overlap + sighting distance + train length + braking distance * 2
- Four (4) aspect signaling: overlap + sighting distance + train length + braking distance * 1,5

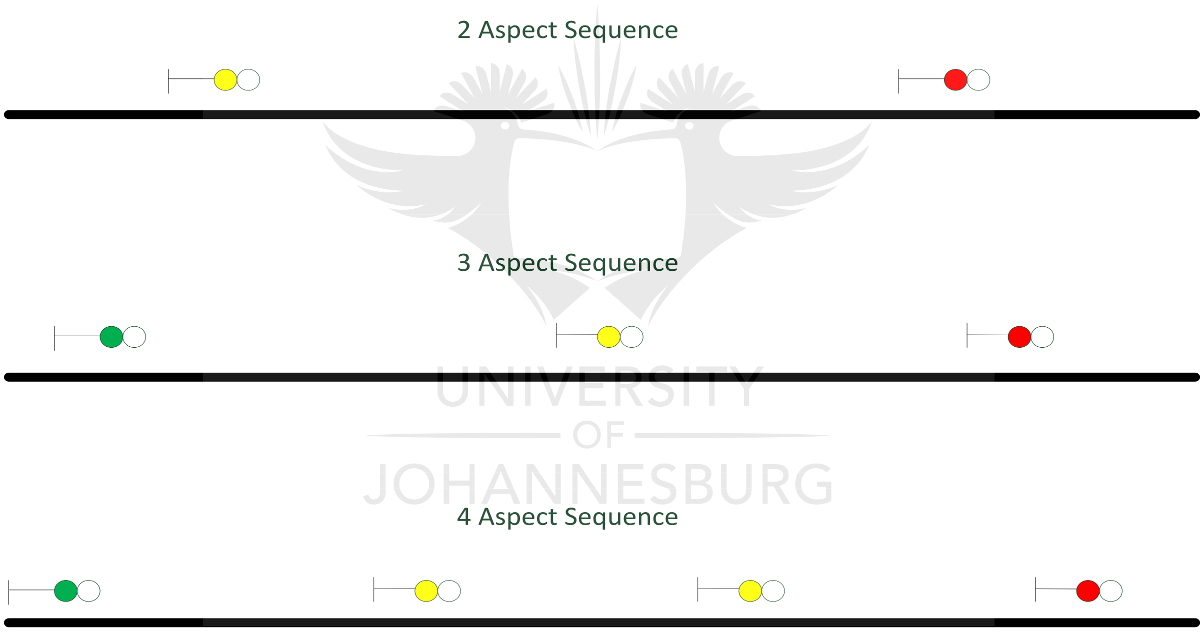


Figure 2: Aspect Sequence

2.5.3. Public Perceptions

This research aims to decide ultimately whether automating designs for a signaling system yields successful business optimization in terms of the public satisfaction and perceptions. Autonomous signaling designs have an effect on a project's duration by possibly reducing the allocated time and commencing with the operational services sooner than anticipated. Safe-Net methodology provides vital information that helps in a better understanding of complex socio-technical systems and their contributing factors (Klockner, Toft 2017). The assistance of input to public perceptions and views of a signaling system are also identified here.

Due to the global ‘driverless train’ trend, (Fraszczyk, Brown et al. 2015) conducted a survey to assess the public's perception of unattended train operation (UTO). The results indicated that the public perception of driverless trains is positive on average. The question that arises concerns what these results reflect. It simply means that the global demand for driverless trains is on the increase and that this approach is viable for the railway industry. The core reason for this research and what this also indicates is that, at a certain time in evolution, the production rate of signaling designs will be at a high pace. Human intervention should be kept minimal and within signaling compliance regulations whilst business optimization is taking the lead through signaling design automation. Whilst maintaining the signaling standards, there are key underlying attributes to utilizing driverless trains such as increased capacity utilization, efficient headways and economic benefits (Powell, Fraszczyk et al. 2016).

2.6. Signaling Compliance

2.6.1. Standards

The global population is increasing and there is a considerable demand for reliable and yet safe signaling systems. It is noticed that railway signaling entities tend to compromise certain reliability and safety-related requirements when the pressure is increased with reference to demand in signaling projects. Due to the project duration and delivery schedule, these entities make compromises and find strategies to fast-track a project, and, as a result, compromise the signaling compliance requirements. For this reason, railway governing bodies are becoming more and more strict on compliance-related requirements. Standards and processes are introduced to assure the best quality and highest safety level compliance.

In seeking better reliability and safety for railway signaling systems, a methodology is introduced that utilizes Weighted Factors Analyses (WeFA) and a tool that conducts a rational compliance assessment aligned with some modelled safety standards and developing procedures (Liu, Mu et al. 2017). This is in line with EN50128 conformity assessment standards. A safety developing procedure is given for a conformance assessment that utilizes the following:

- Black box test;
- White box test;
- Manual test;
- Automated test;

- Static verification and
- Dynamic verification

There is another important standard known as EN50129 which specifically looks at the approval and acceptance of safety-related systems. It enables the life-cycle activities as well as development processes to be documented evidence through high-level structure initiatives for any safety case using acceptance conditions such as (Wang, Guiochet et al. 2018):

- Technical safety and functional evidence
- Quality management evidence
- Safety management evidence

This EN50129 standard is important to note because it explains the principle of technical safety for signaling designs and references all the applicable evidence that is available.

2.6.2. Safety Integrity Level

The highest safety standard, known as the safety integrity level (SIL), introduced through IEC61508, consists of four levels. The highest safety integrity level is SIL4 and is aimed at targeting all signaling systems around the world (Wang, Guiochet et al. 2018). A safety integrity level with functions and no safety requirements is known as SIL0. The railway industry often misuses the SIL concept in the following situations:

- Comparing standards for compliance;
- Electrical/Electronic/Programmable Electronic(E/E/PE) system safety-related functions instead of the system itself; and
- SIL is to be linked to a fixed probability value such as reliability.

It goes unnoticed that on many projects the renowned risk matrix and risk graph are used to determine the safety requirements when the SIL allocation is employed. The SIL allocation drawback is that the focus is on an isolated single function and does not consider that other safety systems coexist in the entire railway system (Ouedraogo, Beugin et al. 2018). The SIL concept is widely misinterpreted despite its great value for safety within a system and system design. There is a great effort in implementing quantitative and qualitative SIL4 safety application functions. A safety function of frequent dangerous failure is defined in SIL of the normal IEC61508 (Dogruguven, Ustoglu 2018). Figure 3 overleaf illustrates a risk matrix that distinguishes between the different SILs using a tolerable hazard rate (THR).

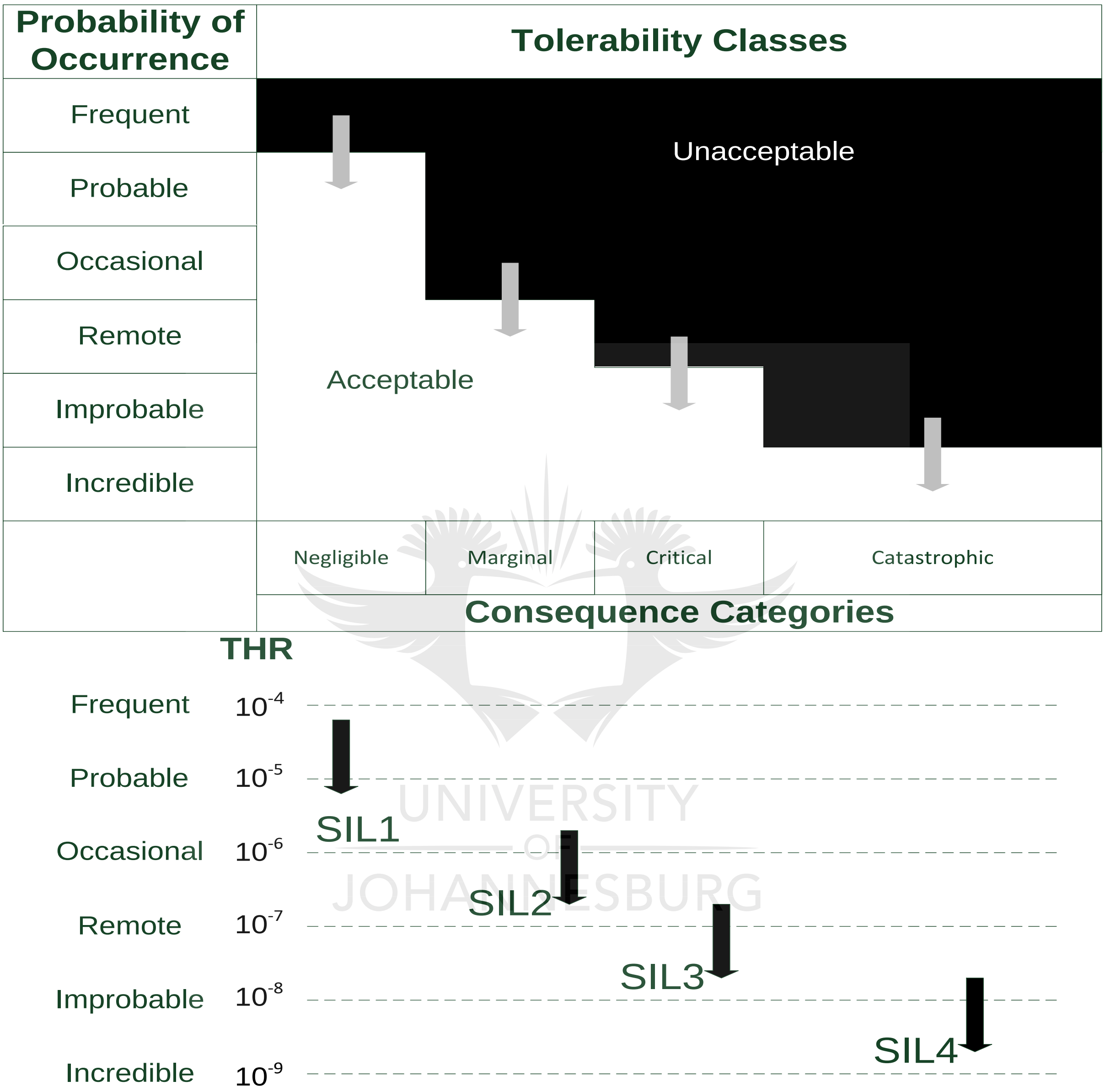


Figure 3: SIL Risk Matrix (Ouedraogo, Beugin et al. 2018)

2.7. Global Application of Train Control Services

2.7.1. ETCS Levels

The world is ever-changing, and the development of train control services is on the rise. Additionally, ETCS is designed ideally for controlled train movements by monitoring train traffic, ensuring compliance to speed, and controlling trains within a section. This is achieved by promoting interoperability across borders. ETCS consists of three levels (Williams 2016, Durmuş, Yildirim et al. 2012):

1) **ETCS level 1**

   Wayside equipment is used for train detection using axle counters and track circuits. Uses ATP balises at signal markers

2) **ETCS level 2**

   Wayside equipment is excluded and replaced with onboard equipment for positional correction using ATP. There is a great dependency on the radio and used Global System for Mobile Communication – Railway (GSM-R).

3) **ETCS level 3**

   Wayside equipment is excluded, and the train detection is provided by GSM-R using the onboard equipment. Uses a moving block for ATP.

There is a global transformation that requires re-signaling of obsolete signaling control systems to migrate to modern control systems such as ETCS L3. This means that the signaling equipment functions on a moving block principle in conjunction with onboard equipment to determine the train location using a data communication system (DCS) via a radio block center (RBC). There are two options available for the system architectures to determine train location on ETCS L3 (Nguyen, Beugin et al. 2019):

- A simple architecture is used for train localization on the onboard equipment. Signaling functions and control come from the RBC. For this reason, RBC can cater for uncertainties. The advantage of this is that major costs are reduced, such as the deployment of the infrastructure, investment costs and operational costs.

- A hybrid architecture is used for train localization on the onboard equipment or for using axle counters and track circuits. This creates redundancy for the RBC. Even though there is more operational performance, this option creates the complexity of train control systems, and, for this reason, maintenance costs are increased (Ghazel 2014).

2.7.2. ERTMS Modelling

The global focus on train control services is on the ERTMS and ETCS due to reliability, performance, safety and cross border interoperability. Radio communication is used to ensure that the moving block is clear to allow for a train to move into a section, ultimately improving capacity on the line. In the past a fixed block signaling was used and would not allow another train to enter a block with train occupancy (Biagi, Carnevali et al. 2017). It is important to note that these train control services are accepted not only in Europe but globally in countries including South Africa, Australia, and India, just to mention a few.

It is important to note that the implementation of ERTM and ETCS must comply with country-specific railway requirements and must also comply with the SIL of ERTMS and ETCS framework. This means that the train control system must comply with two specification sources. Safety culture and logic are required on both. A two-step modelling tool approach is used:

1) A systematic approach to investigate the maintenance approach and steps leading to an accident. A project in France identified that no accidents were reported whilst using ERTMS due to the non-functioning of ETCS L2.

2) A functionality of replaying of all scenarios is a requirement under the ERTMS framework. This assists in compiling evidence and proof of safety.

These modelling tools are approved and accepted by the international railway safety organizations. These modelling tools are not completely formal. As a result, a formal approach is introduced to differentiate the onboard equipment from the wayside equipment, as seen in Figure 4.

