RESEARCH AND DEVELOPMENT OF AN INTELLIGENT AGV-BASED MATERIAL HANDLING SYSTEM FOR INDUSTRIAL APPLICATIONS

by

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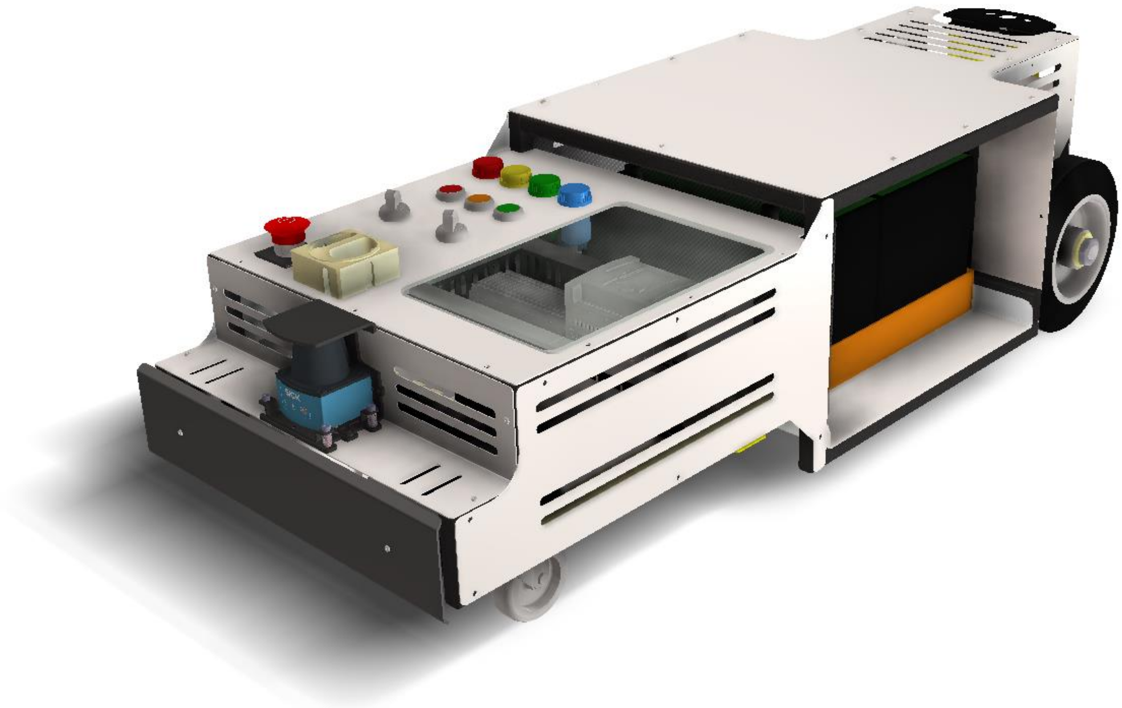

DECLARATION

I, ***<u>Tremaine Pierre Ferreira</u>***, student number ***<u>s208008347</u>*** from the Nelson Mandela Metropolitan University in Port Elizabeth, South Africa, declare the following:

<u>Statement 1</u>

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed ………………..

Date …………………..

<u>Statement 2</u>

This dissertation is being submitted in partial fulfilment of the requirement for the degree of Master in Engineering in Mechatronics.

Signed ………………..

Date …………………..

<u>Statement 3</u>

The dissertation is the result of my own independent work/investigation, except where otherwise stated. Other sources are acknowledged by giving explicit references. A bibliography is appended.

Signed ………………..

Date …………………..

ACKNOWLEDGEMENTS

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ABSTRACT

The use of autonomous robots in industrial applications is growing in popularity and possesses the following advantages: cost effectiveness, job efficiency and safety aspects. Despite the advantages, the major drawback to using autonomous robots is the cost involved to acquire such robots. It is the aim of GMSA to develop a low cost AGV capable of performing material handling in an industrial environment.

Collective autonomous robots are often used to perform tasks, that is, more than one working together to achieve a common goal. The intelligent controller, responsible for establishing coordination between the individual robots, plays a key role in managing the tasks of each robot to achieve the common goal. This dissertation addresses the development of an AGV capable of such functionality. Key research areas include: the development of an autonomous coupling system, integration of key safety devices and the development of an intelligent control strategy that can be used to govern the operation of multiple AGVs in an area.

KEYWORDS: *AGV, Intelligent Controller, Guide-Path Systems*

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ABBREVIATIONS

AGV	-	Automated Guided Cart
AGV	-	Automated Guided Vehicle
GMSA	-	General Motors South Africa
PLC	-	Programmable Logic Controller
SysML	-	OMG Systems Modelling Language
SPS	-	Set Part System
PID	-	Proportional, Integral and Derivative
CAD	-	Computer Aided Design
CCD	-	Charge Coupled Device
ACS	-	Automatic Coupling System
GUI	-	Graphical User Interface
USB	-	Universal Serial Bus
R/C	-	Remote Control
DIP	-	Dual Inline Package
VSR	-	Voltage Sensitive Relay
SCADA	-	Supervisory Control and Data Acquisition

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CHAPTER ONE

INTRODUCTION

The material presented in this dissertation focusses on the research and development of an intelligent controller for use at GMSA. The first section of the paper provides an introduction to the field of robotics and the applications thereof in an industrial environment.

The use of mobile robots for industrial applications is growing in popularity with companies such as Toyota (Trebilcock, 2012) investing largely into incorporating the use of autonomous vehicles into the production process. Stewart (2009) mentions the following reasons for employing robots:

- **Cost Effectiveness**

Robotic workers do not require breaks, vacation or sleep. Aside from the occasional breakdowns and routine maintenance, robotic workers are capable of performing work faster than humans for longer periods of time, hence improving the production rate. Davich (2010) stated that the main cost associated with manual material handling is the labour cost, and that effective material handling solutions can reduce a plant's operating cost by 15-30%.

- **Job Efficiency**

According to Stewart (2009) the use of robotic workers over human workers have enabled the automotive industry to assure that task would be performed according to expectation. Robotic workers are superior to human workers in areas such as speed and accuracy (Yakut Ali, et al., 2010). Furthermore, human workers are limited to the number of hours they are allowed to work or maximum permissible loads they are allowed, or capable, of handling.

- **Safety Aspects**

Safety plays an important role in industry and is therefore a key factor to consider. According to Stewart (2009), one of the main advantages of robotic workers is the elimination of humans needing to perform tasks that are dangerous to their health or situated in hazardous environments.

Despite the major benefits to using robots, the costs involved for such robots are still considerably high and not feasible for some applications. Davich (2010) explored the cost of commercial AGV's. A summary of the cost of commercially available robots can be found in Table 1.

Floreano et al (1999) stated that the costs of smaller robots are lower than for larger robots, with comparable performance, due to the use of smaller mechanical components and electronics. According to Yakut Ali et al (2010) the use of robots in developing countries are not as popular as in developed countries due to low labour costs.

#	Manufacturer	Expected AGV Cost	Additional Fee (Labour)
1	Egemin Automation	$100 000 per unit	$25 000
2	Kiva Systems	$1 000 000 (Includes 30 AGV's plus 300 shelves)	
3	Seegrid	$54 000 - $65 000 per unit	

Table 1. Cost Summary of Commercial AGV's. (Davich, 2010)

With the growing increase in demand for mobile robots and improved production efficiency, companies such as Savant Automation (2012), Egemin Automation, Kiva Systems and Seegrid focuses on delivering robots capable of satisfying customer needs. Figure 1 shows two commercially available robots that can be used for material handling in an industrial environment.

Figure 1. Commercially Available AGV's produced by Savant Automation (2012): AGV Cart Move (Left) and AGV Tow Vehicles (Right)

It is the goal of GMSA to explore the possibilities of developing a low cost AGV that will meet the requirements of industrial robots in terms of safety, reliability and efficiency.

1.1 BACKGROUND AND CONTEXT

Material handling systems in industrial environments are of vital importance to ensure that products are delivered in the shortest possible time. GMSA wishes to change from traditional material handling to the Set Part System to achieve improved efficiency in the plant.

Traditional material handling systems requires an assembly worker to abandon the assembly station in order to retrieve parts. The parts are usually selected from flow racks as shown in Figure 2.

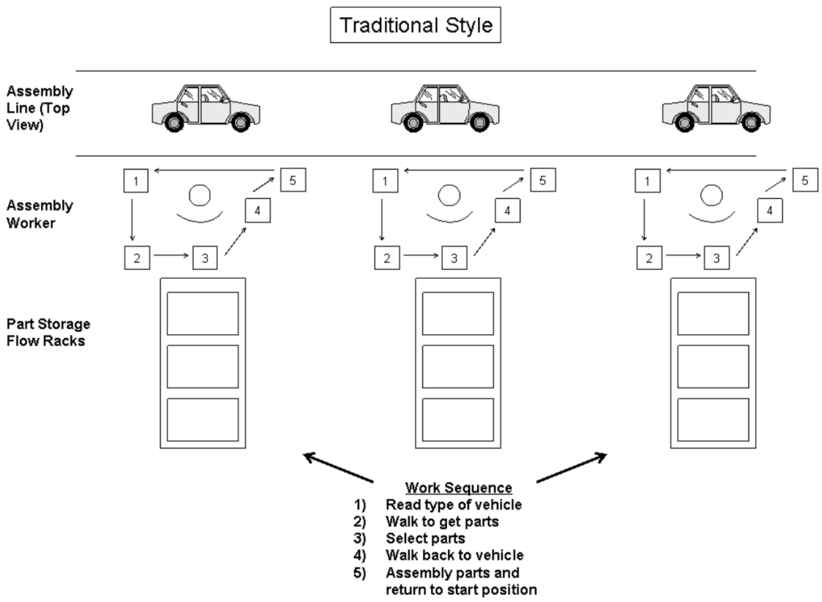


Figure 2. Traditional Material Handling (Smalley, n.d.)

To improve on traditional material handling systems, the set part system was introduced by Toyota and first implemented in Japan and China (Smalley, n.d.). A set part system eliminates the need for an assembly worker to leave his/her station by employing material handlers responsible for transporting material between the storage facility and assembly stations.

The main advantage to using the set part system is simplicity and quality improvement by avoiding assembly or part selection errors. The value added time of the worker is also increased, since walk time as well as search and select time are avoided. The typical layout of a set part system can be seen in Figure 3.

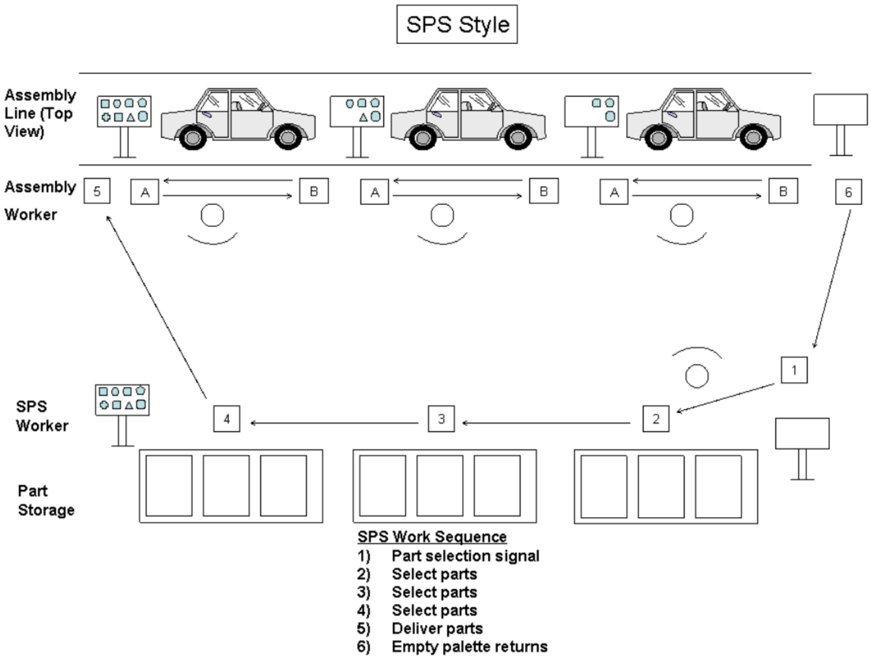


Figure 3. Set Part System (Smalley, n.d.)

