A SYSTEMS ENGINEERING AND MANAGEMENT APPROACH TO ESTABLISHING A FLEET MANAGEMENT SYSTEM IN AN UNDERGROUND UG2 BOARD AND PILLAR PLATINUM MINE IN SOUTH AFRICA

F. Vermaak[1*] and L.D. Erasmus[2]
[1]Department of Engineering and Technology Management
Graduate School of Technology Management
University of Pretoria, South Africa
frik.vermaak@trp.co.za

[2]Integrated Capability Management Research Group
Defence and Security Cluster
Council for Scientific and Industrial Research, South Africa
l.erasmus@ieee.org

ABSTRACT

South Africa is a world-leading Platinum producer. Most of this mining takes place in an underground narrow tabular setting. Mines are heading for challenging times in the coming years because mines are becoming deeper and more expensive to extract. Technology must be implemented to ensure long-term optimal extraction in these underground mines. The literature indicates that surface mines have seen major production increases where fleet management technology has been implemented and that underground mines were trailing in this technology due to the harsh environment. The author, therefore, investigated how data and fleet management technology could be implemented to improve productivity in underground narrow reef board and pillar mines. The research objective was to develop and define a fleet management system using the systems engineering approach to improve productivity at the Two Rivers Platinum mine and to determine all the aspects to be considered. This mixed methods research used the literature, stakeholder interviews, and tests to design and establish the fleet management system. A case study compared the newly developed fleet management system to the current fleet management processes. The results were encouraging, indicating that cost savings and production increases could be realised.

Keywords: Board and Pillar mining, Systems Engineering, Fleet management system, Underground data network, Condition Monitoring

* Corresponding Author

1 INTRODUCTION

The Platinum Group Elements (PGE) is a scarce commodity and essential in modern advanced technologies and chemistry. The PGE comprise the following metals: Platinum, Palladium, Rhodium, Iridium, Ruthenium and Osmium.

South Africa is a world-leading producer of Platinum (92%) and Rhodium (80%) [1] and all these PGEs are mined from the Bushveld Igneous Complex. Mines must improve efficiencies and reduce costs to ensure that mines can mine at the lowest possible dollar per ounce prices and stay salient and profitable.

The mining industry is heading for challenging times in the coming years [2]: High-grade ore is more problematic to obtain because mines are becoming deeper and more difficult and expensive to extract. Mining companies need to shift to a more technological approach to ensure that long-term, cost-effective production is possible [2].

Two Rivers Platinum Mine is situated in the Steelpoort Valley on the eastern side of the Bushveld Igneous Complex and mines the UG2 (underground two chromite layers) with TM3 (Trackless Mobile Mining Machinery) using the fully mechanised board and pillar mining method. The board and pillar mining method best suit a reasonably vast, flat dipping reef. Optimal results are achieved with a reef at least 2m high [3].

The mine has 153 TM3 mobile machines currently working in the underground mining environment. These machines have intelligent capabilities and can provide valuable information and communicate information to a central data system.

These intelligent capabilities can transfer vast amounts of information remotely from an independent mobile platform to an existing data collection system such as Wi-Fi. This allows the user of the telemetry system the opportunity to receive real-time data from this separate device, as well as the ability to have remote control over this system [4].

This information could improve fleet management, maintenance, overall availability, and the utilisation of trackless machinery. The study will use systems engineering processes and more specific requirements engineering processes to define an optimal underground data collecting and management system and propose an architectural framework (AF) that any low-profile board and pillar mine can use to obtain the most optimal and efficient system. Some verification and validation processes will also be performed on the proposed system to determine if the needs of the stakeholders are satisfied. The system can ultimately ensure that machines can be operated autonomously, but this will not be explored in this study.

The data received from the machines and the proper management of this data could lead to a more efficient and effective mine. The productivity of 10 surface mines increased by between 10 and 20% when intelligent scheduling for underground mobile machinery was applied [5].

No wireless underground data system exists at Two Rivers Platinum to convey the data from the machines to a central point. Wireless networks can facilitate communication and data transfer in underground mines [6]. Still in the current underground environment, communication methods are trailing behind what is available in surface mining applications [7]. This is not solely due to a lack of effort in the underground environment but also the harsh and hazardous environment.

There are also currently no theoretical wireless models available for board and pillar mines with tunnel heights lower than 6m, and this area is not well researched [6]. This is the reason for an investigation in how technology – specifically, data and fleet management technology underground, could be used to reduce costs underground to improve the efficiency and effectiveness of the production machines generating the platinum ore.

1.1 Systems Engineering

The wireless backbone underground, the data sending capability of the machines and the data receiving, analysing and management tool can each be described as separate sub-systems. It can be described as a system. A system is an assembly of different elements that, if put together, achieves results that cannot be produced by the elements alone [8].

Systems engineering and system management is a growing trend in project environments. It changes the management principles from "project-based" to "system based" and improves the rate of overall success in a multitude of industries, including mining [9] [10].

In using a top-down and bottom-up approach when designing a system and by proper assessment of the risks and opportunities, you can ensure that the system performs more effectively and efficiently than a system created on an ad-hoc basis [10].

Various promising technologies and products failed to be implemented successfully [11]. Aerospace and defence manage to accomplish ever more challenging missions and endeavours successfully and remain at the cutting edge of technology through their use of the systems engineering approach [11].

From the literature cited above, it can be concluded that a proper way to introduce wireless technology and a fleet management system underground can be achieved by following a Systems engineering approach.

1.2 Rationale of the research

It can be surmised that Platinum Mining in South Africa is a vital industry and that optimising the production and reducing costs will ensure that a mine stays effective, efficient, and sustainable.

