Material Selection of a Tri-adjustable Automated Heavy-Duty Handling System Designed on Industry 4.0 Principles

S.Z. Mafokwane and D.V.V. Kallon
Department of Mechanical and Industrial Engineering Technology,
University of Johannesburg, South Africa.
zamashaun@gmail.com, dkallon@uj.ac.za

Abstract

Over the years, many South African industries have been using Forklift trucks to move bigger loads from one point to another till today. The use of large forklift trucks within indoor manufacturing processes poses OHS risks to workers as its Internal Combustion Engine (ICE) produces fumes (Carbon Monoxide, CO) when in operation and exhaust fumes, (CO), are harmful to human's health. On this basis, a new system design is recommended to eliminate the use of MHS that relies on ICE power source to prevent OHS risks in indoor manufacturing industries. In this project, Autodesk Inventor Professional software was used for design development of technical drawings and simulation as well as validation of the new system's structure. Vehicle Dynamics' principles and equations are used to determine the overall Rolling Resistance, Tractive Effort of the new system, wheel torque, and the power required to drive the system under 20 – ton load capacity. The new system design has been developed to operate using a Hydraulic Power pack source, where it consists of four hydraulic wheel hubs for driving the system, four hydraulic cylinders for lifting & lowering, and a double rod end hydraulic cylinder for steering. Electro-Hydraulic circuit systems were developed and proposed using electronics and fluid mechanics phenomena. Again, principles, laws and equations of Strength of Materials has been carried out for validation of the material selection of the new design system's structure as well as verifying buckling, deflection & bending stresses, and moments. The size and type of a Material Handling System (MHS) and/or equipment influences the effectivity of the internal logistics within manufacturing industries. Therefore, it is very essential to choose a correct MHS for a correct manufacturing process which requires material handling to complete its operation. Incorrect usage or selection of an MHS for an operational process may lead to down time, damage to facility, increase in operating costs and/or pose Occupational Health and Safety (OHS) risks to workers.

Keywords
Material Handling System, Internal Combustion Engine, Occupational Health & Safety, Manufacturing, Hydraulics, Finite Element Methods.

1. Introduction
This research document covers the selection of materials and components to be used in the manufacture and assembly of the new system. Legislation covering lifting machinery, Electrical Machinery, Pressure Equipment Regulations, Environmental Regulations for workplace, ISO (international Organization for Standardization), and SABS (South African Bureau of Standards) are very strict when coming to materials & component selection and the process of manufacture and they need to be adhered to. Therefore, specification of the new system and material selection should be accurate in order to achieve correct results and that the new system may be able to perform at its design capacity and meeting engineering legislation standards and codes as well as achieving heavy duty material handling principles (Mafokwane, at el., 2019).

Again, this document provides a detailed overview for manufacturing process and material selection of the new system's components. Critical components of the new design system will be discussed and assessed, and are namely, Hub Bracket (Rear fixed & Front swivel), Main Frame Structure, Split Flange Joint Shaft, Spreader Beam and Steering Clamp bracket (Mafokwane, 2021).

2. Manufacturing Process for considered Model
2.1. Materials Selection Justification
350WA SANS 1431, SANS 50025 / EN 10025 Grade S355JR and ASTM A36 are the most used mild and hot-rolled steel. Both materials have excellent welding properties and is suitable for grinding, punching, tapping, drilling, and machining processes. Yield strength of ASTM A36 is less than that of cold roll C1018, thus enabling ASTM A36 to bend more readily than C1018. Normally, larger diameters in ASTM A36 are not produced since

C1018 hot roll rounds are used (Macsteel, 2020). 350WA SANS 1431, SANS 50025 / EN 10025 Grade S355JR and ASTM A36 material are usually available in the following forms:

- Rectangle bar.
- Square bar.
- Circular rod.
- Steel shapes such as channels, angles, H-beams, and I-beams.
- Wear Plate (Hard Wearing Plates).

The criteria below are employed for best selection of materials and components discussed in (1. & 2.1.), as shown in Table 1.

Table 1 – Material Selection ranking criterion (Mulcathy, 1999).

CR1	Machinability
CR2	Wear resistance and good toughness
CR3	Corrosion resistance
CR4	Good combination of strength and ductility
CR5	Moderate hardness
CR5	Cost effective

3. Main Frame Structure Manufacturing Process & Material Selection Description

The H-section & I-section are a standard steel and are considered for the construction of the new system main frame structure design. The main frame structure takes a form of a table structure, where it consists of or is built up of a combination of H-section steel, Hollow square tubes and I-section steels all joined together using bolt connection method, (as shown in Figures 1 & 2) (Macsteel, 2020).