GMSA approached the Nelson Mandela Metropolitan University (NMMU) to design and develop a low cost mobile material handling system, or AGV, which will serve as the material handler in their SPS layout. Cawood (2013) designed and developed the initial prototype for the AGV, but no control strategy has been suggested to coordinate multiple AGVs operating at GMSA.

1.2 Problem Statement

The research topic is based on a previous design developed for GMSA by Cawood (2013). The main task of the first generation prototype was to transfer empty instrument panel trolleys back to the start of the sub-assembly line at GMSA. However, GMSA plan to use the AGV's for various tasks in the future and hence the need for a more efficient system arises.

Cooperation between AGVs is necessary to avoid collisions and ensure that tasks are performed quickly and efficiently. The level of effort required to employ AGVs should also be reduced to ensure that production plants can effortlessly and rapidly incorporate AGVs in various stages of their production cycle.

1.3 AIM AND OBJECTIVES

The aim of the research is to deliver an intelligent controller for a AGV-based material handling system capable of performing efficient, intelligent and autonomous material handling at low cost. The goal will be achieved by completing the following objectives:

- Ensuring Reliable Sensory Capabilities
- Design of an Automatic Coupling System
- Development of intelligent routing and control strategy
- Ensuring Low Development Cost

1.4 OVERVIEW OF DISSERTATION

Section 2 of the dissertation will cover a literature review into the field of mobile robotics. The literature review will aid the reader to better understand the technologies available for the design, development and control of mobile material handling systems.

Section 3 focusses on the first generation prototype of the AGV. Section 3 addresses essential improvements that were required to ensure safe and effective operation and ultimately ensure the success of the project.

Section 4 of the dissertation explains the system model created for the project. It clearly states the requirements of each aspect of the project to ensure success of the final product.

Section 5 addresses the various conceptual designs as well as the final design of the AGV. The final design will be addressed under the headings: mechanical design, electrical design and software. Section 5 addresses all aspects of the AGV in detail, while section 6 explains how multiple AGVs will be controlled using an intelligent controller.

Finally, experimentation procedures and results will be addressed before summarising and concluding the paper. All relevant documentation, along with a project schedule, is appended at the end of the dissertation.

CHAPTER 2

LITERATURE REVIEW

This chapter will cover a review on mobile robots along with the design, development and control thereof. The main focus of the literature review will be on autonomous robots used for material handling in an industrial environment.

The literature review will mainly be divided into the following categories: Line following AGVs, Guide-Path Design and Supervisory AGV Control Systems. Line following AGVs are autonomous vehicles which are navigated though its environment by following a physical track on the floor. Line following AGVs are generally comprised of a power source, wheels, electrical motors, a coupling system, safety devices and sensors. Guide-path systems refers to the strategies available for navigating line following AGVs effectively and efficiently. The control of AGVs considers the various strategies for establishing coordination between multiple AGVs through vehicle dispatching and conflict resolution.

2.1 LINE FOLLOWING AGVS

A line following robot, also called a line follower, refers to an autonomous vehicle that navigates through its environment by sensing the presence of a line. The control system senses the line and repositions the robot to stay on course. A line follower can therefore be classified as a simple closed loop system. The track can either be created by coloured tape, as is the case with vision-based line followers, or metallic tape when inductive sensors are used for line detection. Below are some of the advantages and disadvantages to using a line follower:

Advantages:

- Autonomous vehicle navigation
- Cost effective
- Simplicity of implementation

Disadvantages:

- Tracks can become damaged
- Cannot navigate without the presence of a line

- Slow speeds and instability on sharp bends

Magnetic tapes are used for a large number of industrial AGVs, since the magnetic tape can be placed under a non-ferrous floor where it cannot be damaged.

2.1.1 Popular AGV Designs

Different designs for line followers have been researched in the past, but with most of them making use of a differential drive system (Agarwal, et al., 2008; Hymavathi & Vijay Kumar, 2011). A two-wheel differential drive refers to each of the motors moving at different speeds, I.e. they are controlled individually. Other designs for mobile robots include: Single Wheel Drive, Syncro-Drive and Ackermann Steering (Bräunl, 2003).

2.1.1.1 Single Wheel Drive

Single wheel drive robots are constructed using three wheels, namely: two castor wheels at the rear and a single wheel at the front, which is used for both driving and steering. The direction of motion of the robot can be altered by repositioning the drive wheel. Figure 4 illustrates a single wheel drive robot.

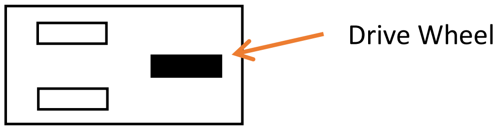


Figure 4. Illustration of Single Wheel Drive Robot. Adopted from (Bräunl, 2003)

2.1.1.2 Differential Drive

According to Bräunl (2003) a differential drive robot has two independently controlled motors located on the left and right side of the robot. Differential drive robots can either have three contact points, i.e. two driving wheels and a single castor wheel when the driving wheels are placed at the rear of the robot, or four contact points when the driving wheels are positioned in the centre of the robot.

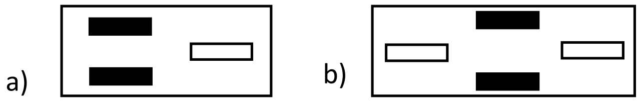


Figure 5. Illustration of Differential Drive Robot. a) Three contact points, b) four contact points. Adopted from (Bräunl, 2003)

If both the motors operate at the same speed, the robot will move forward. If the motors rotate at the same speed, but in opposite directions, the robot will rotate about a midpoint located between the two driven wheels (Bräunl, 2003). If both motors rotate in the same direction, but with different velocities, the robot rotates along a curve and not about a midpoint.

2.1.1.3 Syncro-Drive

Syncro-drive robots consist of three wheels which are all used for driving and steering. The advantage is that the robot is omni-directional, meaning that the robot can move in any direction on the plane. However, syncro-drive robots cannot change direction while driving, thus requiring the robot to be stationary while repositioning the wheels.

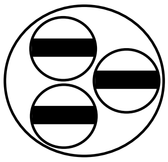


Figure 6. Illustration of Syncro-Drive robots. Adopted from (Bräunl, 2003)

An illustration of a syncro-drive robot can be seen in Figure 6. The next robot design to be addressed is the Ackerman steering robot.

2.1.1.4 Ackermann Steering

Ackerman steering is used by standard automobiles and consist of two driving wheels and two steering wheels. The rear wheels are used for driving, while the front wheels are used for steering. According to Bräunl (2003), Ackermann steering has the following advantages and disadvantages over differential drive robots:

Advantage(s)

- Better driving capabilities in a straight line, since the rear wheels are driven via a common axis

Disadvantage(s)

- Requires a turning radius, i.e. the vehicle cannot rotate about a point
- Driving (rear) wheels experience slipping when traversing around corners

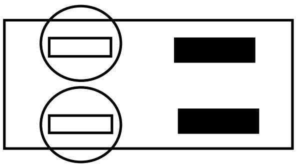


Figure 7. Illustration of Ackermann Steering.
Adopted from (Bräunl, 2003)

Bahruddin et al. (n.d.) analysed the line sensor configuration and concluded that line following can be achieved successfully. However, they did experience problems at high velocities. The initial AGV under consideration is of the line following type with differential drive steering and a single castor located in the front of the AGV.

The next section will address PID control used to establish improved control when performing line following.

2.1.2 AGV Control

The purpose of the control system is to compare the desired path of the robot to the actual path and transmit appropriate commands to the output devices (such as the motors) to insure optimal performance. Closed loop systems with PID control are largely implemented due to the simplicity thereof. According to Holland (2004) PID control is essentially three separate controls whose outputs are summed to produce a single output signal. The measured signal is converted to an error signal, which in turn is presented to the three signal processors of the PID loop.

The **proportional** processor of a PID controller is an amplifier stage that responds to the difference in measured signal to desired signal. If the difference is large, the gain of the proportional stage will be large and the system will oscillate (Holland, 2004).

The **integral** processor of the PID controller takes into consideration the summation of error over a set period of time. If the gain of the integration process is too high it will induce a lower frequency oscillation than that of the proportional term. Previously mentioned is as result of the additional time delay accumulated by the integration process (Holland, 2004).

The last processor of the PID controller is known as the **derivative** processor. The derivative processor takes into consideration the rate of change of error and therefor needs to be subtracted from the other terms, in order to supress the changes in error. According to Holland (2004) the entire PID equation can be written as follows:

$$P_t = (K_p \cdot E) + (K_i \cdot \int E) - (K_d \cdot \frac{dE}{dt})$$

Where P_t is the total power command, E is the instantaneous error measured, and K_p, K_i and K_d are the proportional, integral and derivative gains respectively. The next section will address the issue of determining the error signal, or distance, between the actual path and the desired path.

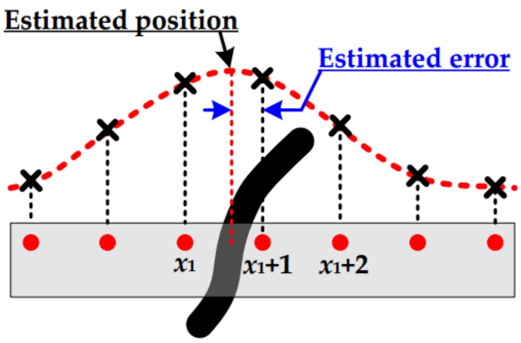


Figure 8. Line Detection via Quadratic Interpolation (Su, et al., 2010)

Su et al (2010) provided insight into determining the offset from a line using quadratic interpolation. Assume a seven sensor array as depicted in Figure 8. If a value of -3 is assigned to the far left sensor, and the distance between two consecutive sensors are chosen to be one, then the nominal position (under the chosen values) will be x and the far right sensor will be $x + 4$. Using analogue sensors, the output will vary according to the proximity of the sensors to the line (Su, et al., 2010) and one will always be able to find three consecutive sensors with higher readings than the remaining sensors. Su et al (2010) presents the following equation for relating the coordinates of the sensors to the output values:

$$y_1 = a{x_1}^2 + bx_1 + c$$

$$y_2 = a(x_1 + 1)^2 + b(x_1 + 1) + c$$

$$y_3 = a(x_1 + 2)^2 + b(x_1 + 2) + c$$

From Figure 8 it can be observed that the curve follows a Gaussian distribution, with the maximum value on the graph representing the actual position of the line. The following equation approximates the error based on the three obtained sensor coordinates (Su, et al., 2010):

$$x = -\frac{b}{2a}$$

Where,

$$a = \frac{y_1 + y_3 - 2y_2}{2}$$

and

$$b = y_2 - y_1 - 2ax_1 - a$$

The error term is therefore calculated as:

$$Error = e = 0 - x = -x$$

The next section will address the issue of obstacle detection and avoidance with regards to mobile platforms.