The machinery used at Two Rivers can provide a wealth of data that the mine can use to manage better and utilise the fleet. This can lead to efficiency improvements, reduce costs and move Two Rivers back into the 25 percentile of the cost curve.

No wireless network, data collection system or fleet management system is currently available to utilise the information. From the literature it also became apparent that wireless systems and fleet management in the board and pillar environment are not well researched.

This study contributes to the current body of knowledge. It also is a value-added proposition for Two Rivers Platinum to improve production and quality by managing the production machines, reducing operating expenditure and becoming the preferred mine of choice for potential investors.

The research proposes a combination of subsystems (data, wireless backbone and management tool) to address this problem using a systems engineering and management approach.

The systems engineering approach ensures that a better data collection and management system is produced in the challenging and complex underground mining environment.

1.3 Objectives

The objectives of this research are to develop and define a system using the systems engineering approach to use the intelligent capabilities of machines, an underground wireless network, and a computer sub-system that could better manage and maintain the Trackless Mobile Machinery at Two Rivers Platinum mine.

This system must be able to collect, interpret, integrate, manage, and verify this data continuously. The fleet management system is complex; therefore, the research will explore a systems engineering approach to ensure an optimum product for the end user and all stakeholders. The systems engineering approach will ensure that it can develop, evolve, and emerge into a management tool that any mine- and engineering manager could use to the overall advantage of the mine.

Given the objectives, the research questions are:

1. What aspects must be considered when implementing a Data sending, Collection and Fleet Management System?

1.1. How can systems engineering be used to define and develop the most efficient and effective data collection and fleet management system?

1.2. What organisational design can be used to define and develop the most efficient and effective data collection and fleet management system?

2 LITERATURE REVIEW

The three major subsystems of the underground fleet management project were highlighted, and proposed systems were investigated. The subsystems were identified as the Smart Machine, the underground data network, and the fleet management systems.

It was determined that modern machines, including Two Rivers TM3 machines, are already equipped with sensors and all the necessary hardware to communicate and send data [11].

As per [12] and [13], the onboard systems and the systems implemented in other mines were explored, and the interaction between the various sub-systems was illustrated. Signal strength and environmental challenges were also highlighted as essential aspects to consider for the machine’s data-sending capabilities [6].

It was determined that underground data networks are currently not as well developed as the surface areas due to unfavourable and harsh underground conditions [7], [14]. [7] listed all the current types of data network available underground and indicated their preferences for wireless systems above permanent cabled infrastructures, echoed by [2].

A procedure for establishing a Wireless Sensor Network underground was explored by [14]. This system benefits the practical design of underground monitoring systems and applies known systems engineering processes to the environment and the controllable and uncontrollable parameters. As part of the design, positioning the underground nodes was an essential environmental aspect because of the large footprint, tunnel shapes and wave propagation of underground signals. All these aspects must be considered to ensure a cost-efficient system and continue to offer positioning solutions [2].

A data wave propagation solution for the underground board and pillar mines is proposed in [6]. Still, this theory was only tested in 6m high board and pillar tunnels and stated that further study was still needed in lower tunnel height mines. The survey into wireless data network systems for underground mines showed no examples for low profile board and pillar platinum mines where integrated data networks are used.

Very few fleet management systems are currently implemented underground, and this problem was also mentioned by [5], [7] and [15].

Productivity improvements of between 10 and 20% were achieved at surface mining operations using fleet management software and that there is no reason why this cannot be done underground because of the improvements in information and communications technology [5]. An algorithm should be used in a blasting cycle operation [5]. This algorithm considers all the production machines, including LHDs, Rigs, Bolters, and the Charging upcycle [5].

A fleet management system diagram is proposed by [13] and [5]. The Finsch model is attractive because Two Rivers uses the same OEM, and similar fleet management software will be used. The cycle algorithm will be shared with the experts from SANDVIK to adjust the fleet management system to suit the low-profile board and pillar cyclical drill and blast mines.

Lack of fleet management and automated underground mines were also mentioned by [6], [7] and [15].

Formal Systems Engineering Processes in Mining was also researched, and the conclusions were that it is currently only an emerging paradigm and there is presently a gap to explore. The advantages of the process were illustrated by [11], [13], [10], [16] and [9].

Examples are given in [9]that proved that systems engineering processes work better in complex project environments and that better results are generally achieved.

Various systems engineering and management processes were explored, and the author decided that ISO 29148 [17] would be adapted and applied to a new problem. The architectural models for the fleet management system will then be developed, and these models can be used industry wide.

3 PROPOSED MODEL OR CONCEPTUAL METHOD

The conceptual models below were used to answer the research questions. A combination of literature was used to develop a conceptual framework for the concept and development phases of the system.

3.1 Conceptual model for Concept phase of the system

A combination of the table below was used as the framework for the concept design phase of the system.

Table 3.1: Conceptual model for Concept phase of the system

Concept Phases as described in different literature			
ISO/IEC TR 24718-1 (2010:14)	ISO/IEC/IEEE 29148 (system requirements, condensed tasks)	Blanchard (2004:16)	Blanchard Requirement Process (Blanchard, 2004:17)
1. Exploratory research	Identify the stakeholders that have interest in system throughout life cycle processes	Research	Identify Need
2. Concept Selection	Elicit stakeholder requirements	Definition of need	Understand the objectives
Characterize solution space	Define stakeholder requirements	**Conceptual design**	Define the system requirements
Identify stakeholders' needs	Analyse and Maintain stakeholder requirements	Needs Analysis	Consider Alternative Configurations
Explore ideas and technologies	Define system requirements	System Operational Requirements	Compare Test Data With Requirements and Objectives
Refine stakeholders' needs	Architectual design: Define the architecture	System Maintenance Concept	Measured Characteristics
Explore feasible concepts	Architectual design: Analyse and evaluate the architecture	Advance product planning (Plans and Specification	Choose the optimum design
Propose viable solutions	Verification and Validation process		
	Management Process of the system		

3.2 Conceptual Model for developmental phase of the system

This section aims to test, using iterative processes, the best possible configuration to meet the required need. The design should be effective [18] and it should also be efficient.