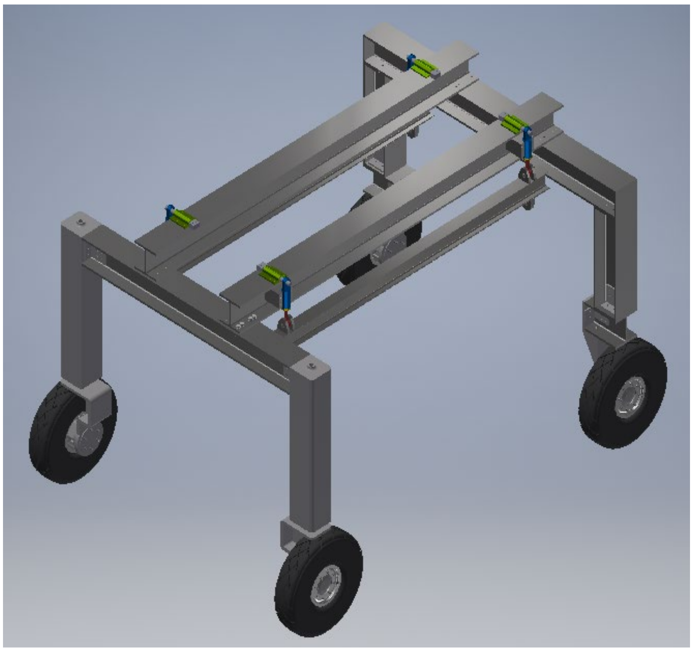


Figure 1 - Main Frame Structure (Mafokwane, at el., 2019).

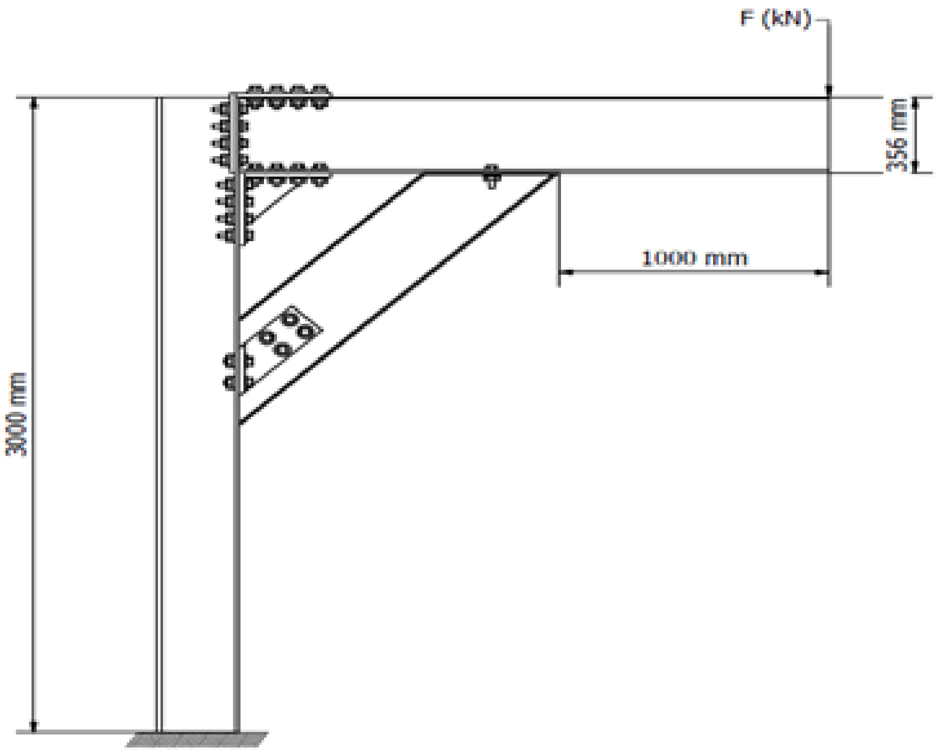


Figure 2 - Bolt Connection Illustration (Quarter of Main Frame) (*Macsteel, 2020*)

General H-section & I-Section steel selection criteria would typically include:

- Deflection limits, according to the specified standard on vertical and lateral deflections of the structure for the purpose of obtaining satisfactory hoisting service performance.
- Vertical deflection due to the maximum wheel loads and level supports. High impact resistance, high fatigue life for the chosen material.
- The beam must support a 20 ton and must be capable of withstanding contact stresses between beam-to-beam connection and bracket to beam.