2.1.3 Obstacle Avoidance

Industrial environments consist of a variety of material handling systems, machinery and workers. Collisions occur when the AGV comes into physical contact with any of the objects found in its environment and should be avoided at all times. This chapter will address the issue of object detection and collision avoidance.

Research studies revealed that only a small number of effective sensing technologies are available for obstacle detection in the field of mobile robotics. These sensors range from small inexpensive devices to complex and expensive devices. Each of the previously mentioned sensors has their own set of advantages and disadvantages and will be addressed in this chapter.

2.1.3.1 Ultrasonic Sensors

The first type of sensor to be considered is the ultrasonic sensor, also referred to as sonar. According to Gray (2000) sonar is the most widely used technology for obstacle detection because it is inexpensive and simple to operate, therefore making them popular among both robot hobbyists and researchers.

Ultrasonic sensors typically transmit a short burst of ultrasonic sound towards an object, which reflects the sound back to the sensor. By measuring the time-of-flight of the sound burst, and knowing the speed of sound to be 340.29 m/s, the distance between the sensor and the object can be calculated. The main advantage, when using ultrasonic sensors for collision detection, is that the sensor's response is not dependent upon the surface colour of optical reflectivity of the object. The following disadvantages need to be considered before selecting an ultrasonic sensor for use on an AGV (Rockwell Automation, 2013):

- The sensor should be positioned such that the sound is reflected back to the sensor. When the object surface is not perpendicular to the sensor, the sound wave might be directed away from the sensor and result in unreliable detection
- Loud noises could result in a false response from the sensor despite the good immunity to background noise that ultrasonic sensors exhibit
- Ultrasonic sensors have a minimum sensing distance

Soto et al. (1999) and Liao et al. (1999) used four sonars on their AGV for the safety system. Each of the sonars are static and used to detect close obstacles that could have been overlooked by the vision system. Other authors (Thrun, et al., 1999) used sonars in conjunction with other sensing technologies as described later in this chapter.

2.1.3.2 Scanning Laser Technology

Safety laser scanners provide a laser safety solution for both mobile vehicles and stationary applications. Two main types of laser scanners are available. The first type emits a continuous beam towards the target and determines the distance based on the returned beam. According to Gray (2000) these type of sensors use class 1 lasers that are not eye safe and thus not recommended. The second type is a pulsed laser directed towards a rotating mirror which scans the sensor surroundings. If an object or obstacle is detected the light pulse is reflected and detected by the scanner's receiver. A light time-of-flight measurement, i.e. the time elapsed between the transmission and reception of a light pulse, is used to determine the distance between the scanner and the object.

The distance measurement between the object and the sensor allows for two field areas, namely: warning field and protective field. Warning fields inform the sensor when an obstacle is a large distance away from the sensor. When the distance decreases to a hazardous set-point the object enters the protective field. Detection of objects in the protective field results in an immediate stop of the system to ensure that no collision or injuries occur. Safety laser scanners are commonly found on AGVs. The main disadvantage of safety laser scanners is the high costs of the sensor modules. The SafeZone™ Singlezone/Multizone Safety Laser Scanner from Allen Bradley was initially considered for the AGV, but was discarded due to its costs of R44 600 in the year 2013.

Figure 9. Allen Bradley Safety Laser Scanner

Laser scanners are available for both 2-dimensional and 3-dimensional scanning. Three dimensional scanning lasers have the same principle of operation as 2D scanners, however they are constructed with an additional rotary mirror and more complex programming is required.

2.1.3.3 Charged Coupled Device (CCD) Camera

CCDs are used in digital cameras and video cameras to record still and moving images. CCDs captures light and converts it to digital information. CCD cameras provide vision-based navigation of AGVs. Processing digital information from the vision system is complex and generally requires a computer to perform the computation.

The next section will address automatic coupling along with design aspects that need to be considered.

2.1.4 Automatic Coupling Systems

Automatic coupling systems are used to establish physical connections between objects without human intervention.

The Robotino® forklift, shown in Figure 10, is a simple example of an autonomous system that can be utilized in the production environment to transport material. The forklift is composed of a linear actuator, two proximity sensors for end-position monitoring and an additional sensor to determine load presence (FESTO, 2013).

Figure 10. Robotino® Forklift (FESTO, 2013)

2.1.5 Battery Management Systems

To ensure that all electrical components function correctly it is important that the supplied power is within the specification of each component. Monitoring the supply of the AGV system is of crucial importance to insure safe operation and optimal performance.

2.2 GUIDE-PATH DESIGN

According to Le-Ahn & De Koster (2004) the guide-path is dependent on: the shop-floor space, layout of storage zones and arrangement of handling stations. The guide-path connects all workstations in the system that requires material transport. The guide path may contain junctions, intersections and shortcuts (Le-Ahn & De Koster, 2004). The following section will address important factors to consider for unidirectional systems and bidirectional systems.

2.2.1 Unidirectional Guide-Path Systems

Vehicles in a unidirectional guide-path system are only capable of travel in a single direction. In unidirectional guide-path systems it is important to ensure that two vehicles do not travel on a single track in opposite directions, since manual intervention will be required before the AGVs will continue. This is the less complex option, but may result in reduced cycle time if the error is not detected early.

2.2.2 Bidirectional Guide-Path Systems

Vehicles in a bidirectional guide-path system are capable of travel in both directions. In order to achieve bidirectional motion the design and control of the AGV are essential. The supervisory control of bidirectional guide-path systems, as discussed in the following section, is more complex and requires provision to be made for obstacle avoidance.

2.3 AGV CONTROL SYSTEMS

This section addresses the factors that need to be addressed when controlling a system comprised of multiple AGVs. According to Holland (2004) the design of mobile robots are complex due to the nature of the inputs. Inputs to mobile robots are non-deterministic and change every time the robot runs a path, since nothing stays constant in the physical world (Holland, 2004). The control system of the robot therefore plays an important part in the developed thereof.

2.3.1 Collective Autonomous Robots

When a team of two or more autonomous mobile robots are used to perform a specific task, it is referred to as *collective autonomous robotics* (Floreano, et al., 1999). Floreano et al (1999) suggests that, when dealing with groups of robots, inspiration should be taken from collective intelligence displayed by social insects. Evolutionary techniques, such as genetic algorithms, can aid an engineer in selecting adequate behaviours for each robot in the team (Floreano, et al., 1999; Zhang & Kube, 1993), hence ensuring optimal team efficiency.

The first topic to be addressed is the communication interface and strategy between the robots in a group. Communications between robots are an important aspect when commissioning them to perform tasks. Communication will allow collaborative function and eliminate the possibility of collision or task duplication (i.e. if multiple robots respond to a single request). Based on the work performed by Floreano et al (1999) as well as Zhang & Kube (1993) there are two possible methods commonly used for robot communication. The first method is a decentralized solution where the robots communicate directly with one another to convey information. The second method is using a centralized global communication strategy, which ensures that all robots know where the other team members are at all times.

A control system, or intelligent controller, is used to ensure collaboration between the various AGVs in the system by establishing efficient vehicle dispatching and conflict resolution. The next section will address the issue of robotic control in more detail by distinguishing between centralized and decentralized control systems mentioned by Davich (2010), Pallottino et al. (2007) and Alami et al. (1998).

2.3.2 Centralized Control Systems

In a centralized control system the entire team of robots convey information to a central unit. The central unit interprets and processes the information before conveying control instructions to all robots in the team (Olmi, et al., 2008). According to Olmi et al. (2008), centralized control systems are used in the majority of industrial applications. In centralized control system the central controller is known as the master and all attached AGVs are referred to the slaves.

2.3.3 Decentralized Control Systems

Manca et al. (2011) investigated a problem similar to the one addressed in this paper. They proposed a decentralized system whereby communication for coordination is only required among neighbouring robots and not the entire team. One way of establishing communication between neighbouring robots is to make use of sign boards. Sign boards are located on each robot in the team and displays information regarding its identification number and the robot state. The sign boards are viewed by neighbouring robots to establish communication and cooperation. Therefore, in a decentralized system, the individual robots are responsible for computing their next action, and do not receive it from a central unit.

Table 2 summarizes the differences between centralized controls systems and decentralized control systems. The system marked with "X" indicates the preferred system for the property under consideration. For example: The decentralized control system is preferred for position detection, but the costs are higher than that of centralized control systems.

#	Property	Centralized Control System	Decentralized Control System
1	Position Detection		X
2	Fault Finding Capabilities		X
3	Number of AGV's in the system	Few AGV's	Many AGV's
4	Effectiveness with High Material Flow		X
5	Simplicity	X	
6	Cost (Reduced Communication Wiring)	X	

Table 2. Summary of Centralized and Decentralized Control Systems (Davich, 2010)

From Table 2 it can be seen that centralized control systems are favoured when considering systems with only a few vehicles and when simplicity is a factor.

The next section will address the basic philosophy of AGV navigation with regards to material handling in a service loop.

2.3.4 Loop Dispatched AGVs

In loop systems the vehicle is loaded with material and is commanded to execute a service loop as depicted in Figure 11. The vehicle collects material from the mail room and delivers it to the pre-defined stop zones. Loop dispatched robots can be either unidirectional or bidirectional depending on the requirements.

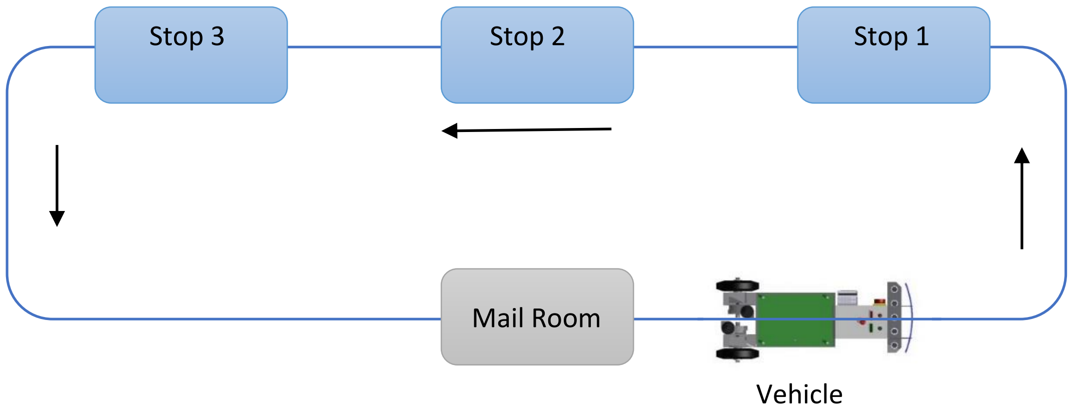


Figure 11. Simplified Diagram of Loop Dispatching. Adopted from (Holland, 2004)

The main disadvantages with loop systems are their low efficiencies, lack of flexibility and the lack of monitoring (Holland, 2004). The low efficiencies arise if the vehicle has to complete a full loop to deliver a single load. One of the methods employed to overcome the efficiency problems is to use a vehicle capable of towing or carrying a payload carrier. By using a payload carrier the vehicle can perform multiple tasks in a single lap, hence reducing the cycle time of the complete process.