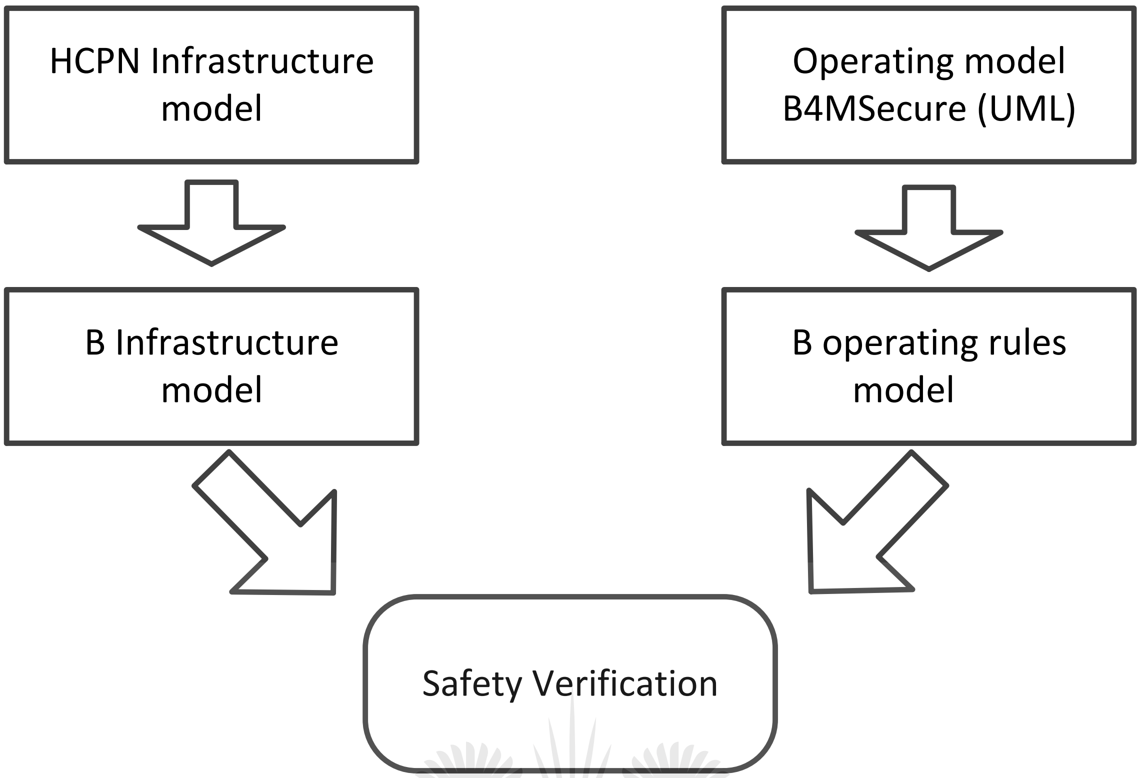


Figure 4: Single Modelling Language Framework (Ferlin, Ben-Ayed et al. 2016).

2.7.3. ETCS Testing Development

ETCS and ERTMS development are affected by signaling designs (Benerecetti, De Guglielmo et al. 2017). This research presents an investigation to see the impact of automated signal designing of modern train control systems and the relation to wireless communication emulation such as of GSM-R. With the implementation of train control systems, it is discovered that there are interferences and noise due to air gaps in communication. These air gaps are caused by electromagnetic interferences (EMI) between the various applications such as communication systems and the rolling stock. The problem with this type of EMI is that the noise on the railway lines is not predictable and can be challenging to mitigate (Durmus 2012). It should not be picked up in the testing however, as the testing does include EMI compliance. Standards such as EN50129 and EN50128 focus rather on safety testing (Senesi, Ridolfi et al. 2016).

The EMI mostly affects the onboard equipment because the communication is air-based. Research has been carried out by *Gonzalo Solas* to progress and improve on the 'Zero On-Site Testing' paradigm (Solas, Mendizabal et al. 2016). The purpose of the research was simply to reduce testing time on the verification and certification processes by eliminating drawbacks (Benerecetti, De Guglielmo et al. 2017). Some of these drawbacks may emanate and infiltrate from their origin during the design stage of the input source documents.

There are strategies that have been used for reducing potential drawbacks and minimizing the testing times and processes. Two methods and strategies are identified:

1. Assign the worst-case scenarios of the wireless interfaces to assess the potential impact on the dynamic behaviour of the onboard equipment.

2. Run a safety assessment of the external and internal interfaces by injecting a fault. Failsafe state is checked by exciting the functionalities imposed by possible saboteurs in the interfaces using the following methodology (Solas, Mendizabal et al. 2016):

    a. Identification of safety function hazards

    b. Identification of the associated safety standard(s)

    c. Identification of onboard equipment specific to its functionality

    d. Identification of onboard equipment specific to its hazard

    e. Identification failure of tasks and their impact on safety

    f. Identification failure of tasks and their impact on the availability

    g. Identification of faults injected to provoke preceded task

This methodology is used to align with ETCS and ERTMS European market requirements.

2.7.4. ETCS and ERTMS European Market

The literature review on this paper focuses on reflecting the importance of the ETCS and ERTMS signaling systems that are implemented in Europe and the influence that it has specific to country adaptations and standards. Much of the detail of this research focuses on computer drawing automation of the company's signaling system specific to the challenges highlighted within this research paper for South Africa.

When designing train control systems, it is required that the signaling system should comply with the country's signaling requirements (Zhang, Wang et al. 2019). A signaling system consists of three sections. The generic product (GP) shall remain the same in all countries However, the generic application (GA) and the specific application (SA) comply with the country's operational requirements, CENELEC requirements and rail safety regulator (RSR) requirements. In South Africa to be specific, required operational capabilities (ROC) signaling design and operation compliance are required. Figure 5 represents the ETCS and ERTMS European market share:

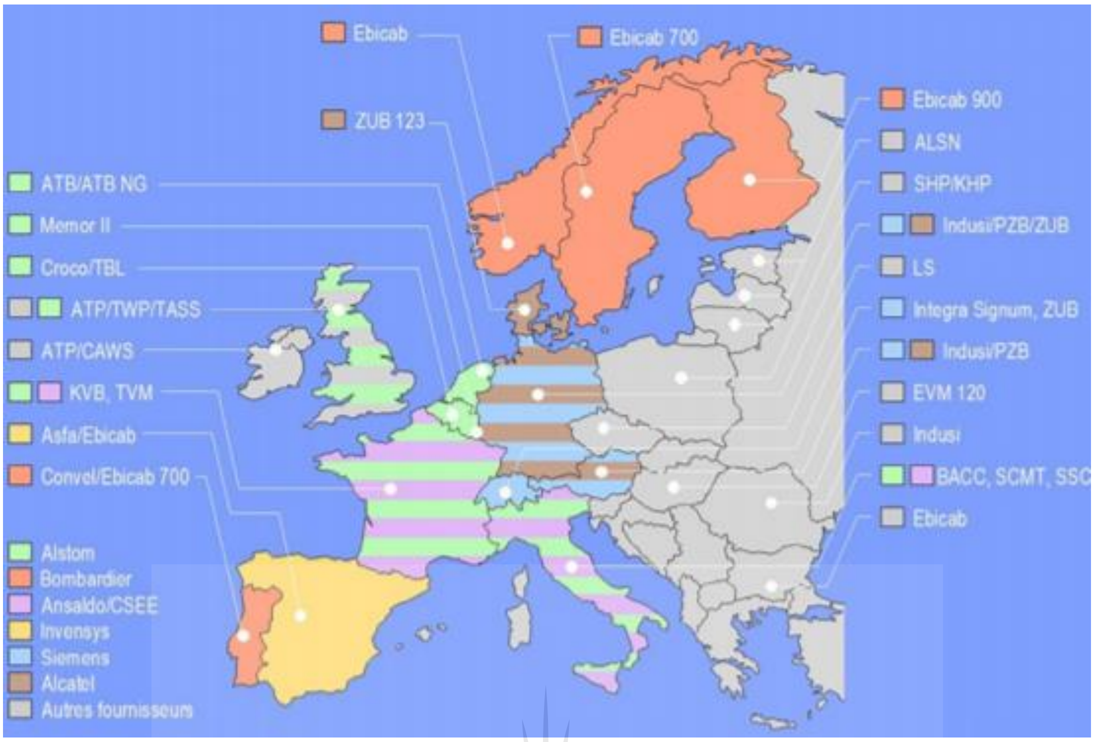


Figure 5: European Market Train Control Systems (Ghazel 2014)

2.8. Signaling Design Through Computer Drawings

2.8.1. Background of Signaling Drawings

Railways signaling controls all train movements within a certain section mainly to prevent accidents from occurring. The controlling of these movements are all functions from the interlocking or intelligence of signaling (Baviskar, Suryawanshi et al. 2018). The interlocking functions from programmed information are known as source documents. There are multiple documents that are required as inputs for the interlocking such as front sheets (FR), control sheets (CS), aspect switching (AS) and element connection diagrams (ECD) to mention but a few.

The railway design and the implementation process require extensive checking and approvals as a CENELEC requirement in South Africa (ter Beek, Gnesi et al. 2018). All possibilities of train movements and scenarios are addressed and catered for during the design stage of a project. Once a project has reached a stage of implementation and commissioning the source documents remain the same unless there are possible future upgrades of railway lines that require interfaces to the existing signaling or possibly decommissioning of certain sections. There are small possibilities of updating the source documents due to certain routes not being utilized (Yin, Tang et al. 2017).

Signaling designs are compiled, reviewed, approved and commissioned by signal design engineers. When compiling these designs, the signaling engineer works closely with the draughts person to align the technical expertise with the signaling drawings. The drawings are produced in a format known as computer drawing files because of the interlocking requirements (Luteberget, Johansen 2018). For this research, the computer drawing application 'AutoCAD 2014 – API' is used. Some signaling designs require the signaling engineer to produce them. The process of designing using computer drawings consumes too many hours and requires a signaling engineer that has the additional skill of producing signaling designs using computer drawings (Bonacchi, Fantechi et al. 2016).

2.8.2. Utilization of Computer Drawings for Source Documents

An important aspect of the signaling interlocking is the input source documents. The interlocking controls all the elements or objects on a station layout. The initial data for the station layout is derived from conceptual designs and the raw data of the civil layout drawings. The controlling of the elements uses Boolean equations or ladder diagrams known as control tables. It is a requirement that the control tables are designed using a computer drawing format. This requires the signaling design engineer to have drawing skills and consumes a lot of time to align the control tables. The engineer must adhere to the ROC and comply with the safety standards to ensure the best and safest train movements. Ultimately, the train movements of the control tables are verified and validated to ensure safety conformance (Bonacchi, Fantechi et al. 2016). The validation is to comply with EN50128 and SIL for safety purposes, should a software failure occur. A software tool is used to identify the positions of the elements for a unique layout. The elements are used within the computer drawing to produce a book of circuits (BOC) through automation (Baviskar, Suryawanshi et al. 2018). The output of these drawings is readable by humans and requires the signal engineer to modify the special cases according to the station layout.

Figure 6 indicates the accessible features during the design stage followed by the verification phase using external software or the signal engineer:

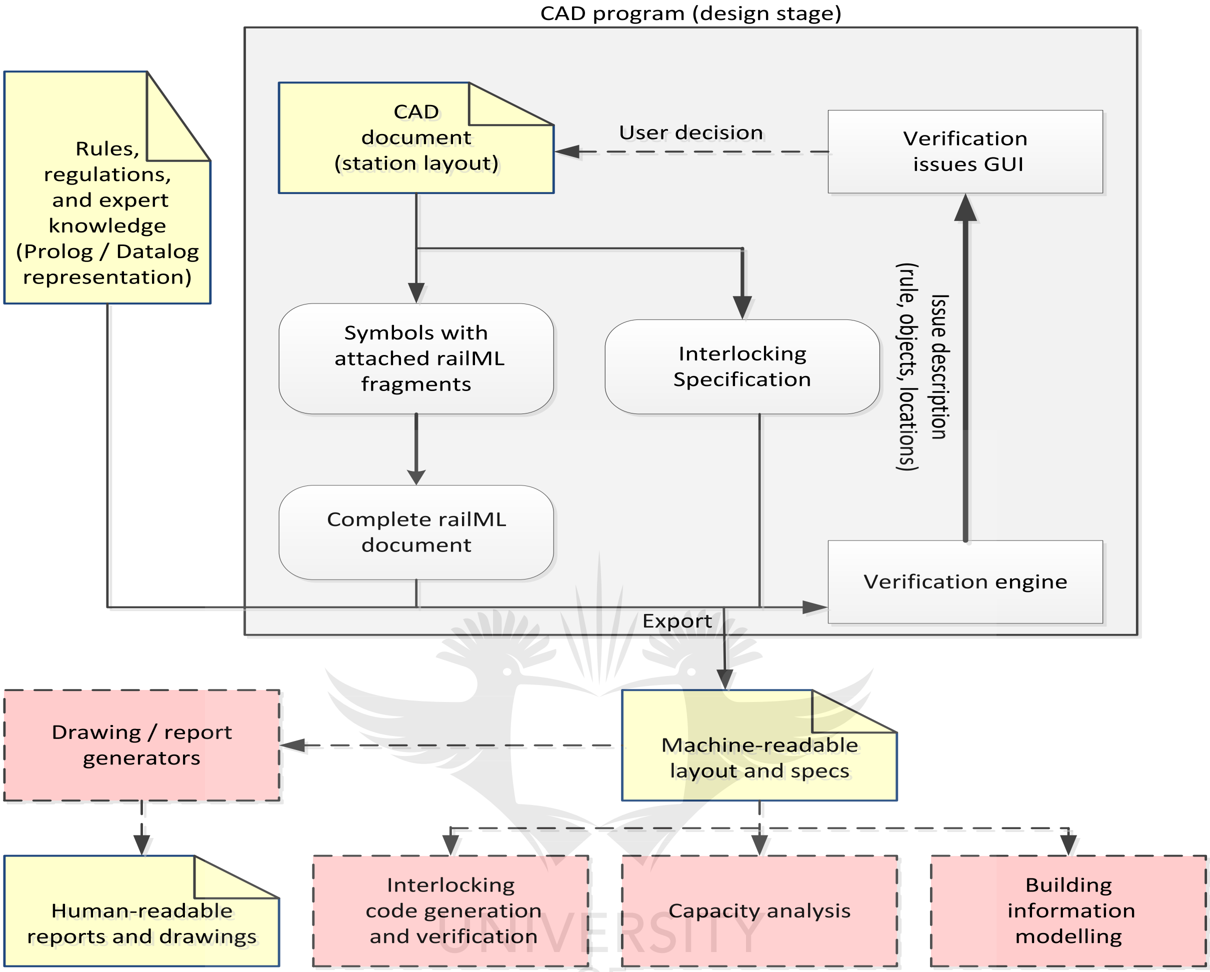


Figure 6: CAD Design Automation Structure (Luteberget, Johansen 2018)

2.8.3. Drawing Conversion

An alternative method is used to generate the control tables for the signaling interlocking. The requirement is that the control tables are to be on a spreadsheet layout that is generated on a computer drawing format. The initial data for the control tables is derived from the line plan and the cable plan for detailed reference.