Section steels comes in standard length; only a cutting torch and very large grinding equipment are used to cut the steel to desired length and for creation of holes for bolts slots. Therefore, the main frame structure consists of steel columns listed below (Macsteel, 2020),

- Four 305×305×158 (mm×mm×kg/m) H-Section, Universal Columns SANS 50025 / EN 10025 Grade S355JR, drilled on both ends with 25 mm diameter holes for bolt slots.
- Two 305×165×54 (mm×mm×kg/m) I-section, Universal Beams SANS 50025 / EN 10025 S355JR, for spreader beam support. Also drilled on both ends with 25 mm diameter holes for bolt slots.
- Two 285 x 285 mm×mm Square Tubing (Hot Rolled).
- Four 40 mm thick wearplates of (W200) - SS10/200 [Hard Wearing Plate (Bennox)], attached thtough weld on both ends of two Square Tubing, having 60 mm diameter bore at the center for Split joint shaft slots. Main Frame metrial’s yield stress is 760 Mpa (Mafokwane and Kallon, 2019).

4. Front and Rear Wheel Hub Support Brackets Manufacturing Process & Material Selection Description

Front & Rear hub support brackets are constructed using fabrication manufacturing method. Hub support brackets are made up of a combination of 40 mm thick plates and 20 mm thick plates to form a strong support structure, i.e. supporting the main frame and wheel hubs, thus joining them together to form a supported movable structure (refer to Figure 3). Hub support brackets consist of five 40 mm thick and two 20 mm thick plates joined by means of welding method (refer to Figure 4). Hub support brackets are used to attach and support hydraulic wheel hubs to the main frame structure. A 40 mm thick plate was chosen for its high strength properties having yield strength of 760 MPa & tensile stress of 650 MPa, (as shown in Tables 2 & 3) (Macsteel, 2020).

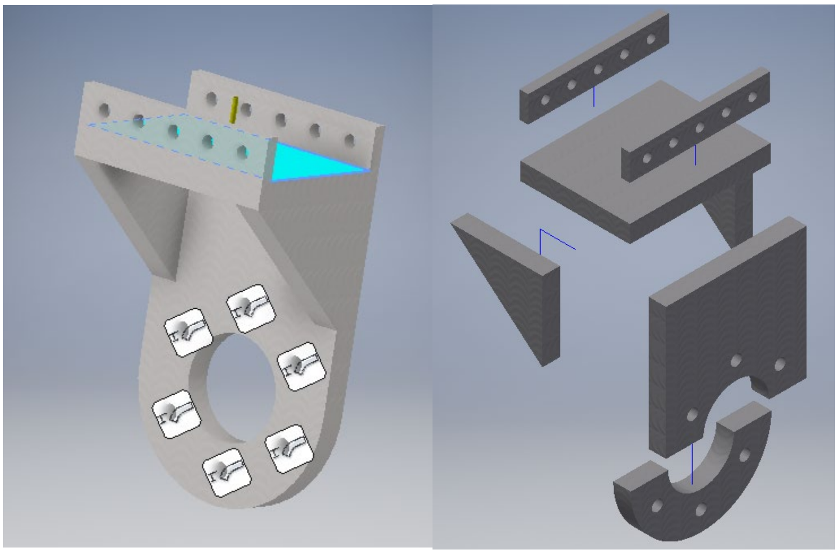


Figure 3. Hub Support bracket (*Macsteel, 2020*)

The rear fixed bracket and front swivel bracket both experiences high loads as they connect the H-Sections and Square Tubing of the main structure in front and rear wheels of the system. The components need to be high strength and possess good ductility to give warning before failure (Mafokwane and Kallon, 2020).

Table 2. Plates (Commercial Quality, S355 JR / JO and Vastrap Plates) data (Mulcathy, 1999).

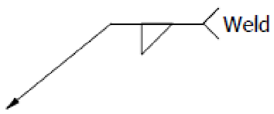
Properties by SANS 1431 Weldable Structural Steel Plate	
Thickness	16 - 40 mm.
Yield Strength	760 MPa
Tensile Strength	480 - 650 MPa
Elongation	> 18 %
Weld Symbol	

Table 3. Hub Bracket Part list (Mafokwane, et al., 2019).