According to Holland (2004), one of the simplest techniques of job management is the *Ping-Pong* method. Under the *Ping-Pong* scheme, the robot cycle is initiated by an on-board interface. Manual labour is required at the various workstations to load the vehicle and send it to the next point using previously mentioned interface. Two problems associated with this technique are:

- The cycle time is dependent on the servicing at each station, and
- There is no central control from which location and status can be monitored

To overcome the problems of *Ping-Pong* job management, a large number of commercial applications aim to employ centrally managed and dispatched systems, also referred to as centralized system as described in 2.3.2.

This section provided insight and information into the different types of control systems, track layouts, AGV designs and common AGV-based handling systems. Information in this section is important for the next section that will address investigations into a previous AGV design.

CHAPTER 3

INVESTIGATION OF PREVOUS DESIGN

Investigations were performed on a previous AGV design for GMSA. The investigations focussed on performance characteristics as well as limitations of the initial design. It is important to consider the previously mentioned factors to ensure a successful outcome of the intelligent controller. From a thorough inspection of the previous design it was evident that multiple alterations were required in order to achieve the desired outcome of the project. The following were identified from the inspection:

- **Control Improvement** – Control improvements are required to reduce the amount of overshoot during operation. An improved control strategy will also ensure more accurate positioning of the AGV when coupling or decoupling a load.
- **Coupling System** – The previous design was comprised of a manual hitch for trolley loading and unloading. A manual hitch will prevent the controller from performing autonomous coupling.
- **Safety and Sensory Improvements** – The previous design was equipped with a Perspex bumper located at the front end of the vehicle. The design was capable of detecting contact collisions, but was not secure (i.e. could be removed effortlessly) and also not durable enough for industrial application.
- **Design Verification/Validation** – Essential customer requirements had to be verified. One of the essential requirements investigated was the performance of the chosen batteries, since the customer aims to use the AGVs for an entire shift without recharging the batteries.
- **Battery Monitoring System (BMS)** – Battery monitoring is essential, since a lack of power can cause undesired functionality of the AGV, which may lead to sensor failure and a potential safety risk.

3.1 CONTROL IMPROVEMENTS

The AGV consists of five proximity sensors, located at the front of the AGV, that are used for navigation by line-following (also referred to as a follower). The five inductive sensors are used to determine the offset of the AGV to the desired path defined by inductive tape located on the floor. The main disadvantage with using distinct digital inputs, for line detection, is that the resolution is limited to the number of sensors used in the configuration. The basic design assigned consisted of five states as summarized below in Table 3. The Telemecanique XS230AANAL2 inductive sensors were used on the AGV. These sensors have a threaded diameter of 30mm and optimal sensing range of 22mm. The five XS230AANAL2 sensors were placed 65mm apart. The tape placed on the floor was 25mm stainless steel tape.

State #	Active Sensor(s)	Binary Representation	Control Command
1	5	00001	Rapidly accelerate wheel 2 while maintaining constant speed on wheel 1
2	4	00010	Slightly accelerate wheel 2 while maintaining constant speed on wheel 1
3	3	00100	Both wheels rotate at same, constant speed
4	2	01000	Slightly accelerate wheel 1 while maintaining constant speed on wheel 2
5	1	10000	Rapidly accelerate wheel 1 while maintaining constant speed on wheel 2

Table 3.Summary of input states

Let us consider the centre sensor, sensor 3(See Figure 12). If the stainless steel tape is perfectly centred with the middle sensor, then the distance between the edge of the tape and the edge of the adjacent sensor will be:

$$GAP = (65 - 15) - \frac{25}{2} = 37.5mm$$

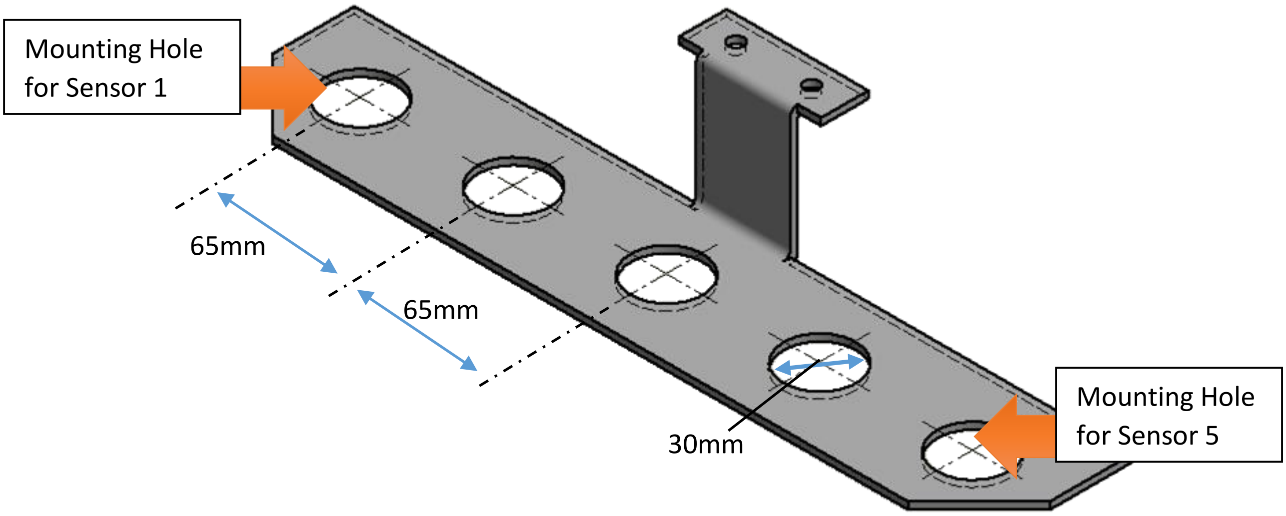


Figure 12. Initial bracket for mounting guidance sensors

This means that there exists a "dead band" of 37.5mm between the sensors, which causes a significant amount of overshoot during operation. The control was improved by increasing the line width as well as redefining the sensor strategy. The improved control strategy is summarized below in Table 4.

State #	Active Sensor(s)	Binary Representation	Control Command
1	5	00001	Rapidly accelerate wheel 2 while drastically decelerating wheel 1
2	4,5	00011	Rapidly accelerate wheel 2 while slightly decelerating wheel 1
3	4	00010	Slightly accelerate wheel 2 while slightly decelerating on wheel 1
4	3,4	00110	Slightly accelerate wheel 2 while maintaining constant speed on wheel 1
5	3	00100	Both wheels rotate at same, constant speed
6	2, 3	01100	Slightly accelerate wheel 1 while maintaining constant speed on wheel 2

7	2	01000	Slightly accelerate wheel 1 while slightly decelerating on wheel 2
8	1, 2	11000	Rapidly accelerate wheel 1 while slightly decelerating wheel 2
9	1	10000	Rapidly accelerate wheel 1 while drastically decelerating wheel 2

Table 4. Proposed control strategy to improve performance

States 4 and 6 are referred to as drift sensors and should be positioned in such a way that they detect minor deviations of the AGV (i.e. close to the edge of the inductive/steel tape). The main difference with the improved strategy is that more than 1 sensor can be active at a time. The number states, and consequently the resolution, of the sensor configuration were therefore improved at minimal cost. To obtain more states and improve the sensory capabilities, the number of sensors should be increased and the space between them reduced. Additional sensors were not added to the sensor array due to financial constraints.

3.2 BUMPER DESIGN

The bumper is a critical component of the AGV as it is a safety feature of the system. Two design requirements are present in the design of the bumper, namely:

- The bumper should protect the inductive sensor array, and
- The bumper should stop the AGV if any collisions do occur.

Ideally the bumper should never be used, since the non-contact sensors should avoid obstacles and collisions. The bumper can therefore be regarded as a secondary safety feature to the system. By aid of collision sensing on the bumper, the intelligent controller will be able to distinguish between collisions and non-contact obstacles that were detected. The controller and the interface to the bumper will be addressed later in this paper.

Due to the autonomy and mobility of the AGV in a dynamic environment, it is difficult to predict the nature of collisions. It is therefore important to consider a variety of possible collisions to ensure satisfactory performance. Mechanical vibrations should be considered to ensure that the bumper does not detect a collision when one is not present.

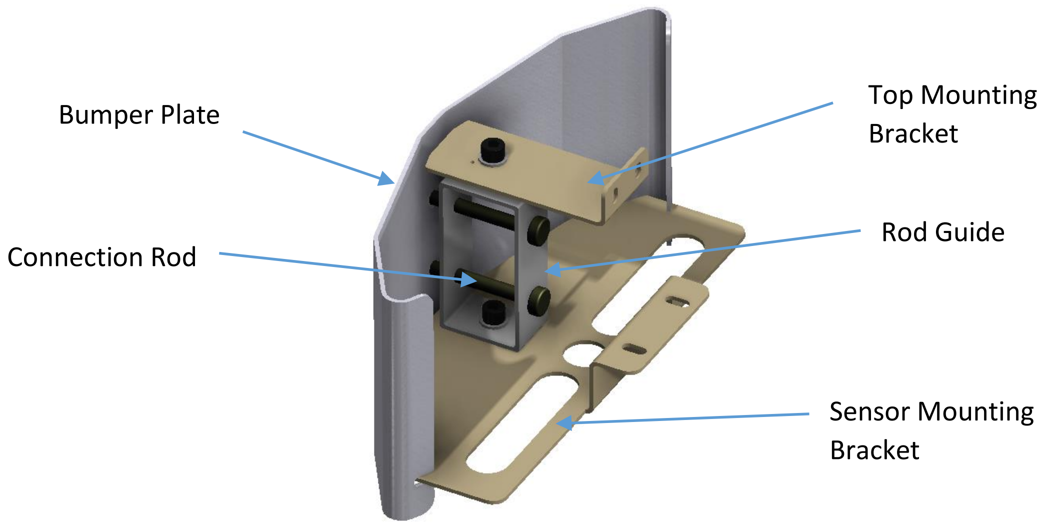


Figure 13. Main components of initial bumper design

The main components of the bumper design are illustrated in Figure 13. The bumper plate is located at the front of the assembly and is the component that will come into direct contact with a colliding obstacle. The bumper plate is bent and slotted to prevent rotation. The bend also ensures that collisions from the side are compensated for and that the centre of mass is moved closed to the swivel joint.

The two connection rods are secured to the bumper plate and secured by the rod guide. The rod guide allows the connection rods, and indirectly the bumper plate, to linearly translate whilst eliminating tilt or rotation. The rod guide is also connected to the sensor mounting bracket and the top mounting bracket by means of swivel joints. This ensures that the bumper plate will be able to rotate freely about the swivel axis if off-centre collisions occur. The sensor mounting bracket is used to house the five inductive sensors used for navigation. A single hole of 30mm diameter is located on the symmetry line of the bumper. This ensures that the centre inductive sensor always remains fixed. The two slots on either side of the centre hole are used to house multiple additional sensors that can be repositioned to accommodate various tape widths.

3.3 BATTERY EVALUATION AND CHARGING

Battery evaluation was performed on the AGV to ensure that it will indeed last for an entire shift of 8 hours. The batteries were evaluated under both no-load and load conditions. Section 3.3.1 describes the testing performed under no-load conditions and section 3.3.2 describes testing using a maximum load of approximately 210kg. During experimentation a clamp meter was first used to determine the current range of the AGV, since a clamp meter is rated up to 1000A, whereas a standard multimeter can only measure a maximum current of 10A.