Since the compiling of these control tables on computer drawings is a tedious, time consuming and skilled process, an automation process approach is a solution to mitigate this. The signal engineer will produce the control sheets using an automated spreadsheet such as Microsoft Excel which is user-friendly and can be used by most engineers.

The Microsoft Excel spreadsheet will be automated by converting the control table Excel file into a computer drawing control table file. (Seijas, Thompson 2016) use a similar approach to illustrate that the human errors on computer drawings are minimized and the review cycles of these designs are reduced. The signaling engineers will set up test cases and scenarios in accordance with the control tables to ensure that safety compliance is enforced, such as no derailment and no collisions. The framework in Figure 7 indicates this simulation verification process.

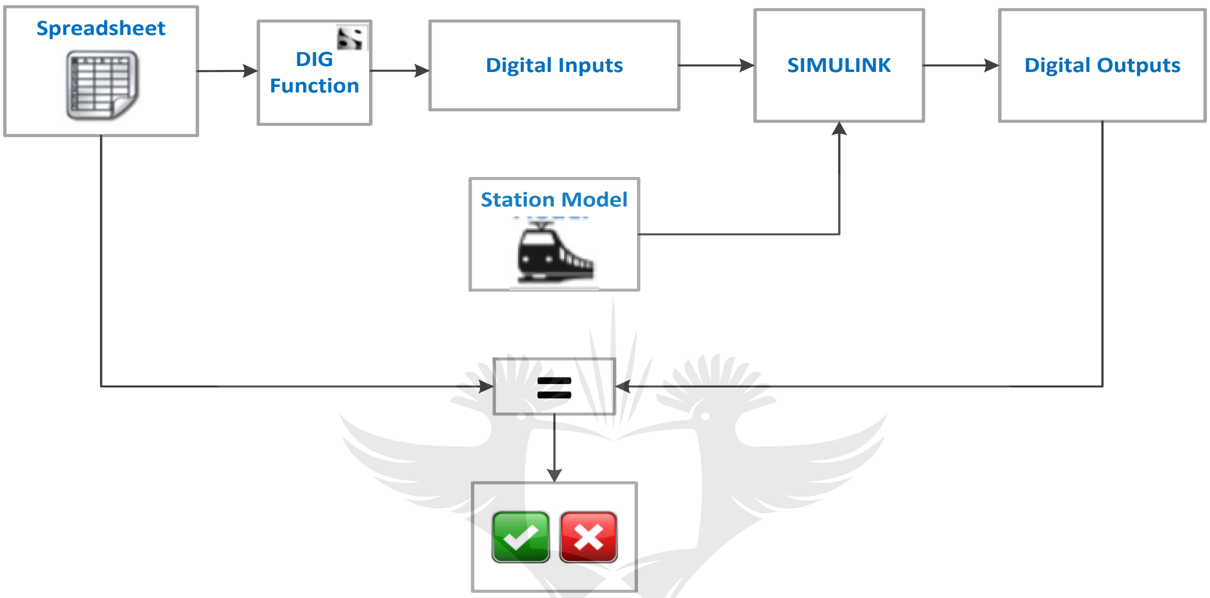


Figure 7: Verification Simulation Process (Bonacchi, Fantechi et al. 2016)

The verification simulation process follows a set SIL requirement structure that demonstrates the relationship and roles of individuals within an organization on a project.

2.8.4. SIL Organization Structure

It is paramount to note that there are key roles that any signaling organization must adhere to in terms of SIL requirements, EN50128 and EN50129 standards (Liu, Mu et al. 2017). There are eight roles that have been identified according to SIL and their relationship in terms of the reporting structure are presented in Figure 8.

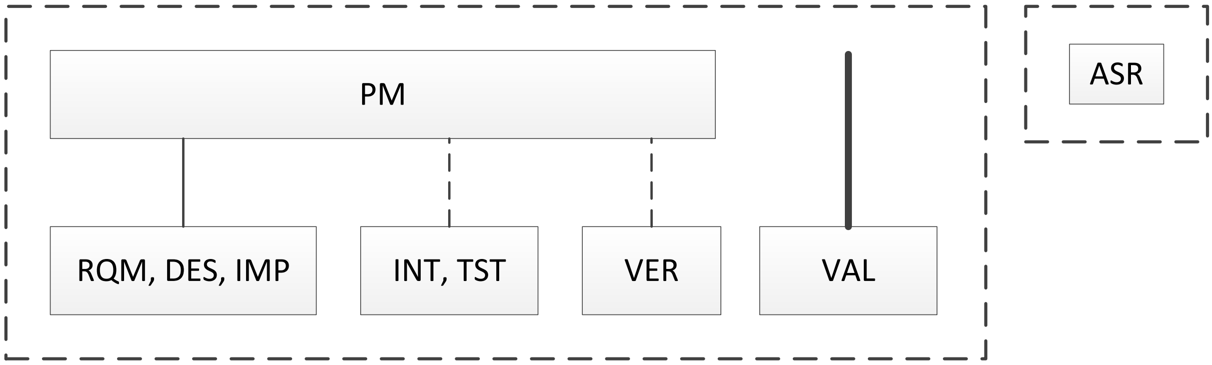


Figure 8: SIL Reporting Structure (Luteberget, Johansen 2018, Bonacchi, Fantechi et al. 2016)

The identified key roles for successful execution of a signaling project are presented in Table 1.

Table 1: Role and Relationship Matrix

Role	Relationship
Requirement Manager	Project Manager, Designer, Implementor
Designer	Project Manager, Requirement Manager, Implementor
Implementor	Project Manager, Requirement Manager, Designer
Integrator	Project Manager, Tester
Tester	Project Manager, Integrator
Verifier	Project Manager
Validator	Independent of the Project Manager
Assessor	Independent of the Project
Project Manager	All relationships except Validator and Assessor

There is another role that is not included in the eight roles in the signaling organization as it is the external assessor and must be independent to ensure good, safe and ethical signaling practice.

Safety requirements such as SIL 3 and SIL 4 follow the reporting structure as indicated in Table 2. Safety compliance of EN50129 for the signaling interlocking verification and validation of various SIL levels are to conform to techniques or measures that are also presented in Table 2.

Table 2: SIL Compliance Approach. Interlocking verification and validation in accordance with EN50129 (Wang, Guiochet et al. 2018)

Techniques / Measures	SIL 1	SIL 2	SIL 3	SIL 4
1 Checklists	R: prepared checklists, concentration on the main safety issues		R: prepared detailed checklists	
2 Simulation	R		R	
3 Functional testing of the system	HR: functional tests, reviews should be carried out to demonstrate that the specified characteristics and safety requirements have been achieved		HR: comprehensive functional tests should be carried out on the basis of well defined test cases to demonstrate the specified characteristics and safety requirements are fulfilled	

2.9. Interlocking Computer Drawings

In the early days railway signaling was different in the sense that it did not depend on any software to function. That was the era of mechanical, electro-mechanical and electrical signaling, also known as relay-based signaling. This type of signaling was enough at that time because the complexity and speed signaling were different from modern signaling due to the recent requirements. These requirements changed with the revolutionary electronic railway signaling.

Railway signaling is quickly becoming the heart of the railway industry. Electronic signaling is complex, yet easier to design with much of the attention to detail focusing on the control of safety-oriented scenarios using a predominantly set framework (Du, Ma et al. 2018). Software safety tests are constantly being undertaken to effectively pick up and eradicate any errors that are caused by humans as it is inevitable (Luteberget, Johansen 2018). A development process is implemented to assess any safety critical case using the SIL framework. Figure 9 demonstrates how control tables are drawn using computer drawings and are source documents for the interlocking software development tests.

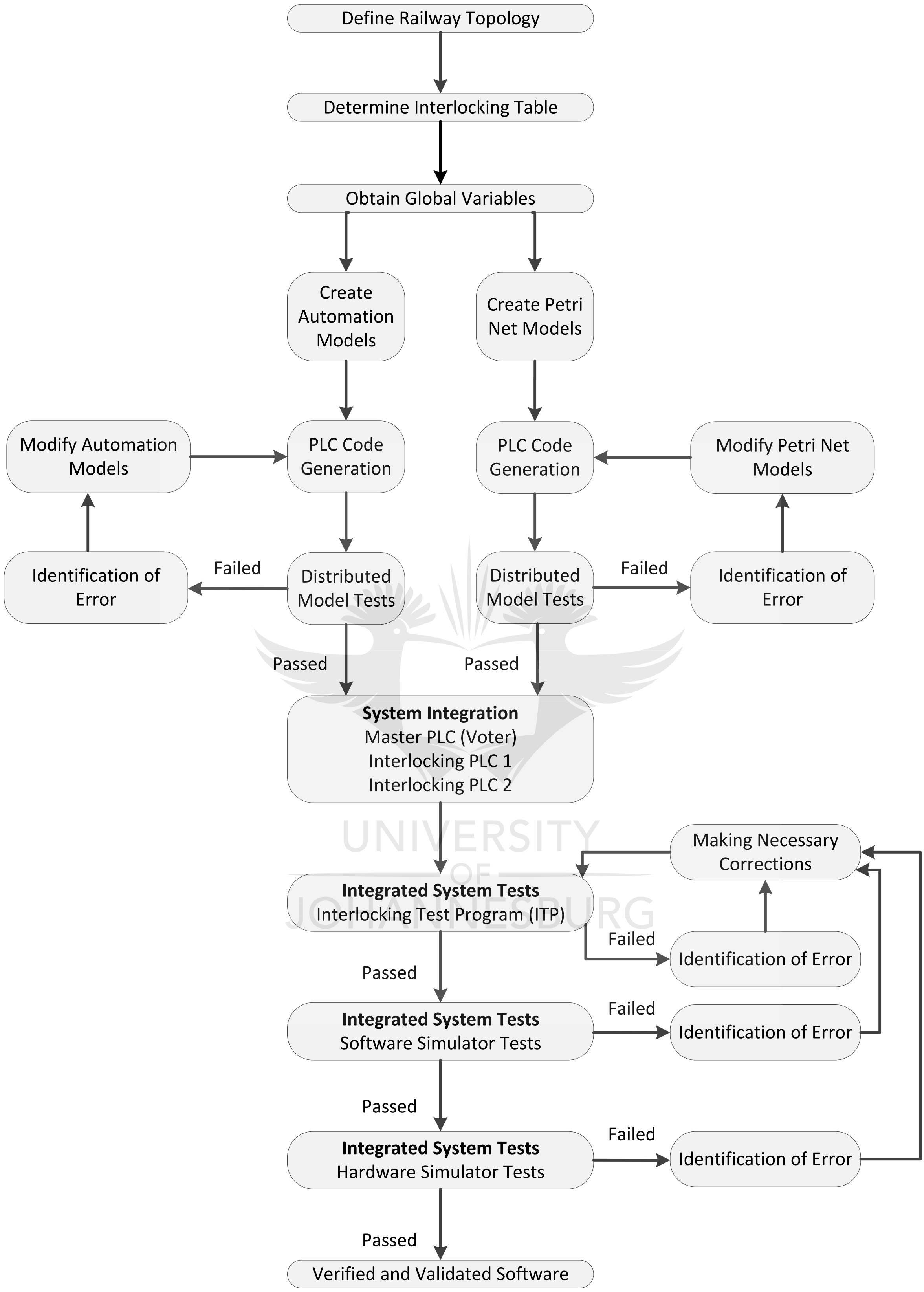


Figure 9: Software Safety Development Process (Durmuş, Yıldırım et al. 2012)

2.9.1. Software Risk Management

At the same time, a risk management process is applicable and adhered to when the control tables are being generated. The railway industry EN50126 safety standards are embedded to assess any significant changes using an evaluation and analysis of hazards approach. Figure 10 details this process. Each component of the risk management is safety-critical and is interconnected to each other component depending on the conditions or the outcome of it. Many high-risk systems that are safety critical have integrating information technology to allow for centralized monitoring and system control. This is known as non-trivial socio-technical systems (Crawford, Kift 2018).