A combination of the literature above will form the basis of the concept and development activities performed in the conceptual method. The method's output will ultimately be a physical system that could be implemented in the underground environment.

Table 3.2: Conceptual Model for developmental phase

Development Phases as described in different literature			
ISO/IEC TR 24718-1 (2010:14)	INCOSE (2015:71)	Blanchard (2004:16)	Blanchard Requirement Process (Blanchard, 2004:17)
Define/refine system requirements	Prepare for design definintion (1)	**Preliminary Synthesis and allocation of design criteria**	Design the system
Create solution description - architecture and design	Establish design characteristics and design enablers related to each system element	Allocation of performance factors, Design factors and effectiveness requirements	Test the system
Implement initial system	Assess alternatives for obtaining system elements	Allocation of system support requirements	Accomplish System integration
Integrate, verify and validated system	Manage the design	System Analysis	Actual characteristics
Production, Utilisation, Support and Retirement portions of the life cycle will only form part of the Concept and Development stages		**System Optimisation**	Update System Characteristics and Data
		System and Subsystem trade offs	Develop Physical System
		Evaluation of alternatives	
		System and Subsystem Analyses	
		System Synthesis and Definition	
		Preliminary Design - - Performance, Configuration and Arrangement of chosen system (Analyses, Data, Physical Models, Testing etc.	
		Detail Specifications	

3.3 Proposition development to test, verify and validate the system.

After the system has been defined and implemented, the system must be tested, verified, and validated. Null propositions were then formulated. These were used during the validation process to ensure that the suggested system adheres to the stakeholders' requirements and the literature.

The following null propositions were introduced:

- Proposition 1: The current intelligent machines do not have all the sensors necessary and the network sending capabilities to ensure proper fleet management.
- Proposition 2: A mixture of wired and wireless technology cannot be used as the backbone of the data network system.
- Proposition 3: The fleet management systems currently in use on the massive ore body mines cannot be adapted and used on a board and pillar operation.
- Proposition 4: The fleet management system cannot improve the productivity of the mine by 10 to 20%
- Proposition 5: Productivity cannot be increased by improving the availability and utilisation of the machines through continuous condition monitoring using the fleet management system.
- Proposition 6: Face time cannot be improved by determining the whereabouts of a machine underground and recording the productive start and stop times of a machine. There is not a direct correlation between more face time and productivity.

The propositions formulated above will be refined later in the process and validated or falsified as part of the results section.

4 RESEARCH METHOD OR APPROACH

The approach to answering the research question was a mixed methods using Design Science Research (DSR) [19]. DSR combines the development of theory and research intervention to answer real-world problems [20]. The method also entails reflecting on the results, learning, and validating as the research continues [21]. This, as explained, was done to get a more holistic view of the research problem because the qualitative and quantitative approaches complement each other. Design is the purpose of the study, and semi-structured interviews and experimental methods will be used to collect the data.

The DSR model shown in Figure 1 was adapted from [22]. The qualitative and quantitative steps are illustrated below.

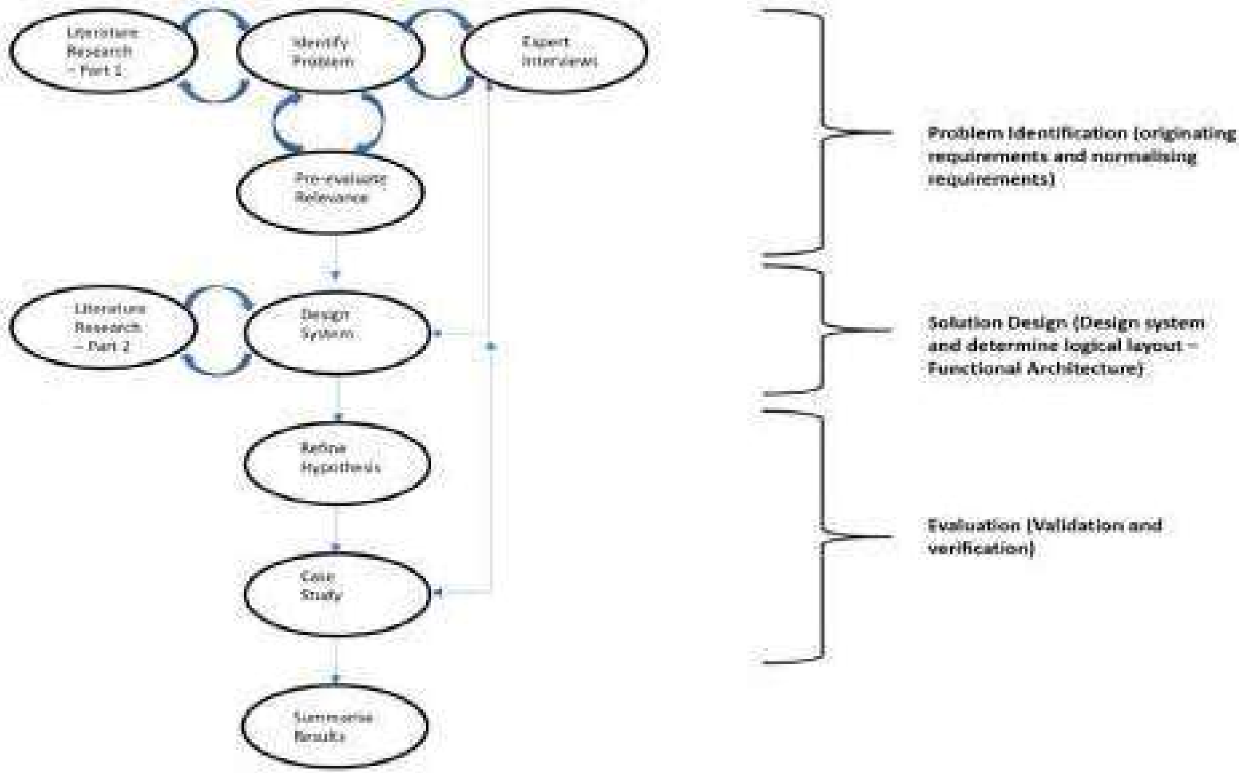

Figure 1: DSR Process (Adapted from [22])