Part List		
Item	**Qty**	**Description**
1	1	Rectangular Piece
2	1	Arc Piece
3	1	Flat Sheet
4	2	Triangular Piece
5	2	Flat Piece

5. Split Joint Shaft Manufacturing Process & Material Selection Description

The split joint shaft is responsible for transmitting the steering cylinder effort of $278.49\ kN$ to the front swivel support bracket to steer the system requiring steering bending moment of $128.1\ kN.m$. The item experiences torsion resistance and the material used is machinable and possess good ductility to give warning before failure. Material for Split Joint Shaft is EN-36A BH 265, (as shown in Table 4) (Macsteel, 2020).

Table 4. Split Joint Shaft Material Properties & Specifications (Shigley, 1996).

Material	Tensile Strength (MPa)	Elongation (%)	Yield Strength (MPa)	Hardness (HB)
4340	920	15	710	270

EN-36A	900	20	730	265

The Split Joint Shaft is 3050 mm long with 100 mm diameter, having a step that is 60 mm long on both ends with 60 mm diameter, (as shown in Figure 4). The shaft also has a flange coupling feature at mid-center for ease of maintenance and assembly, (refer to figure 8). One side of shaft end has a sprocket feature, see Figure 5, where it interconnects with swivel Hub Support Bracket for steering force transmission. The other shaft end is smooth, (refer to Figure 6), a steering clamp bracket, with a bore of 60 mm diameter will be mounted onto it and fastened.

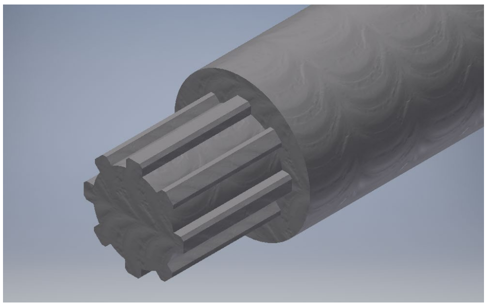


Figure 4. Shaft End having Sprocket Feature – Illustration (Mafokwane, et al.,2019).

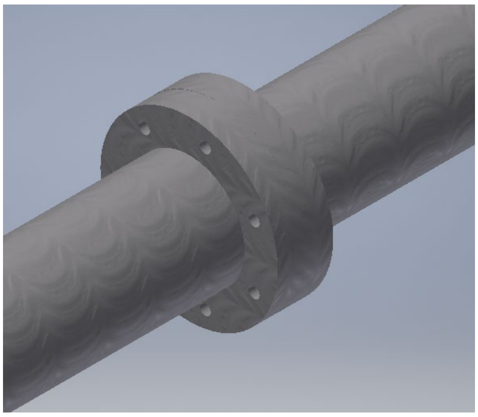


Figure 5. Shaft Mid Center having Flange Feature – Illustration (Mafokwane, et al., 2019).

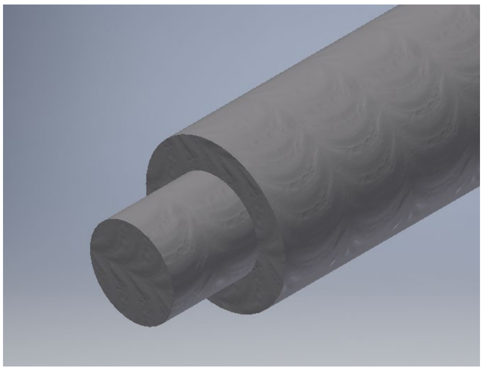


Figure 6. Smooth end Stepped for Steering Cylinder Clamp bracket (Mafokwane, et al., 2019).

6. Steering Clamp Bracket Manufacturing Process & Material Selection.

The Steering Clamp Bracket, (as shown in Figure 7), experiences medium to high stress loads as it transmits $128.1\ kN.m$ torque and $278.49\ kN$ steering force (turning force) induced from the double direction (Left & Right) linear force generated by the Hydraulic Steering Cylinder to the front swivel wheels of the system, (as shown in Figure 8). The component and material selection are focused on high strength and good ductility material properties for good factor of safety during design verification and operation, (as shown in Table 5) (Macsteel, 2020).

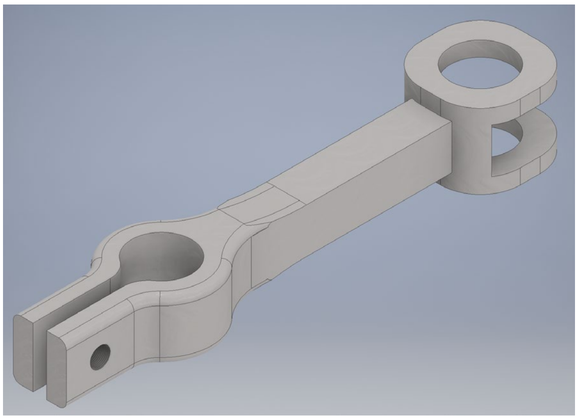


Figure 7. Steering Clamp Bracket (Mafokwane, et al., 2019).