3.3.1 No-Load Evaluation of AGV

The AGV operated constantly by following the track shown in Figure 14. The tape strip perpendicular to the AGV track, referred to as a control marker, informs the AGV that it should slow down to read an RFID tag. During testing, the detection of a valid RFID tag indicates the completion of a lap. The output of the RFID read was transmitted via wireless communication to a MATLAB program created to monitor the number of laps completed as well as the time for each lap.

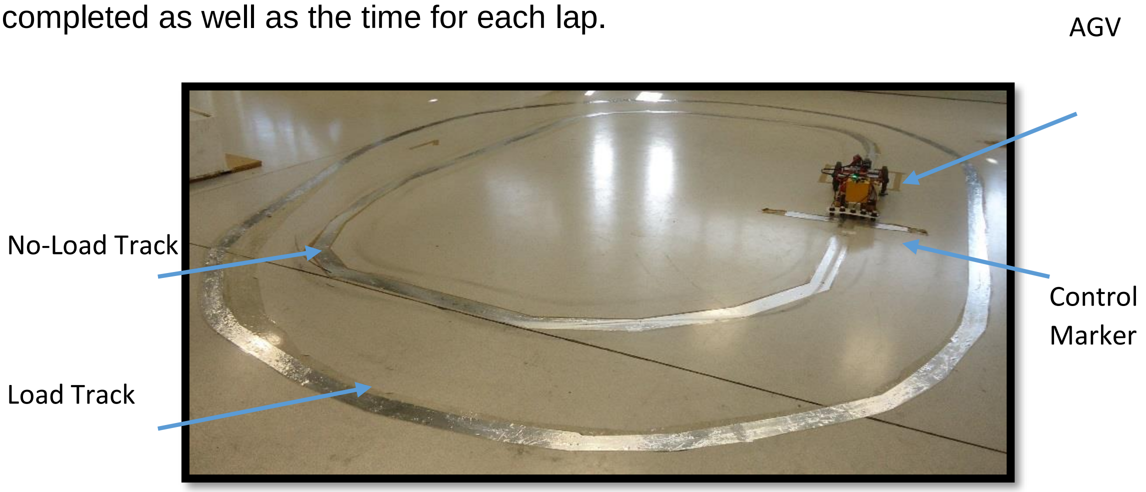


Figure 14.Test track for battery evaluation

The results obtained during two days of no-load testing can be seen in Figure 16. On the first day of no-load testing the AGV was in continuous operation for 8 hours and 43 minutes. The AGV was only stopped for short periods of time to perform measurements or attend to errors. The outliers in Figure 16 shows the lap count at which the various interruptions occurred. Constant inspection of the AGV was carried out during testing to ensure that all errors were noted.

During no-load testing the problems tabulated in Table 5 were identified and corrected. Figure 15 illustrates the use of protective tape used to reduce the number of occurrences of navigational failures.

Problem	Cause	Number of Occurrences	Correction Method
Locknut failure	Mechanical Vibrations during AGV operation	7	Use thread-lock adhesive
Navigational Failure	Small pieces of Aluminium foil tape which bonded to the inductive sensor(s) during operation.	2	Care should be taken when creating the track for the AGV to follow. The track should be covered with a non-metallic material to avoid fault readings on the inductive sensors

Table 5. Problems observed during testing

The voltage gradually decreased as the experimentation was performed. A final voltage of 23.9 V was obtained at the end of experimentation. The current draw of the AGV was measured for three consecutive laps. The current draw varies based on the speed of the motors, which change based on the input from the five inductive sensors located at the front of the AGV. For this reason a range was determined based on the absolute maximum and minimum current readings obtained during the no-load testing. A current range of 1.7A to 3.5A was determined, where higher currents were measured at start-up and when significant overshoot occurs. Using a clamp meter it was determined that the current draw of the AGV was less than 10A, therefore a standard multimeter was used to measure voltage and current with higher accuracy.

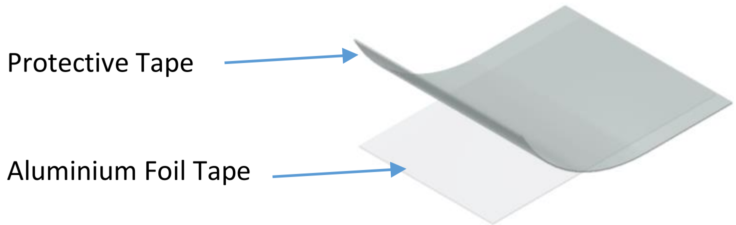


Figure 15. Protective tape illustration

The obtained results are recorded in Figure 16. From the obtained results it is evident that no significant reduction in speed occurred during the duration of no-load testing. The variation in time (and indirectly speed) per lap results from the actual trajectory of the AGV, since the speed of the motors are determined by sensory information that may change for each lap. The total runtime of the AGV was 13 hours and 18 minutes with no load. The total distance travelled during this time is 31200 meters. This equates to an average speed of 0.65 m/s.

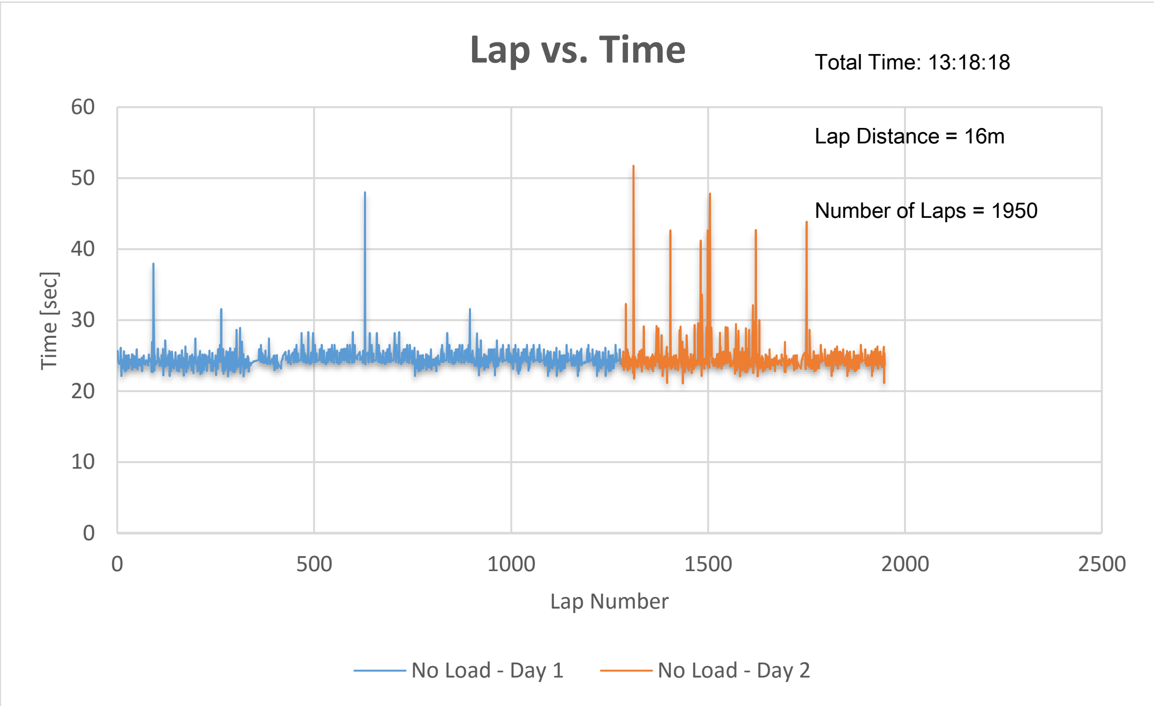


Figure 16. Results for no-load battery evaluation

3.3.2 Full Load Evaluation of AGV

In practice the AGV will not be in operation for an entire shift without a load, since its function is material handling. It is therefore important to verify that the AGV will indeed be able to function for the duration of the shift with a load attached to it. If the AGV can operate for an entire shift under maximum load, it is safe to assume that it will also do so for smaller loads at reduced duty cycle.

Two trolleys were available for testing. The trolley on the right is the maximum load that the AGV is designed to handle. However, due to environmental constraints it could not be used during testing. The trolley on the left is another standard trolley used by GMSA. The trolley is significantly smaller and can be towed by the AGV in refined spaces. To ensure that the same amount of power is required to pull both trolleys, the small trolley was loaded with 200kg of building sand. Bags of building sand were selected due to low cost and disposability after testing. To verify that the same amount of force was required to overcome friction, a force scale was used to pull both trolleys. A force of 43.9 N was required to overcome friction on the large trolley, while a force of 43 N was required for the small trolley.

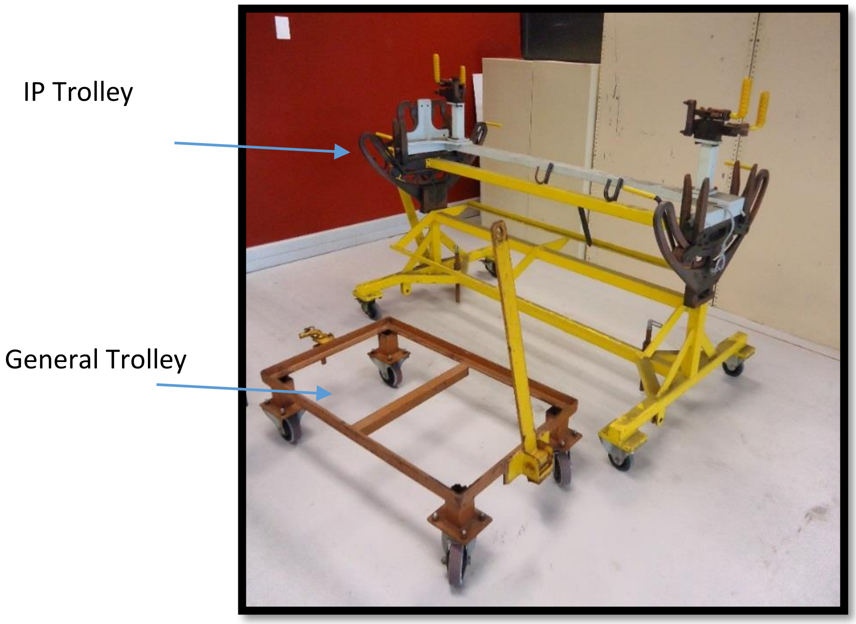


Figure 17. SPS trolleys used for testing

Two days of individual load tests, under maximum load conditions, were performed on the AGV. The initial supply voltage for the first test was 24.8 volts. The supply voltage gradually decreased to 23V after 8 hours and 43 minutes. Significant speed reduction was observed during the first testing exercise.

The second testing exercise was performed using the same load, but with an initial supply voltage of 25.8 volts. A rapid reduction in voltage and speed was evident during the first hour of testing. After 160 minutes of execution it was observed that the speed was reducing significantly and inspection suggested that it resulted from temperature build-up on the motors. The outer motor was observed to be emitting a large amount of heat, whilst the inner motor was at a temperature slightly higher than room temperature. The direction in which the AGV traversed around the track was changed from clockwise to anti-clockwise. An immediate increase in speed was observed. The speed decreased as the temperature on the outer motor increased, hence suggesting that the motor temperatures have a significant effect on the speed of the AGV.

3.4 PRELIMINARY RESULTS

The preliminary results obtained from testing under maximum load is shown in Figure 18. From the obtained results it is evident that the AGV is indeed capable of continuous operation for an entire shift of 8 hours and 30 minutes. However if the batteries are not recharged before the next shift, the AGV is not expected to operate reliability and continuously for the duration of the shift. It is therefore essential to have a simple charging method as charging would occur regularly.