A sequential exploratory design mixed method process was followed where qualitative methods were used first and then quantitative methods; there was not a dominant method because both were equally important to finish the study.

The qualitative methods included semi-structured expert interviews to define the requirements and all the inputs from the owners-, design-, manufacturing- and operations/Support stakeholders. Some aspects of the literature reviewed were also included in this step to define the problem correctly and to create the originating requirements.

A quantitative approach then completed the requirements engineering steps and break up the system into decomposed and normalised requirements.

After this step, inputs were again obtained from the stakeholders to ensure that the requirements were acceptable; this iteration was followed until a good list of requirements was determined. This ensured that the requirements were pre-evaluated, and the relevance and workability of each condition was determined.

The next step was a quantitative step where the system and all its sub-systems were designed to define the architectural framework. In this Solution design stage, the logical layout of the solution will be proposed. This solution was tested and optimised with the inputs from the literature as well as expert interviews.

Propositions were refined to align with the results gathered above.

The next step is to do a case study on the system and to note the results obtained.

5 RESULTS

Sub-system requirements were established using literature, with contextualisation of the problem. Literature findings were shared with mine and industry experts in data networks and fleet management, assessing requirement relevance. This led to problem identification and solution generation. The requirements process aligns literature, stakeholders, and researchers, ensuring an ideal and future-proof system. The iterative problem identification process is depicted below.

The following summarised requirements were gathered for each sub-system. These include inputs from experts, stakeholders, and literature for each sub-system:

5.1 Intelligent machines.

- The TMM machines already have the necessary telemetry to measure condition monitoring parameters.
- Intelligent machines already have a sensor data collector Controller Area Network (CAN) bus to receive all the information from the telemetry.
- Legacy machinery has sensors but no collection method. An Internet of Things (IoT) hub was suggested as a date aggregator.
- The IoT hub was suggested for both legacy and intelligent machinery. The reasoning was that an IoT hub identifies data and arranges it through artificial intelligence, making it more understandable. The IoT hub shall allow other technologies onto the machine, such as Personnel Detection System (PDS), Vehicle Detection System (VDS), Lidar, Camera systems etc.
- The Newtrax vehicle device was recommended as a solution. It is an Original Equipment Manufacturer (OEM)-approved IoT hub, and it fits all the requirements.
- The IoT hub shall be easy to install. The stakeholders noted that initial installation takes 12 hours and replacement takes an hour.
- The device shall hold onto information until data network coverage is detected and dump all the information.
- The device shall withstand the following harsh environmental conditions:
  - Ingress Protection 67 (IP 67) or a better-rated enclosure for the IoT hub to withstand dust, water, heat, and other environmental conditions.
  - Impact protection (IK 10) to withstand the concussions and blasting of the underground environment.
  - Military Standard (MIL-810M) specification ensures modularity and quality, operating in the harshest conditions and quickly achieving interoperability between components.
- Delay in transmission between the machine and the data network shall be between 0 and 5 seconds.
- The signals from the interface IoT hub shall not interfere with any other system.
- The Signal shall be relayed up to 60m if line of sight is available.
- The system shall communicate with various network configurations. 2.4 – 5 GHz and Wi-fi 6 technology was suggested by the stakeholders.
- The machine shall have a (Graphical User Interface) GUI that is interfaced with the IoT hub and indicate to the operator when there are problems and for communication purposes to the control room.

- The IoT hub and data network shall determine the positioning of the machine in the underground environment,
- The system shall be supported. Maintenance, availability, and supportability were listed as requirements.
- The IoT hub shall have a lifespan of between 2 and 5 years.

These requirements were used as the foundation to design the intelligent machine interface.

5.2 Data network

Tests were conducted on the mine to determine what data network configurations would work. These included:

- Bluetooth tags were tested as a data network option; this network layout only addressed the positioning requirements. This system as a solution was discarded.
- Data transfer over the leaky feeder system was tested. This network layout was expensive; only a small data package could be sent, and negative influences on the communication systems and proprietary monopolistic concerns made this system unsuited.
- Long-Term Evolution (LTE) networks performed the best of all the networks if tested in a straight line. Still, the contours of the tunnels, the 2m height and severe undulations in the underground environment caused signal attenuation. The signal propagation around corners was untenable, which could only be mitigated by installing an LTE unit per board. This was not a good solution as only the roadway is open in the board and pillar section, and the rest is packed with waste. The solution was discarded because of these concerns.
- Fibre backbone and Wi-Fi nodes were tested. Stability and repeatability were achieved with this configuration, and because of the vast distances to be covered, this system was seen as the only real solution. Requirements were therefore limited to fibre backbone and wi-fi nodes in the section.

5.2.1 Data network requirements

The following requirements were determined for the data network using the literature and stakeholder inputs.