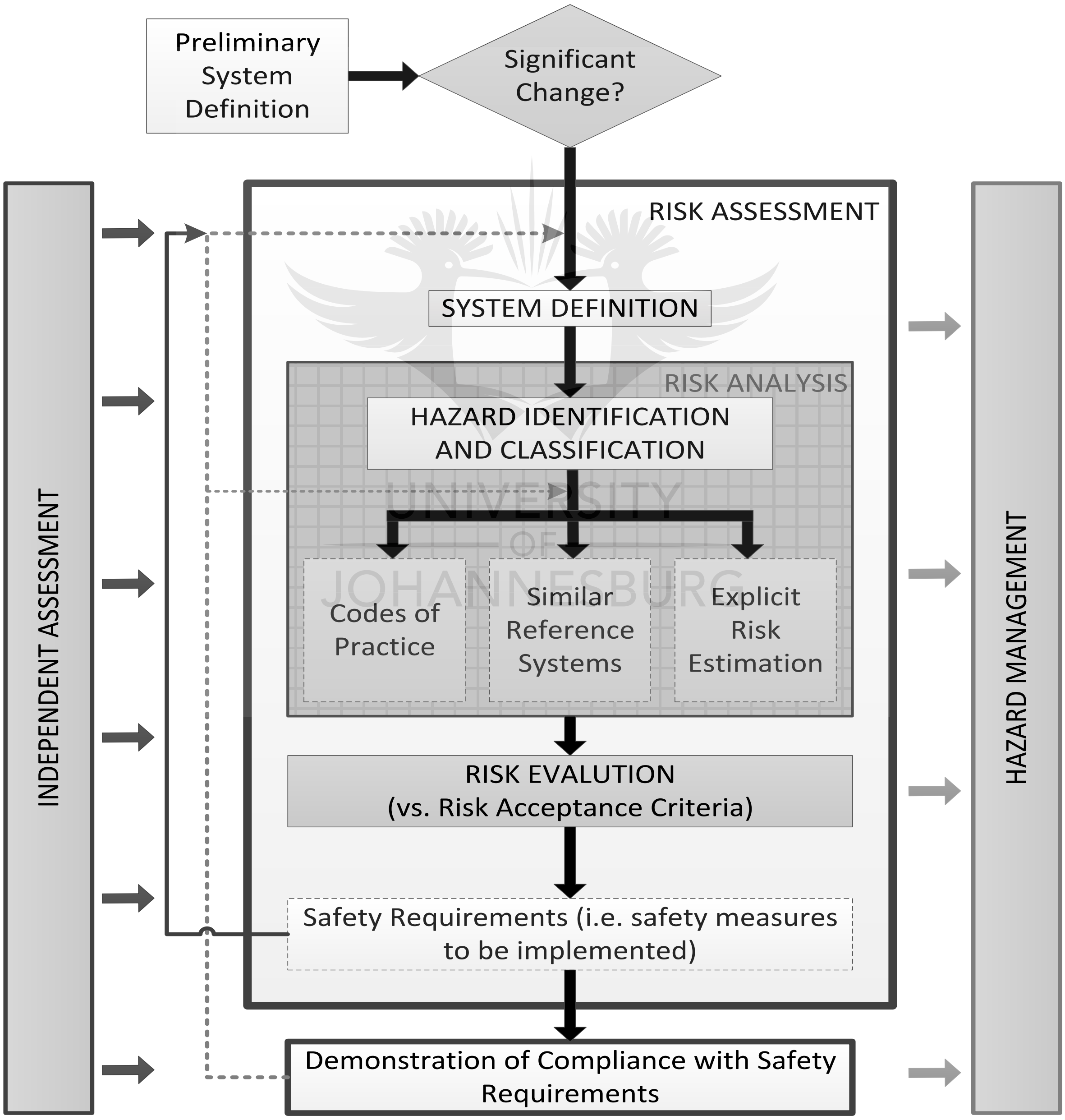


Figure 10: Risk Management Process (Ouedraogo, Beugin et al. 2018)

2.9.2. Source Document Design

With safety taking priority in railway signaling designs, it is important to note that railway signaling engineers are part of the development of the modelling framework. Should any errors occur, it is valuable to maintain and comply with system checks by verification and validation of the conditions on the control tables. The control tables are produced using the following signaling designs in the order presented in Table 3.

Table 3: Signaling Design Stages

Signaling Design	Drawing Design Type
1) Civil Drawings	Conceptual Design
2) Line Plans	Preliminary Design
3) Cable Plans	Preliminary Design
4) Front Sheets	Detailed design
5) Route and Overlap Sheet	Detailed design
6) Aspect Sheets	Detailed design
7) Book of Circuits	Detailed design

This is the basic sequence of producing signaling designs. The control tables consist of the front sheet, route and overlap and the aspect sheet (Bonacchi, Fantechi et al. 2016). Figure 11 demonstrates the basic systematic route request as per the control sheet request whilst Figure 12 indicates the front sheet, control table, and route release table.

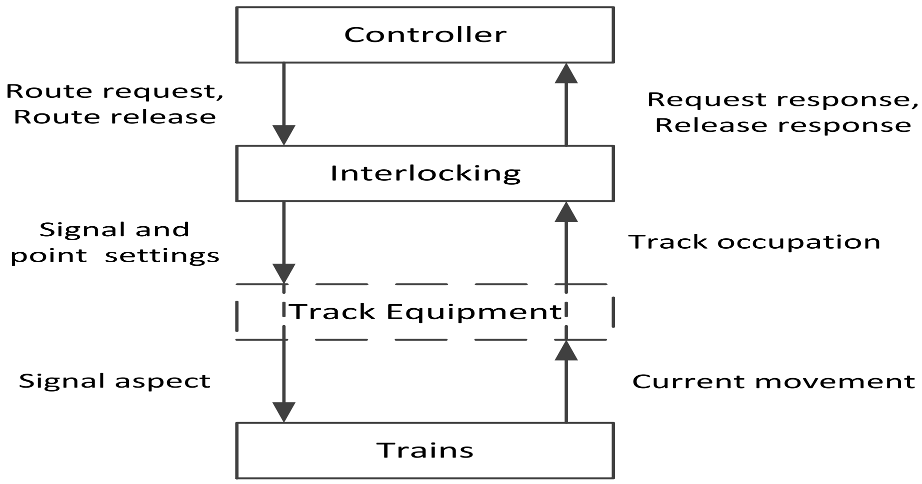
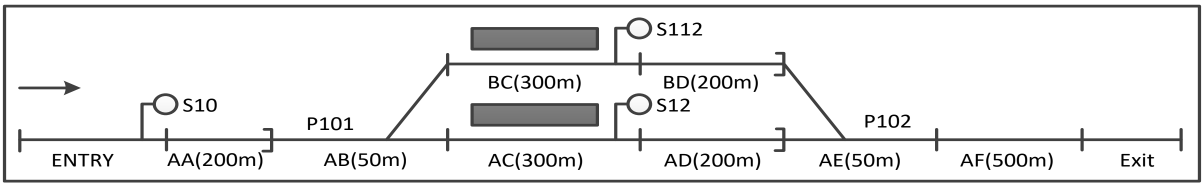


Figure 11: Route Request Topology (James, Moller et al. 2014)



Control table

Route	Normal	Reverse	Clear
R10A	P101		AA, AB, AC, AD
R10B		P101	AA, AB, BC, BD
R12	P102		AD, AE, AF
R112		P102	BD, AE, AF

Release tables

P101	Occupied
R10A	AC
R10B	BC

P102	Occupied
R12	AF
R112	AF

Figure 12: Basic Control Tables (James, Moller et al. 2014)

The front sheets reflect the 2-dimensional (2D) schematic station layout depicted from the line and cable plans (Luteberget, Johansen 2018). It is basically a compressed line plan station layout with the focus on highlighting the route elements such as signals, points, and tracks.

2.10. Summary

The literature review demonstrates that the interlocking is the vital part of the signaling system that processes commands from the train control officer within defined safety criteria. It also controls and monitors the state of the outside signaling elements including the track occupied and free information, signals and the points. In addition, the interlocking provides information regarding the state of the elements to the train control officer.

The purpose of this research is to identify the signaling gap within the literature that is presented. The identified gap that exists within signaling projects focuses on the automation of the signaling designs to possibly reduce the design time and stages. The designs form part of the interlocking and are the important safety aspects within the railway signaling industry.

The signaling specifications describe the general requirements of an electronic interlocking system that is to be considered during the design stages of a project. The requirements of a station or line that are to be improved or investigated are referred to in the methodology that is used.

Chapter 3: Research Design

3.1. Research Objective

This research paper focuses on implementing and improving design time by investigating a method of implementing autonomous signaling designing on railway signaling projects (Luteberget, Johansen 2018). Completing a project on time has economic and social benefits (Ma, Zhang et al. 2018). Automation of signaling designs also reduces human error and saves time and cost by reducing the number of review cycles before approval by the technical advisor (TA) and the client. The use of computer drawings enables other automation criteria that are used for producing the book of circuits (BOC) using the cable plan (CP) and the line plan (LP) that is produced by the draughtsman in the conceptual design stage. This is a measure to optimize the business by using automation on computer drawings on a project.

3.2. Research Design

The research design consists of methods and processes that were previously used to resolve railway signaling challenges within the industry. Previous research is used to assist with resolving similar challenges using similar methods for this research. The literature review from Chapter 2 identifies the gap within these challenges from previous research and enables a new research design to be expedited on re-signaling projects for the same industry. The main objective of the research design is to recognize the challenges and shortcomings within an organization and not substitute the current system but rather to make recommendations on improving that system.

Expediting the re-signaling scope of work for a project can be challenging because it requires extensive design hours and the checking process is intensive as it ensures that the safety requirements for operations are met. The initial phase of the design process commences with site survey activities that yield conceptual designs and conclude with an output design drawing document such as a line plan (Baviskar, Suryawanshi et al. 2018). This design document serves as a foundation for all subsequent detailed design drawings. The design stage and checking process takes a large amount of time to complete and affects the implementation stage of the project directly. This research aims at reducing the amount of time that is consumed during the design and reviewing stages of signaling designs on a project. Time constraint is a great challenge for railway signaling projects.

3.2.1. Research Methodology

The research methodology here is a systematic approach to resolving the challenges of a railway signaling project. There are various signaling functional and safety logic issues that adhere to signaling principles which enable railway specialists to conduct effective checks or audits on signaling designs. These signaling designs follow a sequence of signaling requirements and approval stages at each unique station per phase of a project. The safety requirements and signaling principles are essential and have been discussed in detail on the literature review. Figure 13 indicates the signaling design stages and checking processes that follow the CENELEC structure as a railway requirement (Wang, Guiochet et al. 2018).

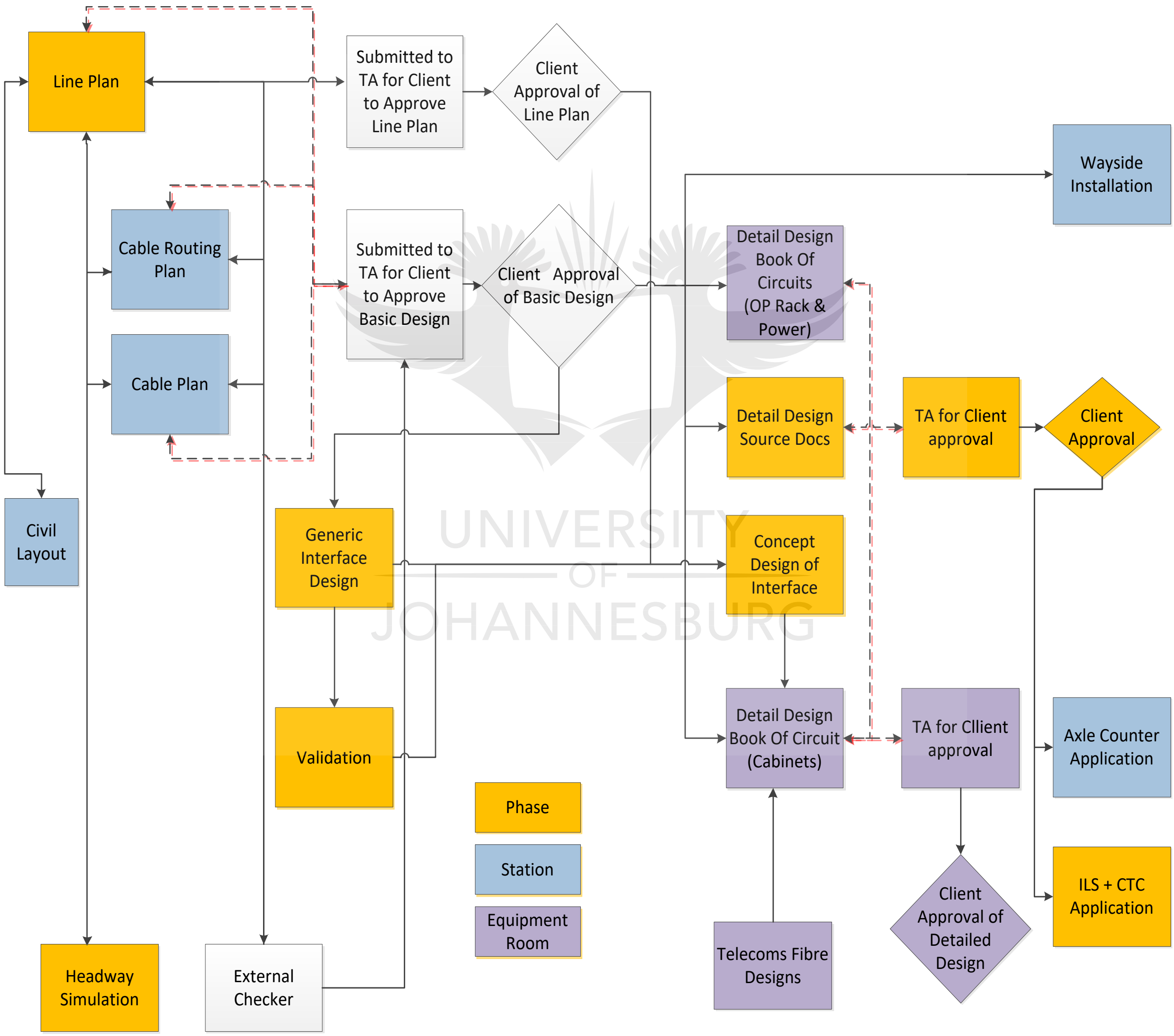


Figure 13: Design and Checking Process Flow

The checking process is defined by the CENELEC structure as a measure to ensure that the signaling designs comply with the safety requirements and signaling principles defined in the ROC (Jooste, Kannemeyer et al. 2012).