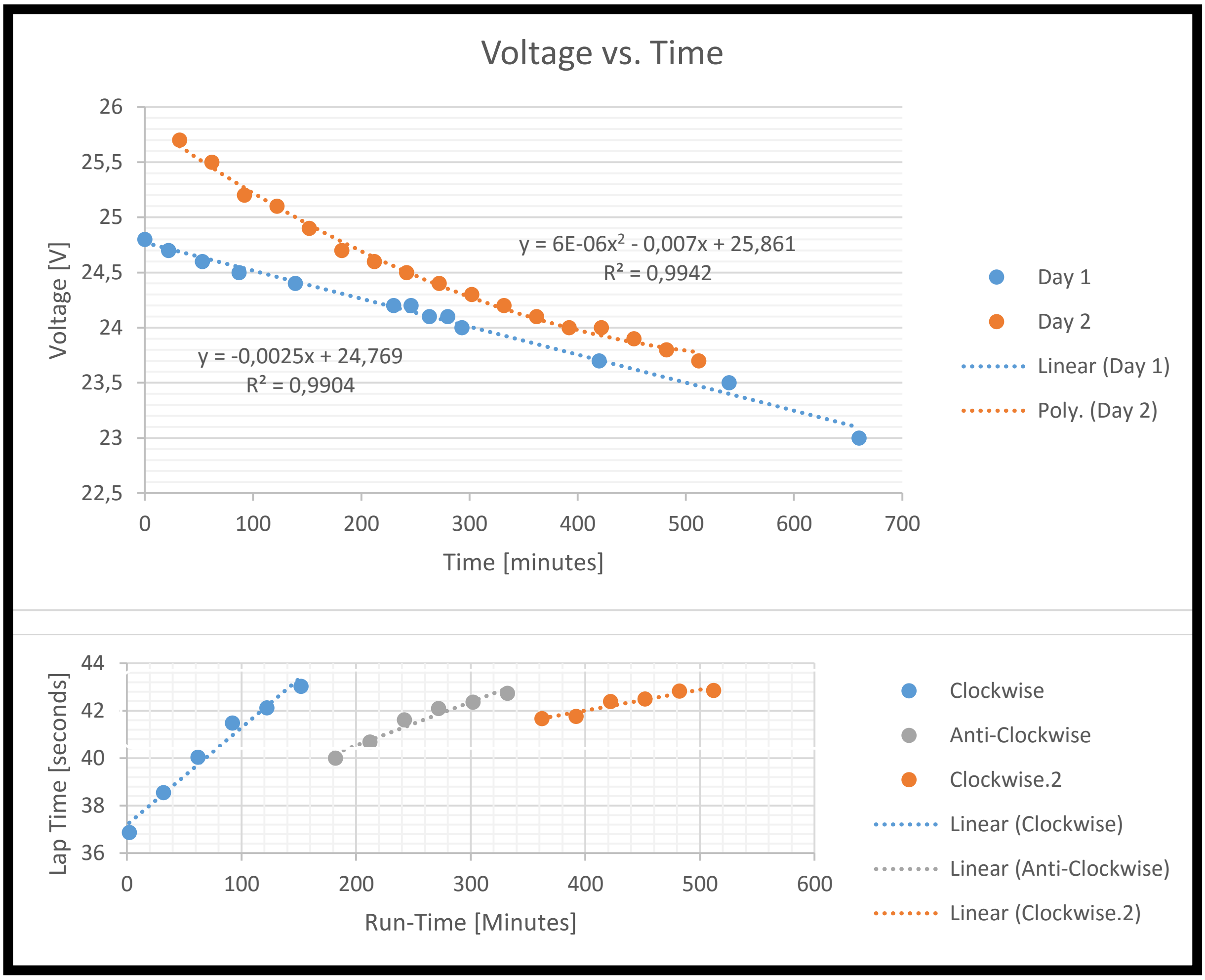


Figure 18. Preliminary results for load testing

The obtained results will be utilized in section 4 when developing a model of the proposed AGV system. The model will include the major components of the system: AGV design, intelligent controller and guide-path design.

CHAPTER 4

MODELLING OF THE AGV SYSTEM

A model-based systems engineering (MBSE) approach was utilized in the development of the intelligent controller. A SysML model was created using Visual Paradigm for UML software and will be referred to during the development process.

4.1 INTRODUCTION TO MBSE

MBSE is advantageous when planning a project, since it improves the probability of success by ensuring that all requirements of the project are accounted for and satisfied. A coherent model ensures that all project aspects are considered prior to implementation which may have a significant effect on the outcome of the project.

Advantages of using MBSE include:

- Enhanced Communication
- Improved Productivity
- Improved Quality
- Re-usable institutional knowledge

The following section will discuss the model created for the intelligent SPS delivery system developed for GMSA.

4.2 INTELLIGENT SPS DELIVERY SYSTEM MODEL

This section will explain the model created for the intelligent SPS delivery system presented in this dissertation. The model is packaged into three separate organizational blocks, namely: Automated Guided Vehicle (AGV), Intelligent Controller and Guide Path Design.

- **Automated Guided Vehicle (AGV)** – Contains information about the design and operation of the AGVs in the system.
- **Intelligent Controller** – Contains information related to the intelligent control of multiple AGVs in a system. Intelligent control addresses issues such as vehicle dispatching, i.e. assigns work to each AGV, and conflict resolution.
- **Guide Path Design** – Contains information related to the requirements and design of the AGV guide path.

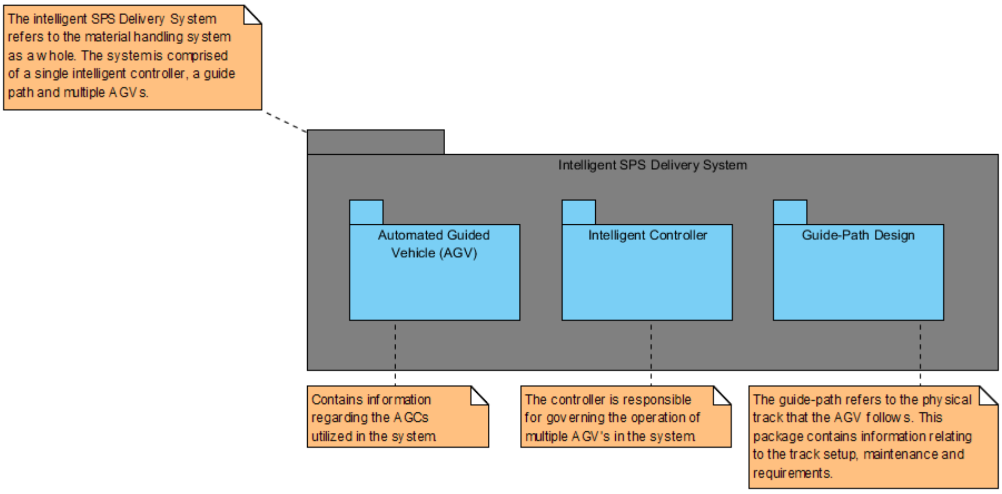


Figure 19. Organization of the model

The organizational diagram of the model is shown in Figure 19. Each of the three organizational blocks will be addressed individually.

4.3 AUTOMATED GUIDED VEHICLE

The first SysML diagram to be addressed is the requirements diagram for the AGV. The requirements diagram assigns a unique identifier to each requirement of the machine which provides traceability. Traceability of the requirements are essential when working with complex systems, since it ensures that requirements are satisfied for each machine as well as the system as a whole. Figure 20 shows the AGV requirements diagram with the requirements that needs to be satisfied to achieve customer goals.

The model also provides information about the mechanical components of the AGV as shown in Figure 21. From Figure 21 it can be seen that the main components of each AGV are: Controller (PLC), power source, line detection sensor, obstacle detection mechanism, collision detection bumper, automatic coupling system, motor controller, and wheel assembly (including motors).

Each of the mechanical components may be modelled to a deeper level if required. For simplicity we will only look at the block diagram for the automatic coupling system.