- Fibre shall be used for the backbone.
- Wi-fi nodes shall be used in the section.
- The stakeholders and subject matter experts shall determine the layout of the network backbone and wi-fi nodes.
- A traditional spliced fibre, network switches and fibre nodes were measured against a Passive Optical Network (PON) system. The PON system was inexpensive, easy to install, modular, upgradeable, uncomplicated, robust, with few components, and complied with most requirements stipulated by Literature and stakeholders. The PON shall be used.
- Ease of deployment was stated as a requirement. The modularity of the PON system addressed this.
- Interfaces shall be easy to install. Plug and play are suggested.
- The environmental considerations shall be:
  - IP 67 or better-rated enclosure and interfaces for the systems to withstand dust, water, heat, and environmental harshness.
  - IK 10 impact protection to withstand the concussions of the underground environment.
  - MIL-810M specification ensures modularity and quality, operating in the harshest conditions and quickly achieving interoperability between components.

    - The network shall be installed where the underground environment cannot damage it.
- The data network shall cover the entire production areas; this includes production panels, waiting areas, production tips and workshop areas. A 12 – 24 node configuration shall be used. This ensures triangulation and total coverage.
- The data network shall be able to provide power to the components in the harsh and remote underground environment.
- Normal connection types and commercially sourced equipment shall be used for the network. This will ensure the maintainability and supportability of the system. Commercially available equipment is also less expensive than a bespoke system and is easier to obtain.
- The network's lifespan shall be 2 – 5 years to ensure economic payback on the system.
- The system shall connect with intelligent machines.
- The network shall have Wi-fi 6 capabilities and a 2.4GHz to 5 GHz frequency range. This will ensure smooth interfacing with the IoT hub.
- The data network shall have a bandwidth of 10GB/s system. This bandwidth is not needed for telemetry because the data packages are relatively small. Still, the bandwidth must be sufficient for voice-over IP and video-sending capabilities that might be required in later projects.
- The system shall segregate different signals on the data network using Virtual Local Area Network (VLAN). Telemetry data shall be ranked as critical information because of the importance of the production information.
- Network spares shall be available on the shelf. The lead time on components shall be less than three weeks. The supplier of the data network shall be a reputable company and have a track record in data networks.
- A maintenance system shall be established, and labour shall be sourced to maintain the system.
- The data system components shall be modular, and components shall be easy to replace.
- The modularity of the components shall also ensure that they can be easily upgraded if newer technology arrives.
- The data network shall be fit for purpose and only have the necessary components to ensure operability.

5.3 Fleet management system requirements

The Fleet Management System (FMS) uses the two sub-systems above, and the following requirements were listed from the literature and stakeholder inputs:

- The FMS shall manage the underground fleet same as surface operations.
- The FMS shall be able to flag any mechanical problem on a machine.
- The FMS shall be able to flag issues with the operation of the machine.
- The FMS shall measure availability of machines.
- The FMS shall measure utilisation of machines.
- The FMS shall calculate Mean-Time-To-Repair (MTTR) and Mean-Time-To-Failure (MTTF) automatically.
- The FMS shall execute as close as possible to real-time.
- The FMS shall be able to indicate the positioning of the machines underground.
- The Graphical User Interface (GUI) shall relay machine info to the operator and send responses to surface.
- The FMS shall determine when machines are due for service.
- The FMS shall display information visually through graphs, charts, and dashboards.
- The FMS shall be secure.
- The FMS shall be supported.

- People shall be trained in maintaining and operating the FMS.
- The FMS shall measure machines' aspects determined by breakdowns and leading indicators.
- LHD shall measure any of the 36 node sensors.
- Rigs and bolters shall measure percussion hours.
- Operation time and face time shall be determined by the system.
- The FMS shall adapt to changes and shall be fully customisable.

5.4 Solution Design phase and logical layout

A logical system layout was determined through iterative methods involving the requirements listed above and solutions offered by system experts.

The results of the solution design and logical layout are summarised below.

5.4.1 Intelligent machine IoT hub.

- The intelligent machines already have all the sensors to facilitate condition monitoring.
- The legacy machines have all the sensors but no data aggregation system. The literature and the stakeholders suggested an IoT hub. The IoT hub is advantageous, even on intelligent machines, to serve as an interface between multiple technologies that might be added to the machine. The hub also serves as a CAN bus replacement on the older type of machinery.
- The research only concentrated on the interface between the machine and the data network system.
- The Newtrax Vehicle Device was suggested by the stakeholders, as it is an Original Equipment Manufacturer (OEM) approved and does what was required from the stakeholders and the literature. The flow diagram between the machine and the data network is illustrated in Figure 2.