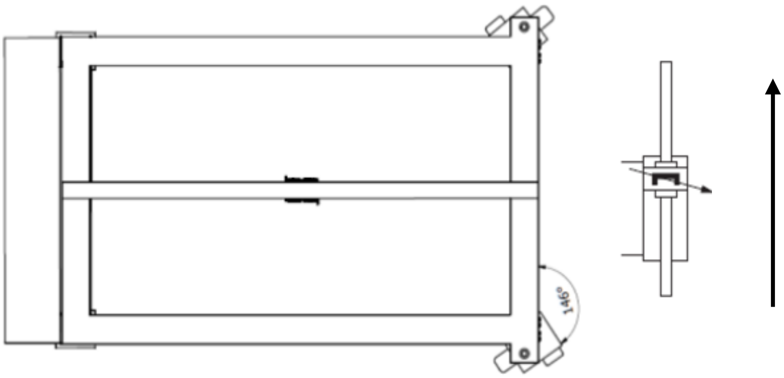


Figure 8 - Steered Wheels Illustration (Mafokwane, et al., 2019).

7. Spreader Beam Manufacturing Process & Material Selection.

The H-section & I-section are a standard steel with high strength properties and are considered for the construction of the spreader beam. The spreader beam's structure consists of a combination of four H-section steels, four 60 mm thick hooking plates and four lifting cylinder locating steel plates, all joined using bolt connection method, (as shown in Figure 9). Material for the spreader beam is SANS 1431, (as shown in Table 5) (Macsteel, 2020).

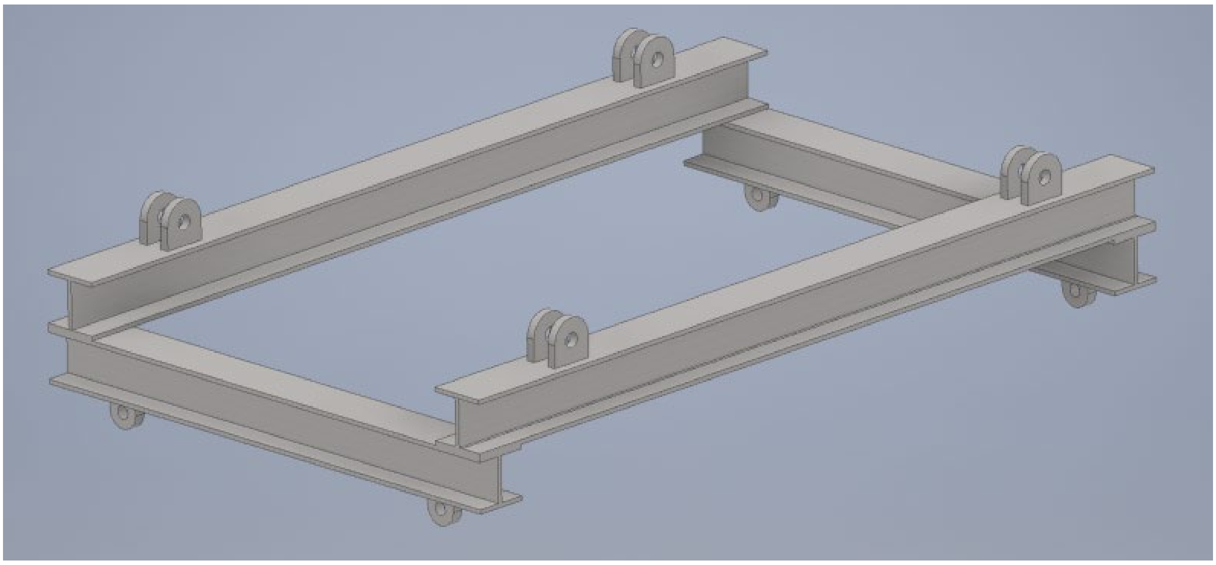


Figure 9. Lifting Spreader beam (Mafokwane, et al., 2019).

Table 5. Standard Steel Material Properties (Shigley, 1996).