The research method applied uses a quantitative approach which focuses on the duration of the design time and checking time before the approval by the client. The problem statement is identified from the signaling industry where the delay time is magnified on re-signaling projects, possibly due to the design phase (Bonacchi, Fantechi et al. 2016). The primary source of the data are the archives of two previous re-signaling projects in South Africa from Cape Town in the province of the Western Cape and Durban in the province of KwaZulu-Natal. These data are taken over a period of four years, 2015 to 2018.

The existing data from the two projects will be compared with the proposed research data using automated signaling designing. The line plan forms the basis of the research methodology as all other signaling designs are generated from the line plan. Figure 13 illustrates the basic design stage outline and key inputs and influences on these design deliverables per phase, station and equipment room. The automation of the signaling designs follows this sequence:

1. The line plan produces the cable plan and the cable plan produces the book of circuits.

2. The subsequent process converts a Microsoft Excel file into a computer aided drawing that is required for the source document.

3. Source documents in Excel (.xlsx file) produce source documents in CAD format (.dwg file).

This process is an additional measure to reduce design and review time that is utilized to produce and check source documents that are initially generated on a computer drawing.

3.2.2. Data Collection

The data are extracted from tracker files and design logs from the year 2015 to 2018. The time frame is small to minimize the risk of data-overloading. Tracker files are chosen for the purpose of this research due to availability and that the existing data are using recorded tables and design logs. The data are extracted from two railway re-signaling projects and filtered according to the designs that are eligible for comparison in terms of variables such as design time frames, resources and safety. A total of five stations with less than thirty elements are selected for both projects. The data are extracted from signaling design logs and submission transmittals for signaling designs such as line plans, cable plans, book of circuits and source documents. The data variables on the signaling designs were chosen due to their extensive design time, the number of employees required and the detected number of errors that it takes to produce and review these designs. The data within the two projects may differ due to different system architecture requirements. Additionally, it is important to note the review cycles could possibly be affected by system complexity such as interlocking (Stankaitis, Iliasov 2017) and the different station layouts of the two projects.

3.2.3. Sampling Method

A sample of the data is taken from the archives based on the station size which is determined by the number of elements on a station. There is a buffer of five design stations per project with less than 30 elements per station of the selected line plans for both projects. For the purpose of the research, all the signaling designs where the automation is applicable are selected, making a 100% sample. The automation of signaling design possibility is determined by computer-aided drawings (.dwg files) that have different layers such as the line plan, cable plan and the book of circuits. The criteria epitomize the sampling method that reflects the best data selection in terms of credibility and reliability.

3.2.4. Research Process

Railway signaling designs are categorized according to three main design streams. These streams are the conceptual, preliminary (known as the basic) and the detailed design. The research process focuses on the automation from the preliminary designs to the detailed designs, that is, the line plan to the cable plan, book of circuits and lastly, source documents. The signaling design data are collected from two projects and compared with the data collected from the automated signaling designs to establish possible time reduction during the design phase on re-signaling projects. The automation of signaling designs is coordinated using layers on computer drawings. These layers represent different elements of a station layout and are programmed to produce a successive signaling design through automation. The signaling drawing standards require that each element be placed on a different layer (Durmuş, Takai et al. 2015). The layers represent the following elements:

- Signals Layer: Contains all elements of type signal.
- Tracks Layer: Contains all railway lines applicable to the design.
- Axle Counter Layer: Contains axel counter heads which divides the railway line into sections.
- Points Layer: Represent the points machine used for switching between rails.

3.2.5. Data Analysis

This research paper uses a quantitative approach as a method for justification to reflect the amount of time that is utilized during the design phase. The data collection considers review cycles from each of the reviewers as a measure to ensure a fair comparison of the design durations.

The approach used in the data collection process for automated signaling designs is described in Chapter 4. These data are compared with the data from the two projects and are covered in the same chapter. The intention is to examine the content of the quantitative data.

3.2.6. Research Considerations

The research is conducted with a few considerations such as time due to project requirements and is limited to the following:

- Automation of the cable route plan (CRP) requires extensive research and therefore produced manually as this was not defined in the line plan.
- The application programme does not define new elements or blocks, it merely manipulates the existing element to create a different design.
- The sampling method covers a limited scope of work due to early termination on one of the two projects.

3.3. Research Summary

This chapter focuses on a critical method that depicts a time reduction of the design phase by using automation to reduce delays on re-signaling projects. The literature review assists in identifying a suitable method to produce the best comparative results. The sampling method selected covers enough diversity in terms of signaling designs to yield the results that reflect an achievable design time frame on projects. Data collection is limited due to one of the two projects being terminated early. Additionally, the time for this research is constrained due to the agreed contractual time frame. The automation of the detailed signaling designs improves the process and duration of completing the design phase on time greatly.

Chapter 4: Data Analysis and Results

4.1. Introduction

This chapter focuses on studies that investigate various comparative analysis methods from data collected on two projects. These data are depicted from documentation, transmittals and tracking files such as logbooks, receipts and spreadsheets. Due to the comparative analysis methodology, a quantitative research approach is used to reflect the design time frames, resources and safety checks that are aimed at targeting design errors.

The automation of the preliminary design to the detailed design is selected as a measure to mitigate delays on projects because the automation of these signaling designs has a pivotal role in providing data to support the current research. A comprehensive comparison of the various projects is reflected in this chapter of results. The research questions originate from the current situation of using manual signaling design generation and this chapter aims at analysing the results to interpret the extent to which the research questions are answered based on automation of generating railway signaling designs.

4.2. Creating the research environment

Data are collected and tabulated on spreadsheets and graphical representations of the required data are presented and form part of the results in this chapter. The stations selected for this chapter have a set limit in terms of the number of elements, as mentioned previously in section 3.2.3. There are five stations that are identified within the selected set limit for two projects. The intention is to set up and configure a programme such as Visual Studio or an equivalent and then automate the generation of signaling designs.

4.3. Automation Configuration

The automation process requires that all railway signaling designs are drawn on a computer drawing programme due to project requirements. The configuration of the manual design generation is compared with the automated design generation. For the purpose of this research, the computer drawing programme AutoCAD 2014 – API is used.

A preliminary design such as the line plan enables the first steps of generating signaling designs leading to the source documents as the final detailed design. Figure 14 indicates the focus area of the research that is extracted from an electronic interlocking system architecture. The generic product is the fundamental system that defines the interlocking product whilst the generic adaptation is merely the rules and regulations that are governed by the generic product for a specific country or region. The results in this chapter are determined by the engineering tools and processes of the specific adaption where automation of a specific station design is applied.

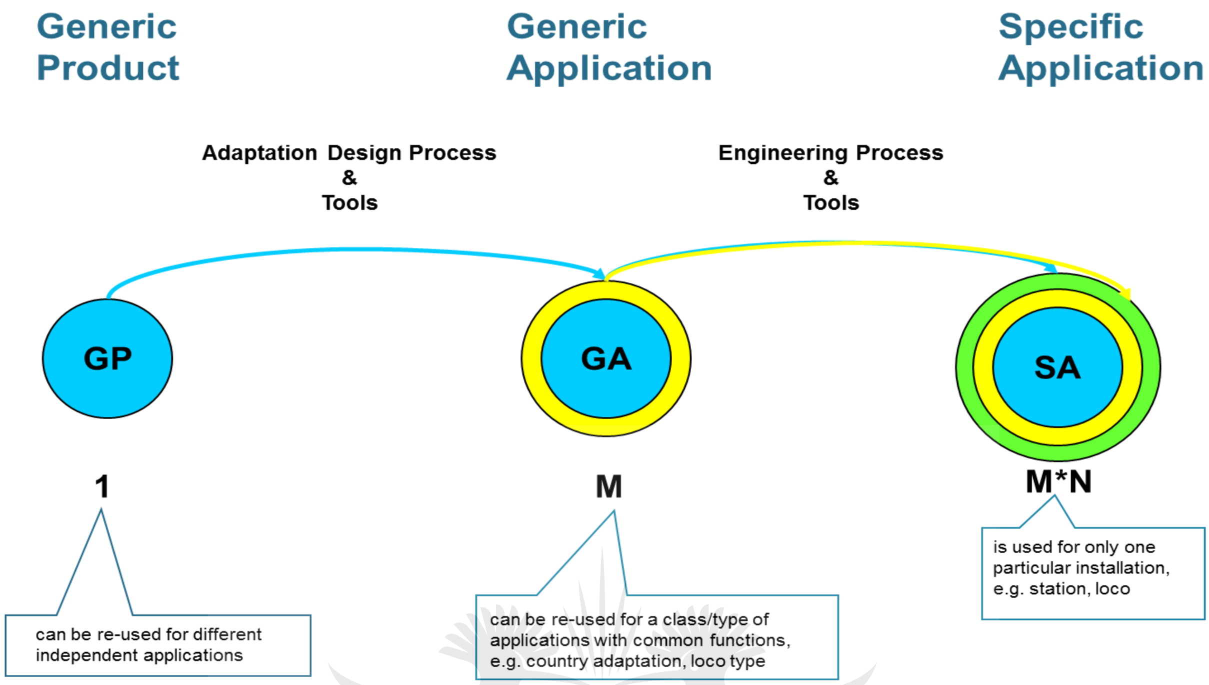


Figure 14: Specific Application for Elements in use

This research focuses on the importance of the specific adaption for generating the preliminary designs in the shortest time using manual design generation versus automation design generation and the impact that it has on the design definition process. The design definition process reflects the steps taken from the input, task and output of the signaling design generation.

Figure 15 illustrates the design definition process using a three-step approach used for the signaling design generation.

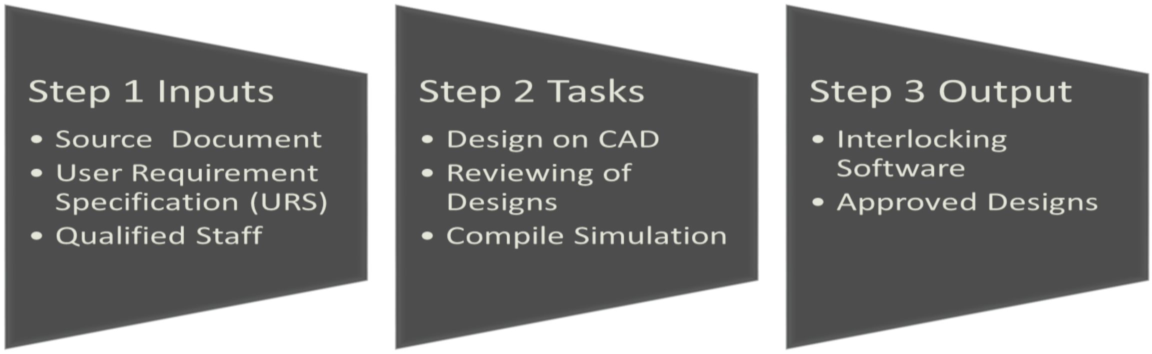


Figure 15: Steps to follow for the Design Definition Process

The design definition process applies a system engineering principle enabled by using the data that are extracted from documentation collected from the projects covering the ten stations. The data serve as the base for the configuration of all design comparisons in this research. Table 4 indicates the number of elements utilized for each line plan per station.

Table 4: Selected Number of Elements per Station

Elements on Western Cape Project					Elements on Durban Project				
Dieprivier	Bellville	Retreat	Wynberg	Steenberg	Pinetown	Montclair	Bayhead	Duffs Rd	Effingham
25	30	22	25	19	22	27	29	30	23

The number of elements reflected on each station is an indication of the complexity of the functions for that station. The number of elements is also a good indication of the design time that is currently being consumed on both re-signaling projects. The production of signaling designs for re-signaling projects covers an extensive design scope of work and requires an intensive checking process to ensure that the operational safety requirements are met.

4.3.1. Application Tool Activity

The line plan drawing serves as the base for all subsequent detailed design documents. All elements on signaling design drawings are grouped according to layers. The manual design generation has these layers for railway design requirements but not for automation purposes. An application tool is used to extract elements using these layers for automation purposes. Visual Studio is an application tool that is configured to operate on .net framework which functions on C#.Net language. A pseudo-code is followed to automate the signaling drawing designs whilst complying to the signaling drawing standards. The signaling drawing design standards require that each element be placed on a different layer. The application tool calls for the following crucial layers:

- Signals Layer: Contains all elements of type signal.
- Tracks Layer: Contains all railway lines applicable to the design.
- Axle Counter Layer: Contains axle counter heads (ACH) which divide the railway line into sections.
- Points Layer: Represents the Points Machine used for switching between rails.