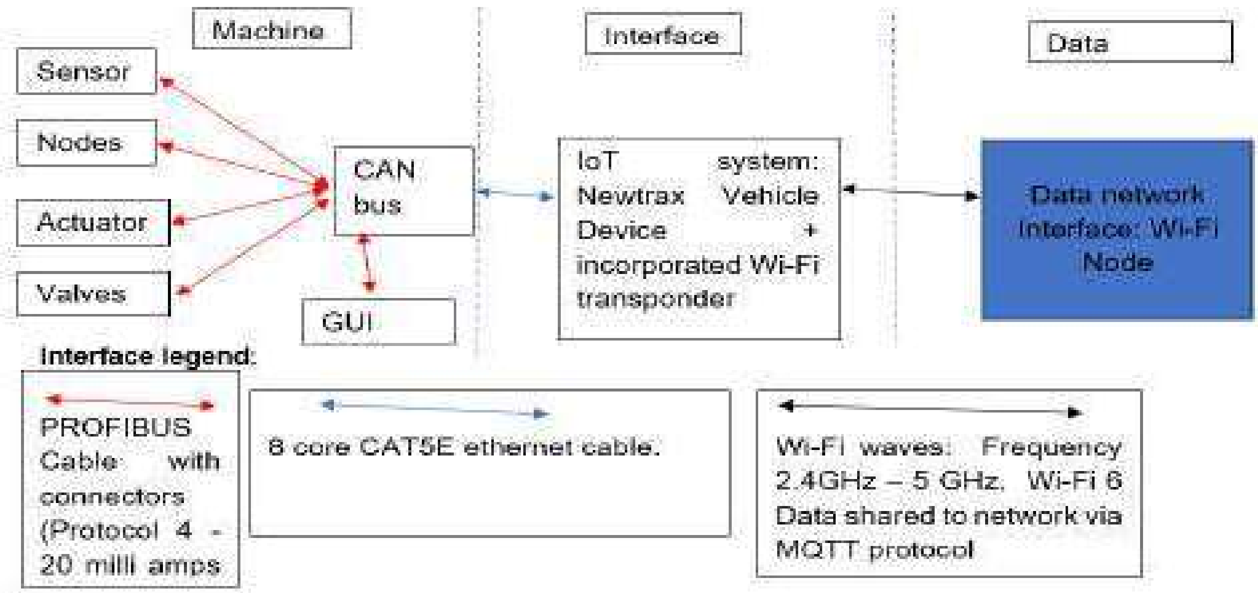

Figure 2: Flow diagram of an intelligent machine system indicating the interfaces

The IoT hub was tested, and up to 140m of transmission distance was achieved.

The hub connected freely to the data network when available. It also dumped the data when the data network was available.

5.4.2 *Data network system*

- The logical layout of the data network system was determined by testing the system underground and optimising the configuration.
- The initial plan had several access switches and aggregation access switches included in the network line after every length of the Gigabit-capable passive optical network (GPON) cable.
- There were also two distinct types of GPON cables, the 1 GB/s type, that were tested between the Optical Distribution Network (ODN) and Optical Network Unit (ONU) components and the 10 GB/s types.
- Extension plugs on the GPON cables made the aggregation access switches and access switches redundant.
- It was also decided that the 1 GB/s GPON is unnecessary and that the 10 GB/s will be the only distribution cable.
- The extension plugs on the GPON saved money due to removing the aggregate and access switches.
- That left the system with only three major electronic devices (Optical Line Network (OLT), ONU and wireless access points).
- The final logical flow diagram of the data network system is indicated below. It complies with the requirements and what is specified in the literature.

The data network in Figure 3 was tested using a layout derived by this study. Many iterative processes have been followed before the system design was determined. The 24 nodes' grid is approximately 30 meters apart, and tests illustrated that proper coverage of the entire section, as stipulated in the requirements, could be obtained using this layout.

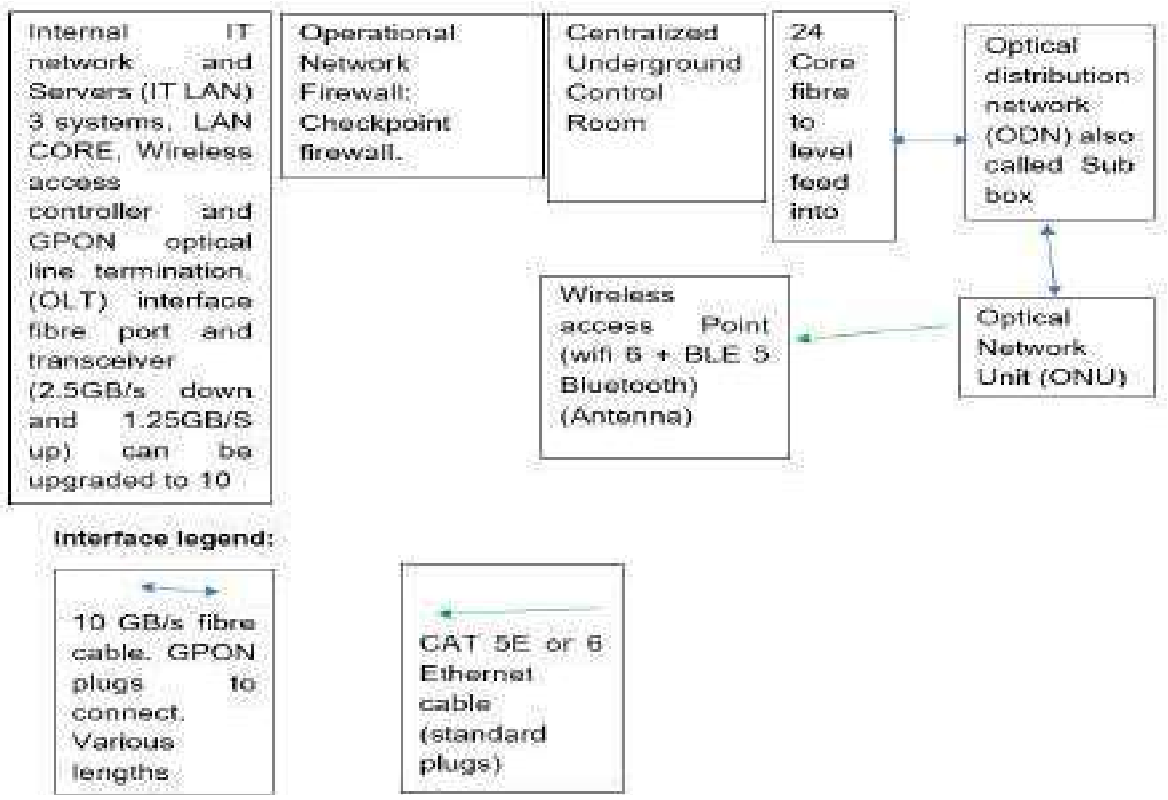

Figure 3: Flow diagram of a data network system.