Material	Tensile Strength (MPa)	Elongation (%)	Yield Strength (MPa)	Hardness (Rockwell B)
AISI 1020	420	15	350	68
Al 6061-T6551 angle unequal leg	276	17	276	60
EN 10025-2	450	18	355	74

8. Conclusion

In conlusion, main objective of this research has been achieved through the design and development of the new proposed Material Handling System that is capable of replacing the use of very big forklift trucks within indoor manufacturing companies. Large forklift trucks rely on Internal Combustion Engine power source which unfortunately poses health risks to workers. ICE produces exhaust fumes (Carbon Monoxide) while running. Exhaust fumes are harmful to human health (Apple, 1972) & (Health & Safety, 2008).

Therefore, the research beacame a success whereby a new proposed MHS has been designed using Autodesk Inventor Professional and material selection of the new design system's components has been carried out and verified in relation with their strength & reliability properties and high strength properties. Technical design shapes and drawing have been populated as well through Autodesk Inventor Professional. Material chosen of component manufacturing of the new design system are readily available from the market, that means there is no need to mould any component when manufacturing (Mafokwane and Kallon, 2021).

References

J. Apple, *Material Handling System Design*, New York: Ronald, 1972.

Macsteel, "Macsteel Structural Steel Catalogue,". Available: *https://macsteel.co.za/product-category/macsteel-special-steels/*. Accessed on August 15, 2020.

Joseph E. Shigley, *Standard Handbook of Machine Design*, New York: McGraw-Hill, 1996.

Health &. Safety, "Prevention of carbon monoxide poisoning from petrol and gas powered equipment," *Chamber of Commerce and Industry Western Australia*, 2008.

S.Z. Mafokwane, D.V.V. Kallon, M. Nkosi, F. Chiromo. Design of a Tri-Adjustable Automated Heavy Duty \Handling System based on Industry 4.0 Principles. *Procedia Manufacturing*. Volume 35, 2019. Pp 187 – 196.

S.Z. Mafokwane and D.V.V. Kallon., Hydraulic System Design of a Tri-Adjustable Automated Heavy-Duty Handling System Based on Industry 4.0 Principles. *2019 Open Innovations (OI),* 2019. Pp 420 - 424.

Mafokwane S.Z., Kallon D.V.V. Design of electro-hydraulic circuits for tri-adjustable automated heavy-duty industrial handling system. *Proceedings of the International Conference on Industrial Engineering and Operations Management. 2*020. 59. Pp 357 – 367.

Mafokwane S.Z 2021a.. Design of a Tri-Adjustable Automated Heavy-Duty Handling System Based on Industry 4.0 Principles. *Masters* d*issertation submitted to the University of Johannesburg*.

Mafokwane S.Z., Kallon D.V.V. Performance Analysis of a Tri-Adjustable Automated Heavy-Duty Handling System Designed on Industry 4.0 Principles. *Proceedings of the International Conference on Industrial Engineering and Operations Management. 2*021. Pp 2910 - 2921.

D. Mulcathy, *Materials Handling Handbook*, New York: Mcgraw-Hill, 1999.

Westinghouse, *Practical Mechanical Drawing and Machine Design*, Chicago: Federick. J Drake & CO. Publishers, 1907.

Biographies

Shaun Zamawelase Mafokwane is a PhD candidate at the University of Johannesburg, Department of Mechanical and Industrial Engineering. Shaun is currently employed by Tetra Pak SA Pty Ltd and works as an Electro-Mechanical Service Engineer. He earned a National Diploma, a BTech degree, and MPhil in mechanical engineering from the University of Johannesburg. He is a member of the Institution of Certified Mechanical & Electrical Engineers and he is currently completing his GCC examination.

Dr. Daramy Vandi Von Kallon is a Sierra Leonean holder of a PhD degree obtained from the University of Cape Town (UCT) in 2013. He holds a year-long experience as a Postdoctoral researcher at UCT. At the start of 2014 Dr Kallon was formally employed by the Centre for Minerals Research (CMR) at UCT as a Scientific Officer. In

May 2014 Dr Kallon transferred to the University of Johannesburg as a full-time Lecturer and later a Senior Lecturer in the Department of Mechanical and Industrial Engineering Technology (DMIET). Dr Kallon has more than twelve (12) years of experience in research and six (6) years of teaching at University level, with industry-based collaborations. He is widely published, has supervised from master's to Postdoctoral and has graduated seven (7) Masters Candidates. Dr. Kallon's primary research areas are Acoustics Technologies, Mathematical Analysis and Optimization, Vibration Analysis, Water Research and Engineering Education.