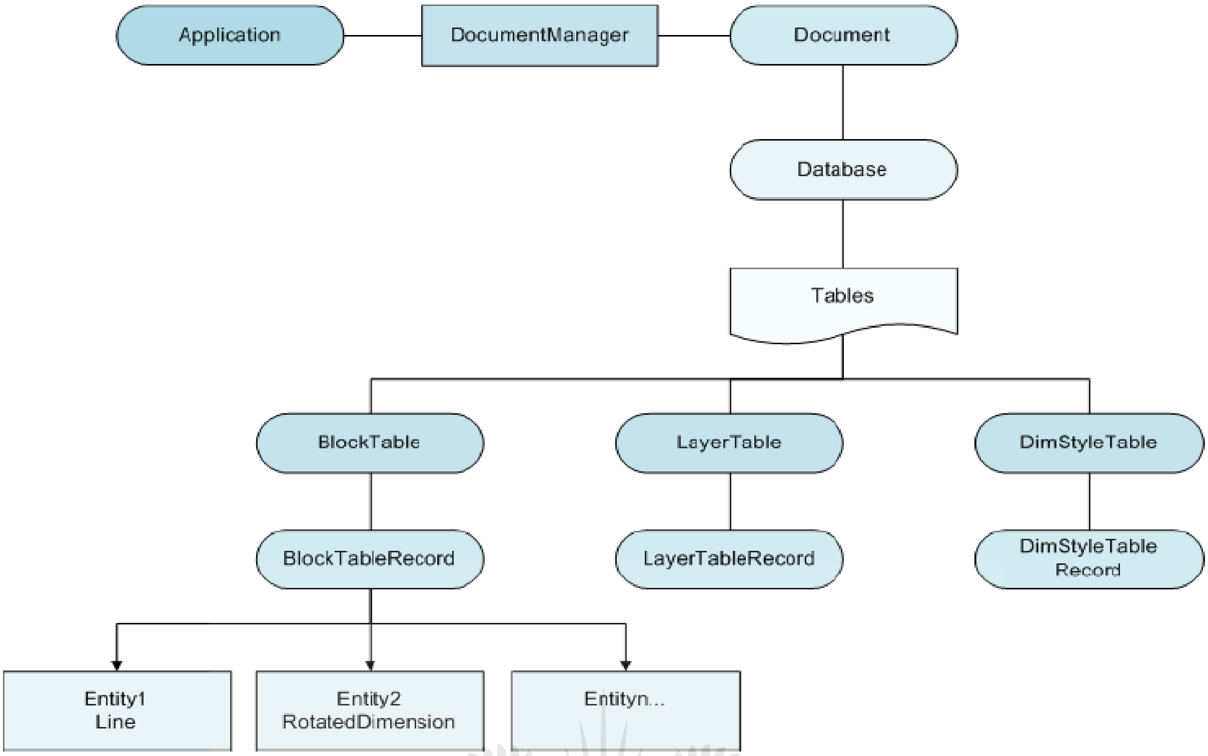


Figure 16: Automating by Extracting Elements

The different layers enable the application tool to extract the elements separately by automating the line plan to produce the cable plan. A systematic pseudo-code approach is presented in Figure 16 on how the process flow is structured within the application tool.

4.3.2. Drawing Activity

The current configuration of manual design generation for detailed design documents and drawings may take a few years to produce depending the project scope. Additionally, the subsequent checking process is complex and may potentially delay the initial implementation of a project. Automating the signal design generation process requires less time when using an application tool. Figure 16 uses an application tool (Visual Studio) that aims at reducing the lead time of producing and checking the detailed design documents.

The next stage is initiated by configuring all elements in their correct layers as presented in the screenshot in Figure 17. The elements are selected in groups and assigned to layers in alignment with the sample method stated in section 3.2.3.

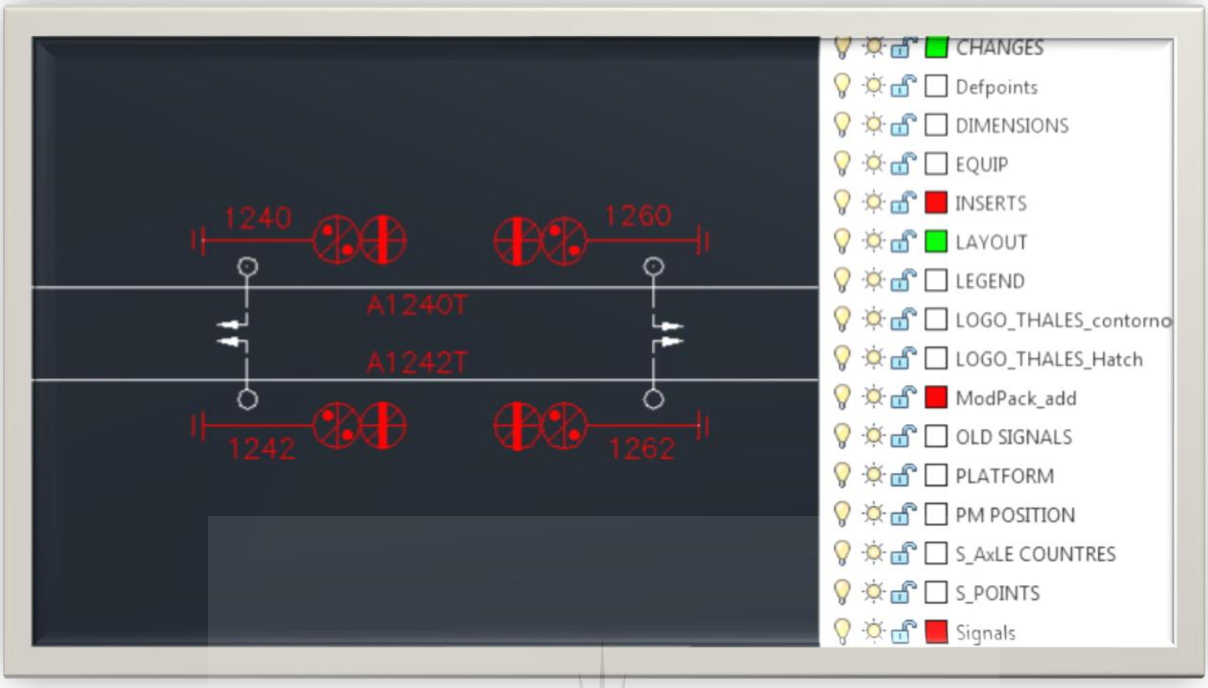


Figure 17: Allocating elements to layers

The allocation of the elements to their specific layers also enables the counting of elements to determine the stations that qualify for comparison for this chapter. In instances where an element comprises of multiple parts of the same layer, such as the 'S_Axle COUNTRES' (as presented in Figure 17), these individual parts of the same layer are merged and grouped collectively to form a single element. The element is counted as a single element as seen with the axle counter head (ACH).

4.3.3. Excel as a Drawing Tool

The automation execution is deduced from the pseudo-code using an excel spreadsheet configuration to generate the book of circuit and source documents from the cable plan. This process is enabled by extracting elements from the cable plan and applying automation configuration procedures of the pre-defined layers for each element to produce detailed designs. The layers are retrieved as elements and serve as an input for an Excel file template. The Excel spreadsheet has two parts. The first automation tool uses the excel spreadsheet to tabulate and convert the source document into the required CAD (.dwg) file. The second automation tool uses the Excel spreadsheet to convert elements such as axle counters to produce that section of the book of circuits. The results of automating signaling designs using the various methods are reflected in the next section.

4.4. Results of the Application Tool

The cable route is manually drawn and configured on AutoCAD as it is not defined as part of the initial line plan elements. The application does not define new elements or blocks, it merely manipulates the existing elements to create a different signaling design. After successful execution of the pseudo-code, the output result for the cable plan is produced from the line plan. This is presented in Figure 18.

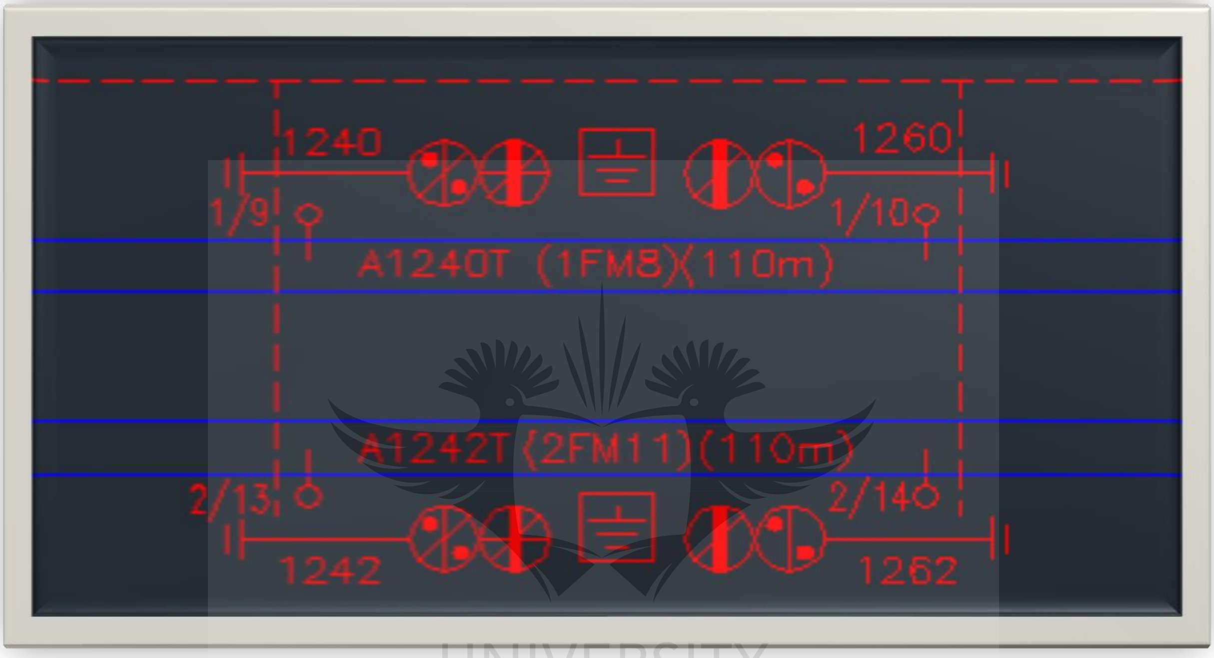


Figure 18: Sample Results of a Cable Plan Group

The next section reflects the extracted documentation data from the design logs and tracker files. The data are represented in a form of duration per design and are taken from the start date of the design to the end date of the design, taking into consideration whether the design is at the production, review or approval stage.

It is important that the signaling designs adhere to a technical management process to ensure that the safety requirements are followed from the line plans to produce a safe final product for the signaling interlocking. Steps are followed to complete the design phase with minimal design errors. The next section gives the results of the documentation collected from the projects.

4.4.1. Results for Signaling Design Comparison

Figure 19 demonstrates the results of documented data from both projects. The data presented include a combination of the four main aspects of the basic and detailed design such as the line plan, cable plan, book of circuits and source documents. These signaling designs are translated from the number of elements on each station and are compared to the signaling designs that are generated using automation. The elements are wayside equipment such as signals, point machines, axle counters (detection points) and track sections. (Luteberget, Johansen 2018) explains that the automated designs have a few errors due to station layouts that require unique signaling principles and safety regulations. The results in Figure 19 indicate a gap to improve the current manual design approach, and whether automation of computer drawings for signaling detailed designs from the preliminary designs is the solution for business optimization in railway projects based on the results from the Western Cape and Durban projects. The results demonstrate that the design durations on both projects are exceeding the projected completion target durations. Automating the design processes reduces the design durations extensively with less resources and safer design solutions. Figure 19 is a graphical representation of the raw data. The durations are calculated using this formula: Duration (Days) = End date of the design – Start date of the design