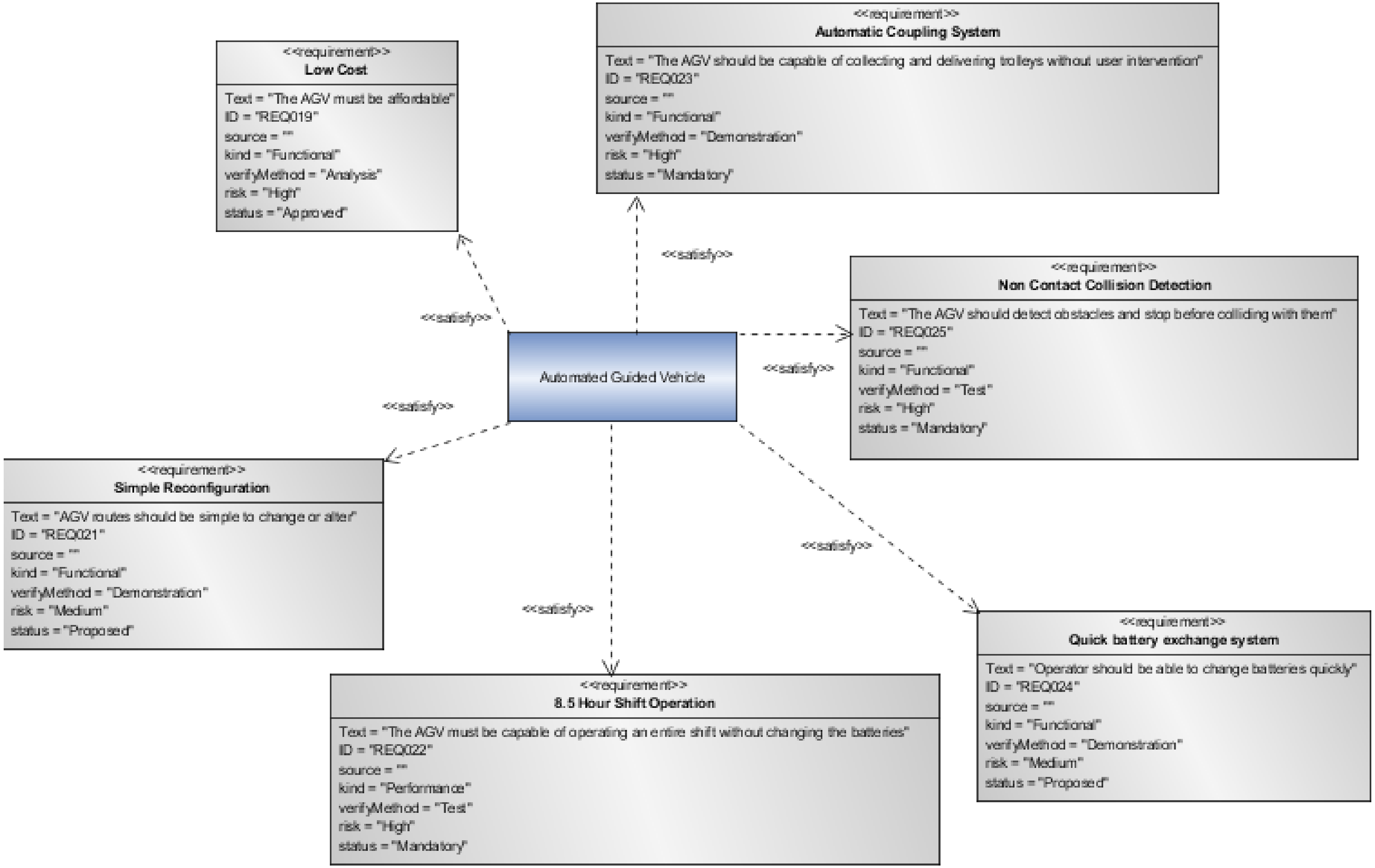


Figure 20. Requirements diagram of AGV

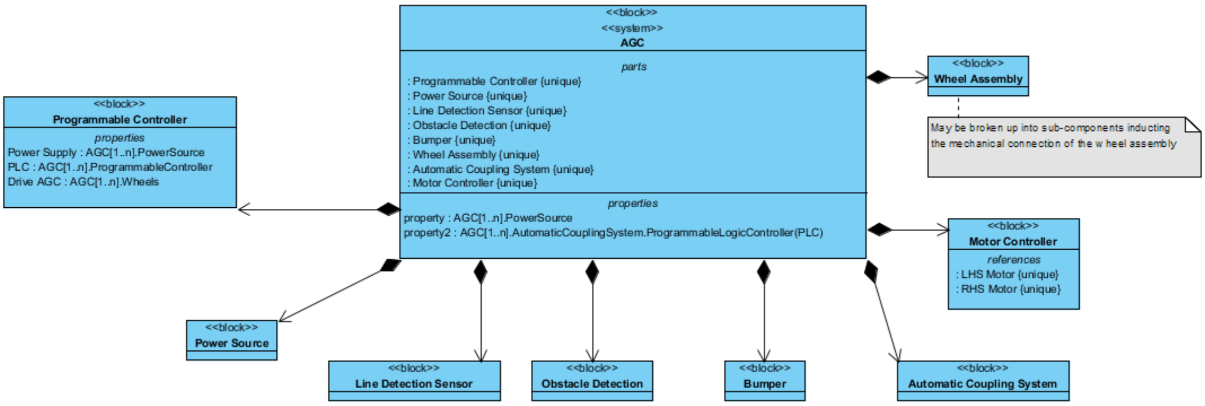


Figure 21. Block diagram of mechanical components of AGV

From the block diagram of the automatic coupling system, as shown in Figure 22, it can be seen that a selector switch is connected to the power supply of the AGV. The switch selection may either be automatic or manual. In manual mode the operator is required to manually toggle a double pole double throw (DPDT) switch to control the motion of the linear actuator. In automatic mode the actuator is controlled by a control signal from the PLC. Positional feedback of the actuator is obtained from the potentiometer output.

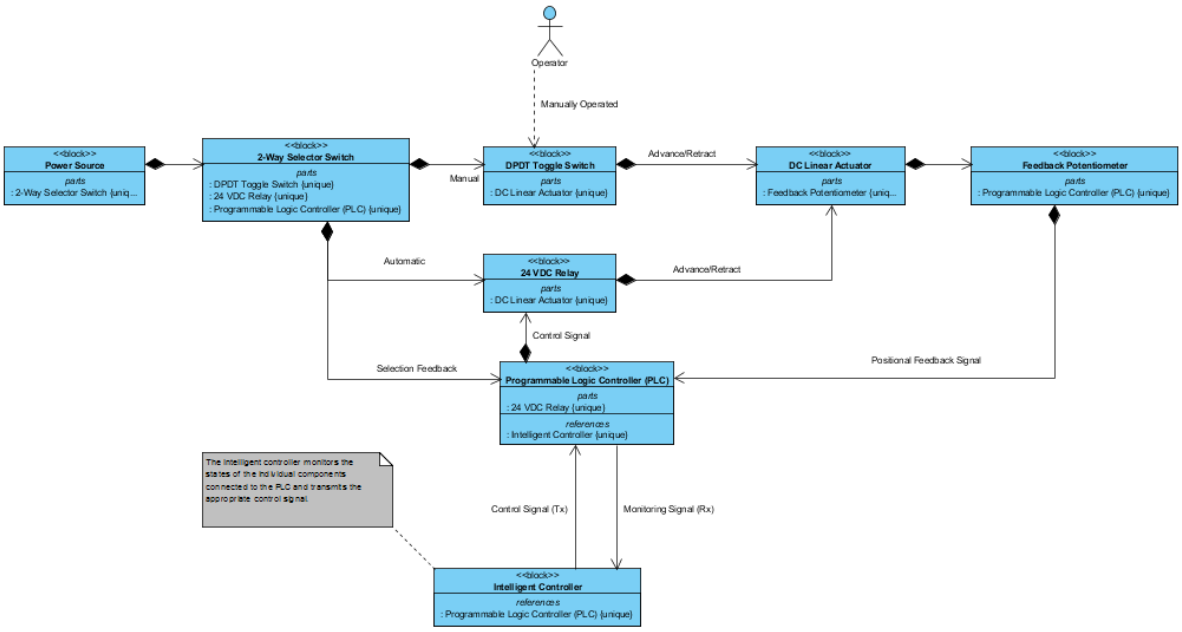


Figure 22. Block diagram of Automatic Coupling System

The next section will explain the model for the intelligent controller. The controller model will focus on the requirements of the controller as well as the tasks the user should be capable of performing when using the controller.

4.4 INTELLIGENT CONTROLLER

The intelligent controller is a dedicated central computer that obtains information from the various field devices and transmits appropriate control instructions. The model defines the requirements of the controller. Figure 24 shows the five requirements of the intelligent controller. It can also be seen that collision avoidance is contained in the intelligent coordination requirement. This means that the intelligent controller should dispatch vehicles in such a way that it eliminates the risk of two or more vehicles colliding with one another.

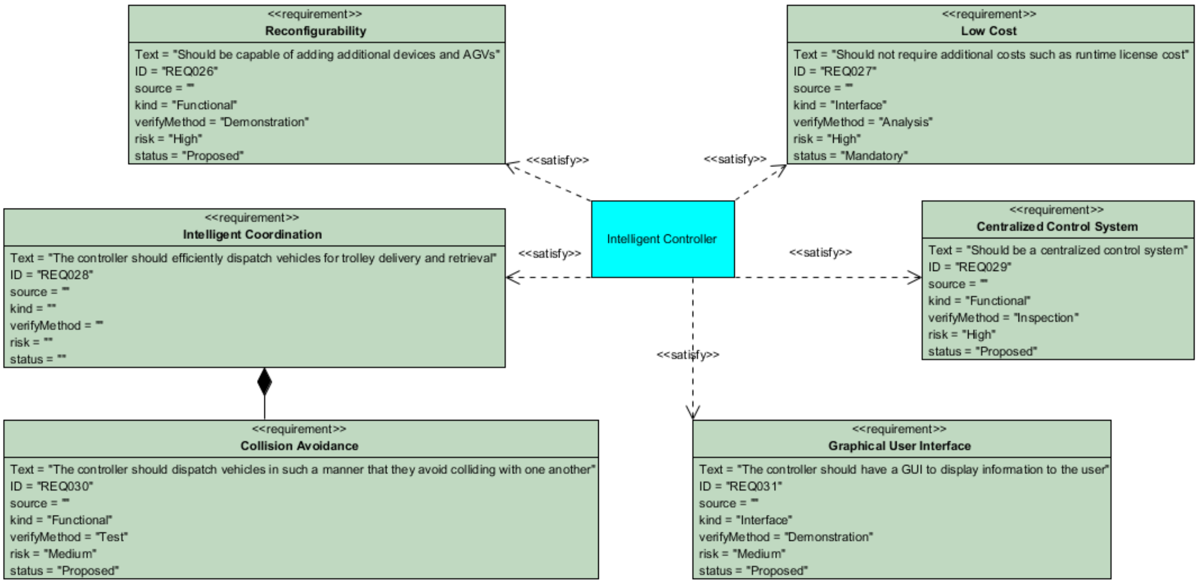


Figure 23. Requirements diagram for intelligent controller

The structure of the intelligent controller is shown in Figure 24. From Figure 24 it can be seen that each AGV is equipped with a RFID scanner which provides information about the station or location of the AGV. The intelligent controller also relies on operator input before dispatching a vehicle for SPS deliver or retrieval. The operator input can either be a button, proximity sensor or a combination of the two.

Now that the requirements and the structure of the intelligent controller have been addressed we will model how the user will interact with the controller. The use case diagram addresses the tasks that the user is required, and capable, of performing on the controller. The use case diagram for the intelligent controller is shown in Figure 25 .

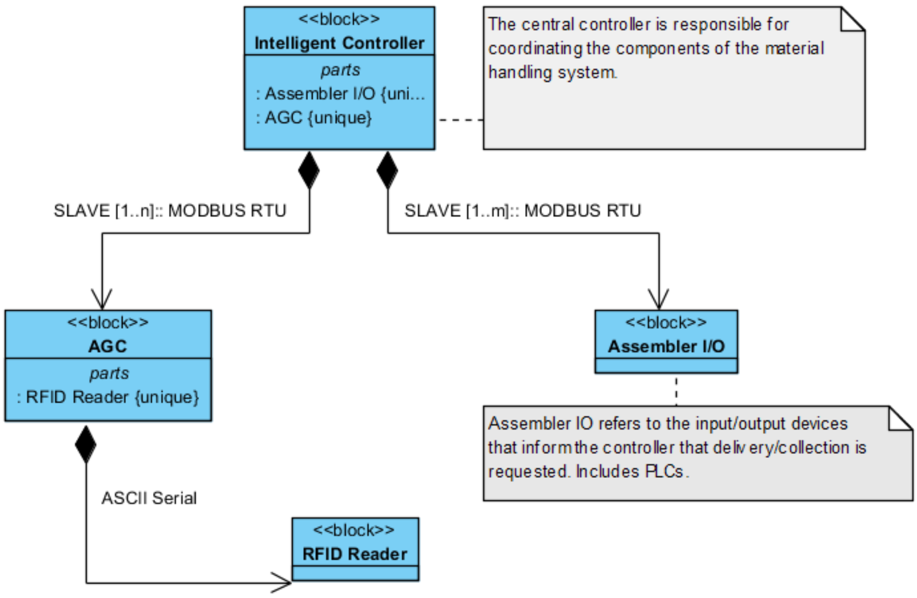


Figure 24. Block diagram of intelligent controller

The user, provided they have sufficient access, should be capable of starting and stopping the controller. The controller may need to be stopped at the end of production or when maintenance is required. The main task of the controller operator will be route teaching.

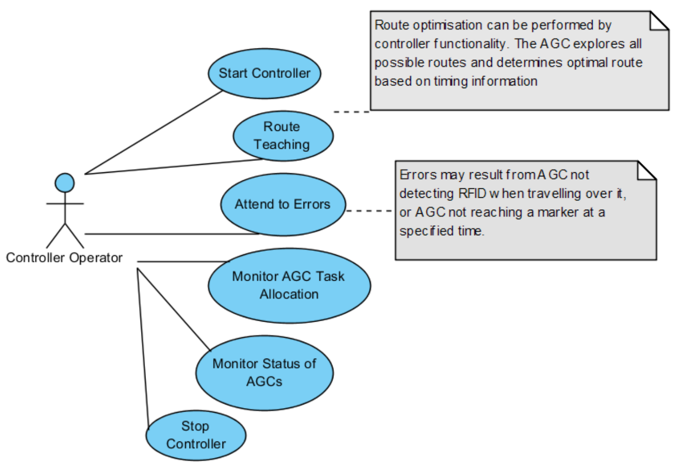


Figure 25. Intelligent controller use case diagram

The use case diagram for route teaching is shown in Figure 26. On the GUI the user should be capable of configuring RFID tags. This includes scanning a valid RFID tag and assigning a function to the scanned tag. For example, a scanned tag may be assigned a command to reduce the speed of the vehicle or to branch left at the next split in the guide path.