All the verification processes were done on the system requirements as stipulated. And the stakeholders demonstrated, tested, and analysed each requirement to comply with the verification and validation requirements. Each test was met, and the system did what it set out to do.

The results and layout are the conclusions of multitudes of tests conducted on the mine since 2012, and the layout gave the most optimal results when tested.

5.4.3 Fleet management system

- An assumption was made in the study that OEM fleet management systems prevalent on massive ore body mines will be used to manage the fleet underground; this was not the case; these products are still in the development phase for the low-profile machinery.
- The researcher and stakeholders opted for their developed system.
- In the results, the stakeholders decided on a fully customisable mine-produced system. They used cloud-based technology and Grafana visualisation programmes to indicate the health of the machinery.
- This ensures that the system is fully customisable.
- The logical flow of the system is illustrated below.
- The system of systems was tested in Level 9 on Main Decline as a Proof of Concept. The intelligent machine, Data network and Fleet management system were configured precisely as illustrated above.
- The results conformed to the requirements as anticipated, and the system operated as intended.
- The systems engineering approach will ensure that the system is functional, economical, sustainable, reliable, obtainable, maintainable, supportable, survivable, modular, upgradeable, durable, and fit throughout the system's lifecycle.
- All the verification processes were done on the system requirements as stipulated. And the stakeholders demonstrated, tested, and analysed each requirement to comply with the verification and validation requirements.
- Test results are available for the data network and IoT hub tests performed on the intelligent machines.

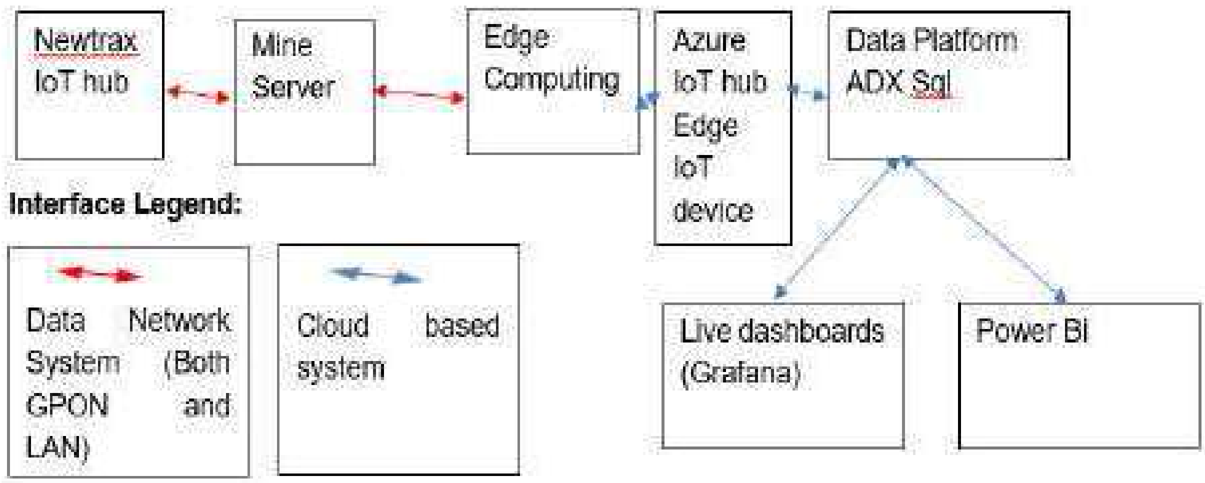

Figure 4: Flow diagram of a fleet management system.

5.5 The case study (Old manual system vs new fleet management test)

The current Two Rivers Platinum condition monitoring system was determined by conducting interviews with the engineering planning department, engineers, and production personnel. It was determined that the current system is very labour intensive and that many manual inputs must be included to calculate and track all the machine condition monitoring and production monitoring aspects on the mine.

The case study focussed on hour capturing of machines, breakdown procedures, productivity, and face time procedures and how the location of machines was determined.

A breakdown of Load Haul Dumper (LHD) 184 was also tracked to explain the current procedure. Each of the aspects of the current system above was compared to the system as it should be if fleet management is implemented.

The case study also served to validate the system and all the requirements. The requirement of the fleet management system was validated and verified. The verified requirements that were tested and validated are tabled below.

Table 5.1: Fleet management requirements

Requirement	**Literature or Stakeholders' requirement?**	**Verification and Validation**
Manage the underground fleet same as surface operations	[5] and stakeholder requirement	Demonstrate
Must be able to flag any mechanical problem on a machine.	[13], [7] and stakeholder requirement	Demonstrate
Must be able to flag issues with the operation of the machine	[13], [5] and stakeholder requirements	Demonstrate
Measure availability of machines	[23] and stakeholder requirements	Demonstrate
Measure utilisation of machines	[23] and stakeholder requirements	Demonstrate
Determine MTTR and MTTF figures automatically.	[23] and stakeholder requirements	Demonstrate
As close as possible to real-time	[5] and stakeholder requirement	Demonstrate
Must be able to indicate the positioning of the machine underground	[5] "Interaction with TMM equipment", [13] and stakeholder requirement	Demonstrate
GUI to relay info to the operator and set responses to surface	[13] and stakeholder requirement	Demonstrate
The system must determine when machines are due for service	[13] and stakeholder requirements	Demonstrate
The system must display information visually through graphs, charts, and dashboards.	Stakeholder requirement	Demonstrate
The system must be secure.	[17]	Analyse
The system must be supported.	[17] [18]	Analyse
People should be trained in the system	[18] p.37	Demonstrate
The system should be able to measure machines' aspects determined by breakdowns and leading indicators.	Stakeholders	Demonstrate
LHD measure any of the 36 nodes sensors	Stakeholders	Demonstrate