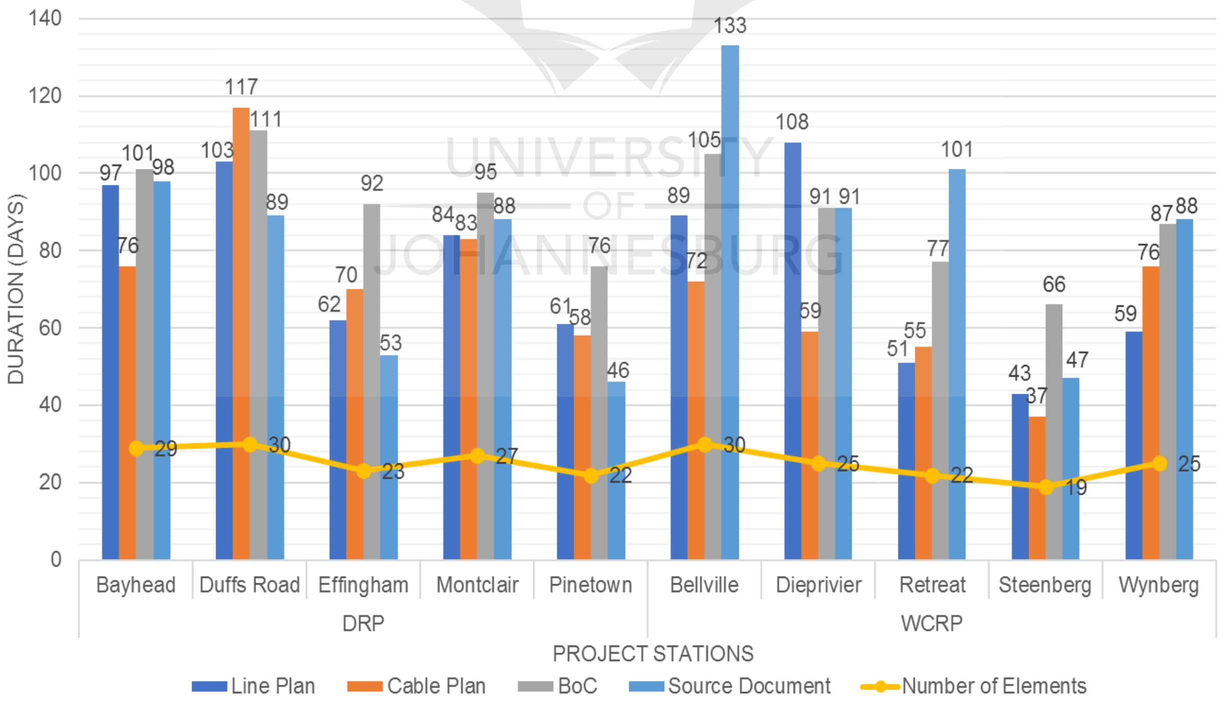


Figure 19: Results from Documented Data of Manual Designs

The X-axis and Y-axis reflect the stations of both projects and the design durations respectively. The results indicate that there is an improvement when generating signaling designs through automation. All signaling design durations reflect on average 50 percent above the estimated design durations on both projects based the number of elements on each station. The difference in durations have a significant impact on the next stages of the project and possibly delay the project if the time lost is not recovered at different phases of the project. The measure points (durations) are taken directly from the design log documentation of the design and review stages presented in section 3.2.1 using a CENELEC structure and approach to railway requirements (Wang, Guiochet et al. 2018)

The time taken to automate the cable plan to the source documents from the original line plan is generated by the amount of time it takes to execute the pseudo-code. Figure 20 demonstrates that the line plan takes a comparatively larger amount of time to create in relation to the automation of detailed designs. The important point to note is that the manual design generation of the preliminary design such as the line plan consumes a high amount of design time with both approaches of the research. The duration for generating the signaling designs includes the checking time of each design as there are errors that require correction prior to submission and then review by the technical advisors and approval by the client. The results in Figure 20 are very different to the results generated through the manual design generation presented in Figure 19**: Results from Documented Data of Manual Designs**

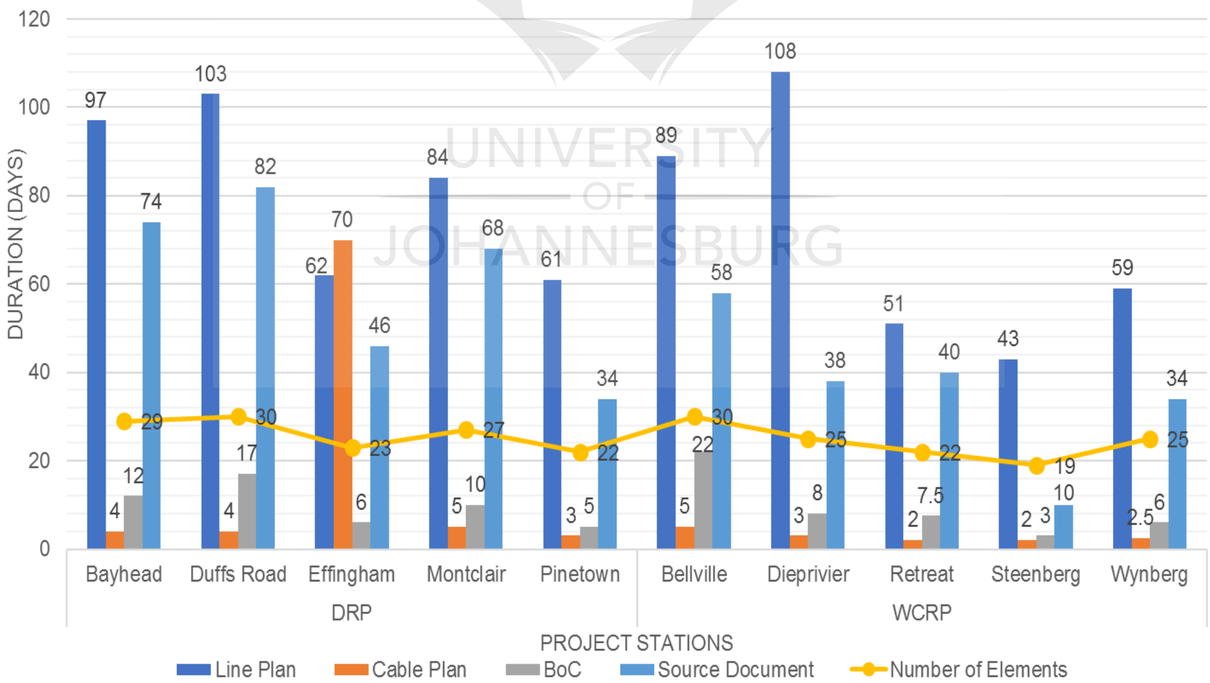


Figure 20: Design Results Through Automation

The results indicate a decrement of about 55 percent in the project design duration when comparing the manual design generation with the automated design generation of the signaling detailed designs. The results indicate a significant improvement when generating automated computer drawings of the detailed designs. These results also reflect efficiency for the cable plan, book of circuits and source documents, all of which have a direct relation to project deliverable duration targets. This affects both organizations positively with the Western Cape research project (WCRP) results reflecting the most improvement on the cable plans compared to the Durban research project (DRP). The research results above indicate that the automation of signaling design drawings optimises the business for both organizations, WCRP and DRP. The comparison of the associated resources required is presented in the next section.

4.4.2. Design Resource Assignment

This section compares the resources required. The comparison is based on the number of resources required between designs that are created manually and designs that are created through automation. The creation of the line plans requires four resources with both approaches due to the initial manual design creation. The results are generated from the creation of signaling designs from line plans, cable plans, book of circuits and the source documents using manual and automated design generation. The results reflect a reduction in resources when using design automation in comparison to manual design of signaling drawings.

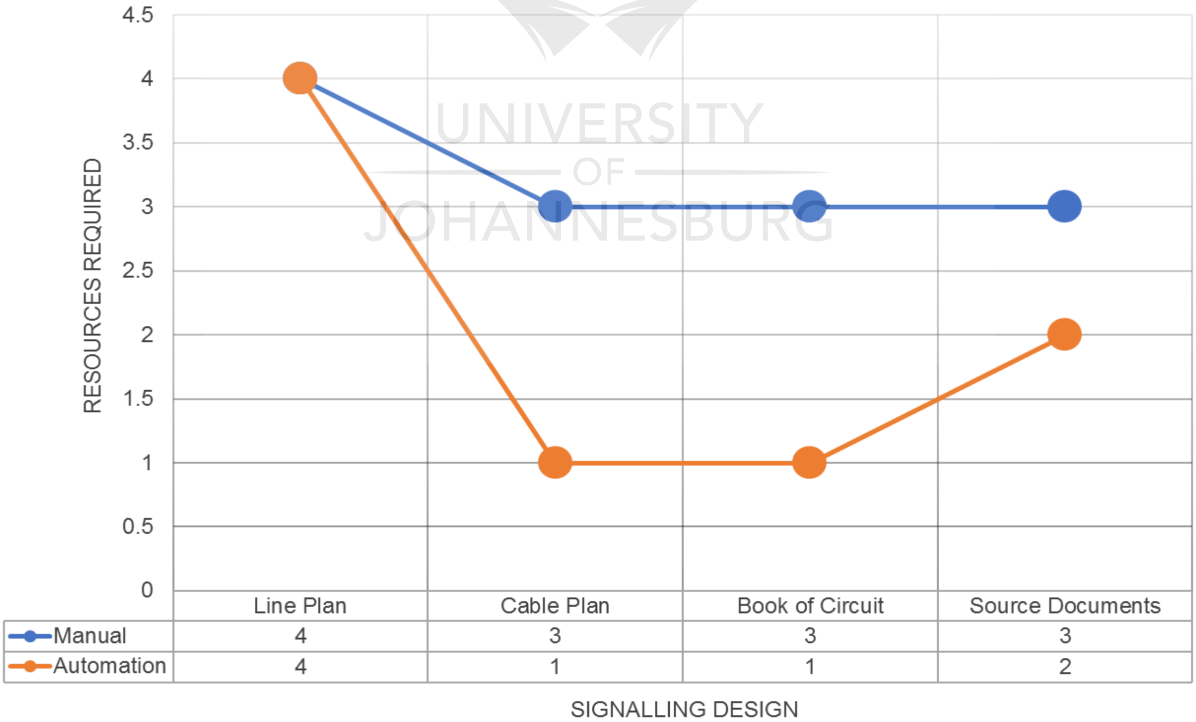


Figure 21: Resource Comparison of Results

The results demonstrate a significant difference in design resources. The number of resources used for the design of cable plans, book of circuits and source documents is reduced when automating detailed designs. The detailed designs are all signaling designs that follow from the line plan. The resources required when automating detailed designs are reduced by two thirds for cable plans and book of circuits and reduced by one third for source documents. These results demonstrate that automating signaling designs enables the signaling engineer to generate signaling detailed designs without depending on the draughts-person and a design review engineer.

Figure 22 indicates a breakdown of the results pertaining to resource durations that are required for the manually generated designs compared to the designs that are generated through automation. Figure 22 indicates a detailed breakdown of both projects, reflecting the resource duration of the manual design generation and the automated design generation extracted from Figure 19 and Figure 20. The research results indicate clearly that there is great dependence on the signaling engineer when automating the designs in comparison to the manual design generation on both projects. Furthermore, the results indicate that the duration required to produce the detailed design through automation is less than that of the manual design. The duration for generating signaling designs also has a direct influence on the resources required, as presented in Figure 21. The research results therefore demonstrate that business optimization is attained through automation of signaling designs.

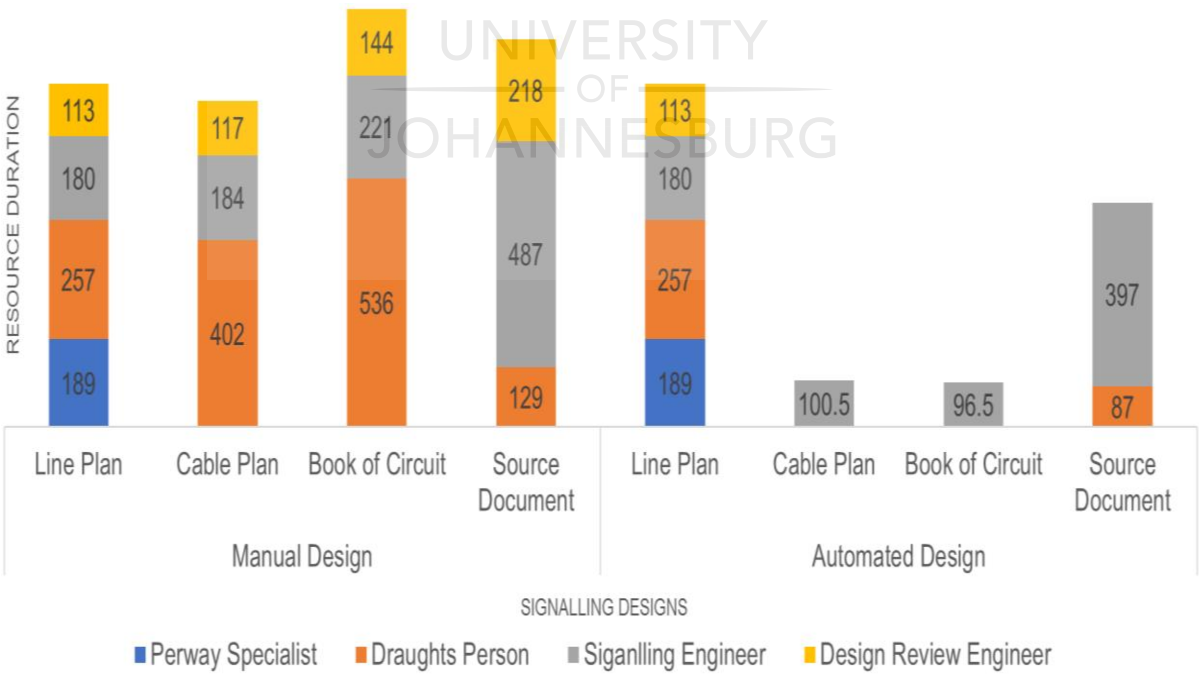


Figure 22: Results of Resource Durations

The results reflect that the resources required using automation design are less than the resources required for manual design for various reasons such as drawing tools, computer programmes and the skills of the signaling engineer. This means that the signaling engineer has sufficient time for manual adjustments and reviewing of designs in comparison to employing additional resources for these tasks (Baviskar, Suryawanshi et al. 2018, Luteberget, Johansen 2018). Subsequently, the compliance with safety requirements and signaling principles is attained using remedial action for design errors that do not conform to railway signaling requirements.

The next section of the research results revisits the review process by focusing on the comparison of the number of review cycles when designs are generated manually compared to designs generated through automation. These results are an indication of the review cycles dated from 2015 to 2018.

4.4.3. Compliance of Safe Signaling Principles

Figure 23 illustrates the total number of review cycles of source documents from both projects. The source documents are selected for the research due to the precise accuracy that is required for the generation of the ILS. The source document carries critical safety principles that may result in a catastrophic situation if a project is designed or configured incorrectly. The results indicate that the signaling design engineer can complete all design tasks originating from the line plan when using signaling design automation in comparison to a manual signaling design. The creation of the signaling designs using automation takes a few minutes to execute with additional time consumption on reviewing and manually adjusting each signaling design. Due to complex station layouts, the signaling engineer reviews and updates unique cases that are inaccurate during the automation process for compliance with safety requirements and signaling principles (Jooste, Kannemeyer et al. 2012, Luteberget, Johansen 2018). These inaccuracies affect the ATP, UTO, DTO and EN50129 safety requirements. It is a requirement that all signaling designs and comply with SIL 4 structure (Wang, Guiochet et al. 2018).

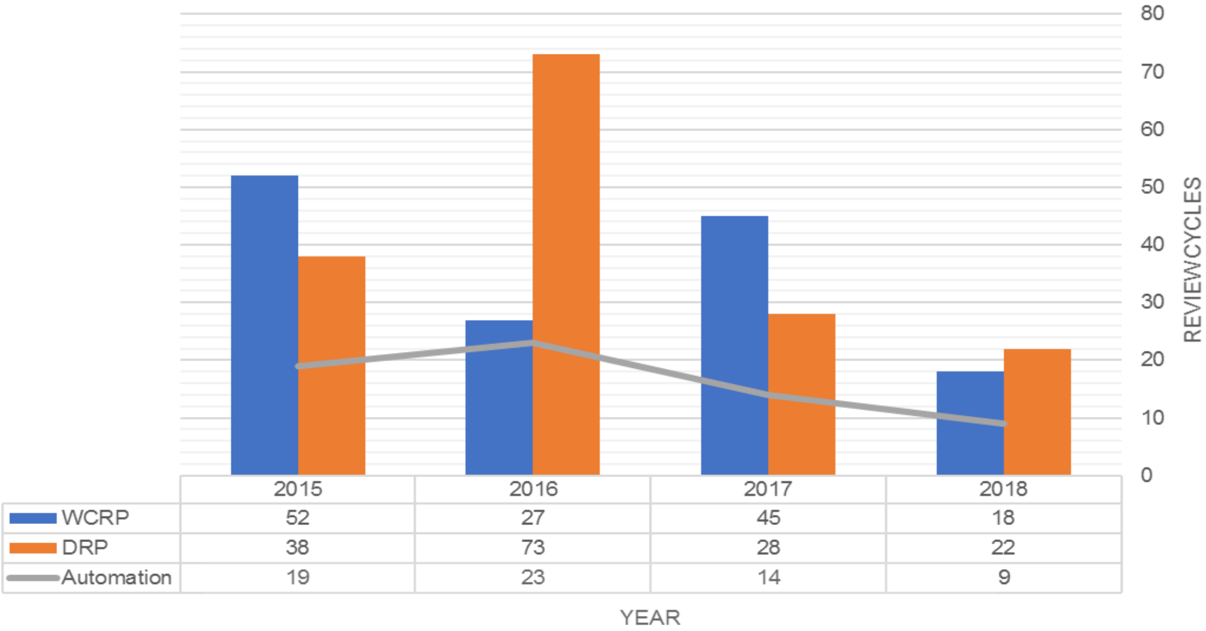


Figure 23: Review Cycle Results

The results reflect a decrease in the number of review cycles on source documents for both projects when generating signaling designs through automation. From 2015 to 2018 the review cycles decrease on average as a result of alignment between the signaling design engineers and reviewers over time. These results also reflect a reduction in the number of review cycles through automation due to the fine tuning or modification of the automation tool.

4.5. Summary of Results

The results in this section use a comparative approach to demonstrate the impact of using automation to generate railway signaling designs originating from line plans to source documents. The data generated in this research are extracted from documentation of the projects and form the basis of the quantitative analyses to generate reliable and credible results. Signaling engineers have additional time to review and manually adjust railway signaling designs after execution of design automation. The adjustments ensure design consistency by adhering to signaling principles and safety requirements. The results obtained consider design durations, resources required and compliance with safety principles. Design automation takes less time than manually generated designs.

Chapter 5: Conclusion and Recommendation

5.1. Conclusion

Signaling design automation has a significant impact on generating railway computer drawings as opposed to manual generation. The research results demonstrate key aspects to mitigate project delays in areas such as the project detailed design duration, resources required and safety within signaling designs by focusing on the number of review cycles in designs. The automation of the computer drawings for the signaling detailed designs from the preliminary designs is the solution for business optimization in railway signaling because this research finds that the manual generation of signaling designs is found to consume around 50 percent more of a project's projected duration in comparison to the automation of generating signaling designs that consumes around 55 percent less of a project's manual design duration.

This research finds that less resources are required for computer drawings that are generated using automation tools in contrast to computer drawings that are generated manually by a draughts-person. The resources required when automating the generation of signaling detailed designs are reduced by two-thirds for cable plans and book of circuits and reduced by one third for source documents. This means that the business is optimized by utilizing less resources and subsequently the risk of delays during the design stage is reduced. Moreover, the business optimization is greatly achieved and in compliance with CENELEC.

Railway signaling safety is critical and must conform to the governing safety standards and requirements (EN50126) and comply fully with the interlocking verification and validation in accordance with EN50129. It is imperative that detailed designs such as source documents do follow this standard due to the safety functionalities that are embedded as part of the design generation. This research demonstrates that an approach from two projects encompasses the SIL 4 requirements by eliminating the risks associated within its interlocking module. As a result, the review cycles are decreased using an automated generation of signaling designs as opposed to a manual design generation within the various review stages of a project as stipulated in the design and process flow. It is from the review stages to implementation phase that the associated organizations benefit from business optimization through automated signaling design. This means that re-signaling projects have a great chance of being completed on the forecasted contractual end date. Railway commuters will benefit from the stipulated contractual end date and enjoy railway operations with fewer signaling glitches and interruptions across all signaling systems.

5.2. Research Limitation

Business optimization through automated signaling design is based on a computer drawing and limits the research to generate automated signaling designs using AutoCAD. This compromises the use of alternative drawing methods that are required for the automation tool and South African railway requirements.

5.3. Recommendation for Future Research

Future research should consider automation methods to generate railway signaling designs from the conceptual design stage using various or alternative computer drawing tools that are available at the time.

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Appendices

Appendices of raw data tracker files relating to designs that are generated manually.

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		Signalling											
				Preliminary Design									
Project	**Station**	**Line Plan**											
		Production		IDC		EDC		TA		PRASA		Doc	Ver
DRP		50.00%		15.00%		15.00%		15.00%		5.00%			
	BAYHEAD	5/15/2018	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	8/20/2018	TRUE	DRP BMC SIG BWD 2.3 DWG 00001	0XE
	DUFFS ROAD	11/12/2017	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2/23/2018	TRUE	DRP BMC SIG BWD 1.1 DWG 00002	0XH
	EFFINGHAM	6/27/2016	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	8/28/2016	TRUE	DRP BMC SIG BWD 1.3 DWG 00003	0XH
	MONTCLAIR	8/25/2015	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	11/17/2015	TRUE	DRP BMC SIG BWD 1.1 DWG 00004	0XH
	PINETOWN	10/15/2016	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	12/15/2016	TRUE	DRP BMC SIG BWD 3.3 DWG 00005	0XG
WCRP		50.00%		15.00%		15.00%		15.00%		5.00%			
	WYNBERG	2015/01/16	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2015/03/16	TRUE	WCRP TMC SIG BWD 1.2 DWG 00001	0XJ
	DIEPRIVIER	2015/04/23	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2015/08/09	TRUE	WCRP TMC SIG BWD 1.2 DWG 00003	0XL
	RETREAT	2015/04/27	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2015/06/17	TRUE	WCRP TMC SIG BWD 1.2 DWG 00004	0XH
	STEENBERG	2016/02/03	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2016/03/17	TRUE	WCRP TMC SIG BWD 1.2 DWG 00005	0XM
	BELLVILLE	2017/09/14	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2017/12/20	TRUE	WCRP TMC SIG BWD 4.1 DWG 00002	0XL

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		Signalling											
				Preliminary Design									
Project	**Station**	**Cable Plan**											
		Production		IDC		EDC		TA		PRASA		Doc	Ver
DRP		50.00%		15.00%		15.00%		15.00%		5.00%			
	BAYHEAD	8/22/2018	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	11/6/2018	TRUE	DRP BMC SIG CPL 2.3 DWG 00001	0XF
	DUFFS ROAD	2/25/2018	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	6/22/2018	TRUE	DRP BMC SIG CPL 1.1 DWG 00002	0XG
	EFFINGHAM	8/30/2016	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	11/8/2016	TRUE	DRP BMC SIG CPL 1.3 DWG 00003	0XI
	MONTCLAIR	11/19/2015	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2/10/2016	TRUE	DRP BMC SIG CPL 1.1 DWG 00004	0XD
	PINETOWN	12/17/2016	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2/13/2017	TRUE	DRP BMC SIG CPL 3.3 DWG 00005	0XF
WCRP		50.00%		15.00%		15.00%		15.00%		5.00%			
	WYNBERG	2015/03/17	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2015/06/01	TRUE	WCRP TMC SIG CPL 1.2 DWG 00001	0XH
	DIEPRIVIER	2015/08/10	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2015/10/08	TRUE	WCRP TMC SIG CPL 1.2 DWG 00003	0XY
	RETREAT	2015/06/18	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2015/08/12	TRUE	WCRP TMC SIG CPL 1.2 DWG 00004	0XK
	STEENBERG	2016/03/18	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2016/04/24	TRUE	WCRP TMC SIG CPL 1.2 DWG 00005	0XM
	BELLVILLE	2017/12/21	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2018/03/03	TRUE	WCRP TMC SIG CPL 4.1 DWG 00002	0XE

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		Signalling											
				Preliminary Design									
Project	**Station**	**BoC**											
		Production		IDC		EDC		TA		PRASA		Doc	Ver
DRP		50.00%		15.00%		15.00%		15.00%		5.00%			
	BAYHEAD	9/6/2018	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	12/16/2018	TRUE	DRP BMC SIG BOC 2.3 DWG 00001	0XE
	DUFFS ROAD	6/22/2018	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	10/11/2018	TRUE	DRP BMC SIG BOC 1.1 DWG 00002	0XH
	EFFINGHAM	11/8/2016	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2/8/2017	TRUE	DRP BMC SIG BOC 1.3 DWG 00003	0XG
	MONTCLAIR	2/10/2016	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	5/15/2016	TRUE	DRP BMC SIG BOC 1.1 DWG 00004	0XD
	PINETOWN	2/13/2017	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	4/30/2017	TRUE	DRP BMC SIG BOC 3.3 DWG 00005	0XD
WCRP		50.00%		15.00%		15.00%		15.00%		5.00%			
	WYNBERG	2015/06/01	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2015/08/27	TRUE	WCRP TMC SIG BOC 1.2 DWG 00001	0XE
	DIEPRIVIER	2015/10/08	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2016/01/07	TRUE	WCRP TMC SIG BOC 1.2 DWG 00003	0XF
	RETREAT	2015/08/12	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2015/10/28	TRUE	WCRP TMC SIG BOC 1.2 DWG 00004	0XD
	STEENBERG	2016/04/24	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2016/06/29	TRUE	WCRP TMC SIG BOC 1.2 DWG 00005	0XH
	BELLVILLE	2018/03/03	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2018/06/16	TRUE	WCRP TMC SIG BOC 4.1 DWG 00002	0XI

		Signalling											
				Preliminary Design									
Project	**Station**	**Source Doc**											
		Production		IDC		EDC		TA		PRASA		Doc	Ver
DRP		50.00%		15.00%		15.00%		15.00%		5.00%			
	BAYHEAD	9/11/2018	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	12/18/2018	TRUE	DRP BMC SIG SDC 2.3 DWG 00001	0XG
	DUFFS ROAD	6/27/2018	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	9/24/2018	TRUE	DRP BMC SIG SDC 1.1 DWG 00002	0XH
	EFFINGHAM	11/13/2016	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	1/5/2017	TRUE	DRP BMC SIG SDC 1.3 DWG 00003	0XC
	MONTCLAIR	2/15/2016	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	5/13/2016	TRUE	DRP BMC SIG SDC 1.1 DWG 00004	0XB
	PINETOWN	2/18/2017	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	4/5/2017	TRUE	DRP BMC SIG SDC 3.3 DWG 00005	0XC
WCRP		50.00%		15.00%		15.00%		15.00%		5.00%			
	WYNBERG	2015/06/04	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2015/08/31	TRUE	WCRP TMC SIG SDC 1.2 DWG 00001	0XE
	DIEPRIVIER	2015/10/11	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2016/01/10	TRUE	WCRP TMC SIG SDC 1.2 DWG 00003	0XE
	RETREAT	2015/08/15	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2015/11/24	TRUE	WCRP TMC SIG SDC 1.2 DWG 00004	0XD
	STEENBERG	2016/04/27	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2016/06/13	TRUE	WCRP TMC SIG SDC 1.2 DWG 00005	0XB
	BELLVILLE	2018/03/06	TRUE	Complet	TRUE	Complet	TRUE	Complet	TRUE	2018/07/17	TRUE	WCRP TMC SIG SDC 4.1 DWG 00002	0XJ