Requirement	Literature or Stakeholders' requirement?	Verification and Validation
Rigs and bolters should measure percussion hours.	Used for efficiency calculations and face time calculations. [23] [24] [25]	Demonstrate
Operation time and face time to be determined by the system	[24] [25]	Demonstrate
The system must be able to adapt to changes and be fully customisable	Design attributes - [18] p.37 and stakeholder requirements	Demonstrate

The new proposed fleet management system results are encouraging, and all the requirements are met during the case study. The new fleet management system:

- Makes the filling of checklists redundant to update the hours of each machine.
- Labour required to capture machine-hour readings can be reduced or applied elsewhere. The system reads the machine hours automatically.
- The fleet management system updates the hours in the Centralised Asset Management system (CAMS) and Delta. Availability, utilisation, MTTF and MTTR calculations can be updated constantly for each machine, and trends could be established automatically. Manual inputs into excel sheets and the labour required to perform these inputs are no longer needed.
- Breakdowns do not have to be communicated to the control room; the system does it automatically and gets flagged immediately in the control room.
- Time off is accurately captured, improving the data's integrity.
- Breakdowns can also be prioritised immediately, and the control room can already tell the artisans what the telemetry is indicating and what parts will be required.
- The system automatically registers when a machine starts working, and the trends will be documented throughout the shift.
- Face time of machines can be tracked, and the trends could be used to improve and manage the productive time of machines. Manual call-ins from underground by the Shift boss and artisan to the control room operator are no longer required to state when a machine starts working.
- The wi-fi node's IP address is superimposed on a plan. Finding machinery underground will no longer rely on writing the location of a machine on a whiteboard on the surface at the end of the shift.
- The case study verified all requirements stipulated by the literature and stakeholders to prove the concept.
- The fleet management system is fully customisable, and the immersive behaviour of the system is guaranteed.
- The system conforms to all the requirements as prescribed.

5.6 Proposition Testing

Some limitations were that there is only a short time allowed to test the results in mining environments. Longer-term test results will be available in the future. The propositions testing is discussed below, but longer-term tests will demonstrate what the impact will be.

5.6.1 Propositions of improvement

The following propositions was stated in the research, and the results of the proposition validation or disproval thereof will be listed after each statement.

- Proposition 1: The current intelligent machines do not have all the sensors necessary and the network sending capabilities to ensure proper fleet management. The research proved that telemetry and sensors are available on all machines, thus this proposition is false.
  - Thus, the alternative proposition is accepted: The current intelligent machines have all the sensors necessary and the network sending capabilities to ensure proper fleet management.
- Proposition 2: A mixture of wired and wireless technology cannot be used as the backbone of the data network system. LTE networks did not work in the board and pillar set-up, and because of the vast distances to be covered, a combination of fibre and wi-fi nodes was suggested. This echoed [2] that stipulated cost-efficient coverage with a hybrid solution.
  - Thus, this proposition is rejected, and the alternative is accepted: A mixture of wired and wireless technology can be used as the backbone of the data network system.
- Proposition 3: The fleet management systems currently in use on the massive ore body mines cannot be adapted and used on a board and pillar operation. The fleet management system provided by the OEM is more suited for massive ore body mines, and the board and pillar system is still under development.
  - This proposition is weakly accepted. It can be concluded that an own adaptable system is more advantageous.
- Proposition 4: The fleet management system cannot improve the productivity of the mine by 10 to 20%, as per [5].
  - This proposition cannot be proofed or rejected. Initial results from the case study show that productivity might improve.
- Proposition 5: Productivity cannot be increased by improving the availability and utilisation of the machines through continuous condition monitoring using the fleet management system.
  - This proposition cannot be proofed or rejected. Initial results from the case study show that productivity might improve.
- Proposition 6: Face time cannot be improved by determining the whereabouts of a machine underground and recording the productive start and stop times of a machine.
  - This proposition cannot be proofed or rejected. Initial results from the case study, shows that there is a direct correlation between more face time and productivity.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The objective of the research was to develop and define a system using the systems engineering approach that uses the intelligent capabilities of trackless underground equipment, a suggested data network, and a to-be-determined fleet management system that can be used as a business solution at Two Rivers platinum to manage better and maintain trackless mobile machinery.

The conclusion, in short, is that a fleet management system was developed using a Systems Engineering approach. The stakeholders and the literature specified the system's requirements, and these attributes were incorporated into the designed system as presented. Each sub-system's needs and the overall system were verified and validated. A case study was performed to test the system's capabilities, and the results indicated that production improvements and labour savings are likely if the system is fully implemented. The aspects one needs to consider when implementing data sending, collection and a fleet management system in a board and pillar mine were addressed through the research and will give future researchers an excellent foundation to work from. The enterprise portion of the systems engineering process has not been addressed and must be addressed in future research. If the management of the system is defined correctly, the project can be implemented, and success will be achieved.

6.2 Recommendations

- The scheduling of the fleet and reference back to the monthly planning was not addressed yet, but all the systems are adaptable to address this requirement; the IoT hub on the machine also ensures that more technology and different systems could be incorporated into the machine. Further work is needed in this area.
- Long-term testing must commence on the designed system to determine if the production's 10 – 20% improvement could be achieved (Proposition 4).
- Based on the labour savings noted in the case study, the system will reach its payback period in less than two years. It is recommended that the system be implemented to optimise the condition monitoring of machines. The scheduling portion can be added later, and the system is ready to accommodate this.
- The enterprise aspect of the system must be done to determine how the system will fit into the organisation and to address the systems engineering management process. It is recommended that SEMBASE theory be applied to the problem.
- Further development and optimisation of the fleet management visualisation dashboards are recommended to make them more user-friendly and easier to interpret.
- An evaluation plan for the evaluation of proposition 5 and 6 needs to be drafted and implemented.

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