Once all tags have been configured the user will put them on the guide path at the required positions and place an AGV at the starting position of the teaching run. The AGV will continuously move through the track until all configured RFID tags have been detected and timing information has been obtained between all tags.

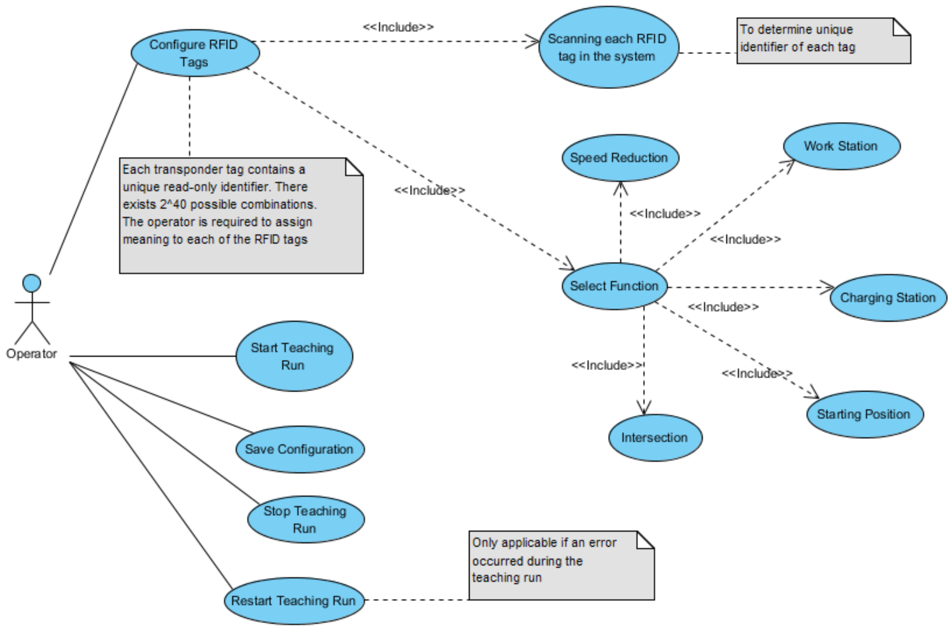


Figure 26. Use case diagram for route teaching

The next section is related to creating the guide path of the AGV.

4.5 GUIDE PATH DESIGN

The guide path is constructed from magnetic tape due to the robustness and cost-effectiveness thereof. In addition to the magnetic track it is also important for control markers to be placed at various locations on the track. The control markers provide information to the AGV regarding which action to take when passing them. These control markers may either be magnetic markers, constructed from the same magnetic tape as the guide path, or RFID markers. The control markers will be addressed further in section 5.

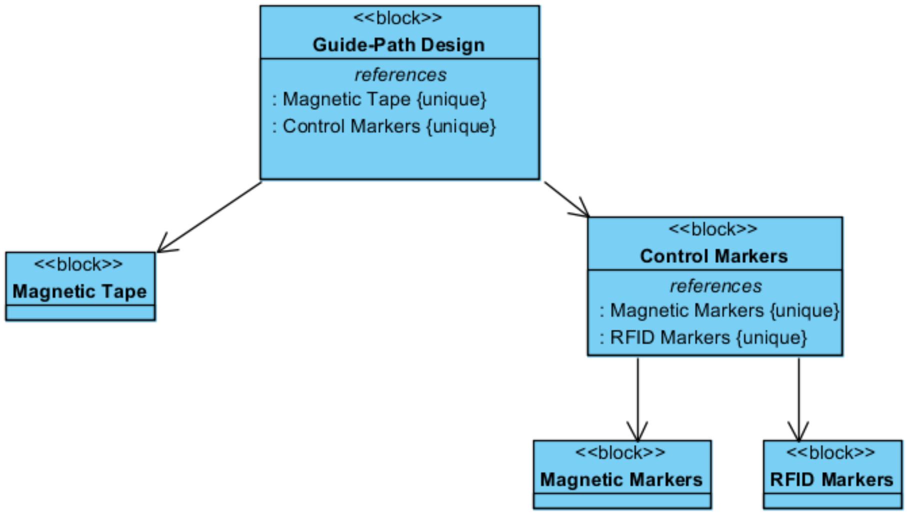


Figure 27. Block diagram of guide-path design and components

CHAPTER 5

DESIGN AND DEVELOPMENT OF AGV SYSTEM

Due to limitations mentioned previously (see section 3) it was required to develop a second AGV prototype that will allow the requirements to be met. The following additional requirements of the basic AGV system were identified after testing the first generation prototype:

- Battery terminals and motors need to be covered for safety reasons
- A method for quick and simple removal of batteries must be implemented
- A more efficient no-contact collision detection system needs to be installed
- Mechanical stability of the AGV system needs to be addressed
- Track detection and line sensing capability needs to be improved

The first step of the design process is to consider the different technologies available and evaluate conceptual designs to ensure that the best suited design option is selected.

5.1 CONCEPTUAL DESIGN OF AGV

This section describes conceptual designs of the AGV system and the evaluation thereof. It is essential to investigate alternatives to ensure that the final design is satisfactory in areas such as robustness, cost effectiveness and configurability for possible future applications.

5.1.1 Automatic Coupling System

An automatic coupling system is required to obtain coupling without human intervention. The coupling mechanism should advance or retract based on control instruction, while sensory information should inform the controller on the presence of a load. The manufacturing process should be as simple and standard components utilized where possible. This section will address the various concept designs considered for the coupling system as well as the evaluation thereof.

The first conceptual design was based on research into belt driven linear actuators. The major components of a belt driven actuator are:

- Electrical Motor
- Belt
- Pulleys
- Carriage

The shaft of an electrical motor is connected to a pulley on which the belt is connected. The rotary motion of the motor imposes linear motion into the belt as well as the carriage attached to the belt. An EGC-TB-KF recirculating ball bearing guide from FESTO was considered for the coupling design. The guide offers high precision and reliability in a compact module, which comes standard with various mounting options and stroke lengths.

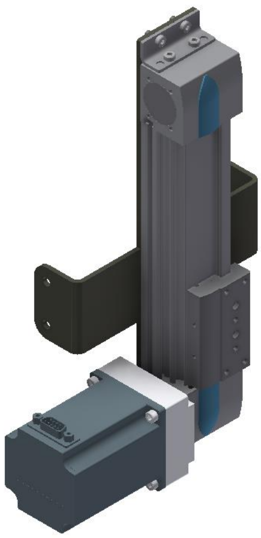


Figure 28. Automatic Coupling System: Conceptual Design 1

The major advantage of the belt driven linear actuator is that various attachments can effortlessly be fitted to the carriage, which offers a secure connection for a single degree of freedom. The belt driven actuator would be well suited for towing applications. However, due to the construction of belt driven actuators, coupling from underneath a trolley may prove to be more complex. The cost of these units are also high in comparison to alternative technologies.

The second conceptual design is based on a 24 V linear actuator. The actuator consists of a 24 Volt DC motor, timing belt and lead screw. By application of a

24V DC supply, the shaft of the actuator extends or retracts based on the polarity. The actuators are mainly used for push-pull applications and are connected using two universal clevis brackets. During normal operation, the linear actuators have two degrees of freedom, namely rotation about the bottom clevis bracket and axial translation of the shaft. For the application of an autonomous coupling system it is desired to only have a single degree of freedom, namely the axial translation of the shaft.

The mounting scheme for the second conceptual design places the electrical motor facing the rear of the AGV, thus establishing symmetry in the design. Two buttons are located on one side of the actuator. These buttons are used to advance and retract the actuator shaft. While the green button is pushed and held, the shaft will advance upwards until the button is released or the internal limit switch is activated. When pushing and holding the red button, the shaft retracts until the internal limit switch is activated or until the button is released.

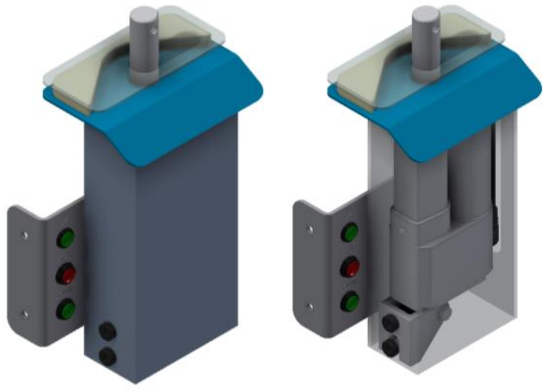
At the top of the coupling system is a guide bracket that will ensure correct insertion of the trolley arm. The guide bracket also ensures that the shaft is secured, hence eliminating all degrees of freedom except the axial translation of the shaft.

Figure 29.Automatic Coupling System: Conceptual Design 2

The third conceptual design is similar to the second conceptual design in that they use the same linear actuation technology, namely a motorized lead screw assembly. The main difference in the designs is the chosen mounting scheme.

For the third conceptual design the actuator motor is placed facing towards the side of the AGV. This allows a shorter overall length of the AGV. Furthermore, the actuator is fully enclosed in standard rectangular tubing that will both house and protect the actuator and electrical motor. The guide bracket at the top of the coupling system has the same functionality as described in section 5.2.

Three buttons are located on the coupling design, namely: up, stop and down. By pressing and releasing the “up” button, the actuator shaft will extend until the “stop” button is pressed or internal limit switch activated. By pressing and releasing the “down” button the actuator shaft will retract at a constant velocity until the internal limit switch is activated or until the “stop” button has been pressed.



a) b)

Figure 30. Automatic Coupling System: Conceptual Design 3.a) Normal CAD model. b) Semi-transparent CAD model

5.1.2 Evaluation of Conceptual Designs

Evaluation of the conceptual designs is based on a weighted decision matrix. The evaluation scheme for the conceptual designs is as follows:

5- Point Scale	Description
0	Inadequate
1	Weak
2	Satisfactory
3	Good
4	Excellent

Table 6. Scale for concept evaluation

Design Criterion	Weight Factor, α	Concept 1		Concept 2		Concept 3	
		Scale Value, N	**N α**	**Scale Value, N**	**N α**	**Scale Value, N**	**N α**
Material Cost	0.2	1	0.2	3	0.6	3	0.6
Manufacturing Effort	0.15	3	0.45	2	0.3	2	0.3
Safety	0.3	2	0.6	2	0.6	3	0.9
Manual Control Strategy	0.05	1	0.05	3	0.15	3	0.15
Flexibility	0.15	3	0.45	2	0.3	2	0.3
Component Availability	0.15	3	0.45	2	0.3	2	0.3
TOTAL			**2.2**		**2.25**		**2.55**

Table 7. Weighted decision matrix for concept evaluation

From Table 7 it was determined that the third conceptual design would be best suited for the application. Concept design 3 is therefore selected as a basis for developing the final design of the coupling system.

5.1.3 AGV Frame

The frame of the AGV was developed in such a way that it allows stability and flexibility while ensuring protection for the components as well as operators. The design of the frame allows components to be mounted effortlessly by means of holes drilled into the base frame. Slotted rectangular tubing is located towards the front of the frame. The slotted tubing houses the electrical panel containing the PLC, relays, contactors and the breakout board for the laser scanner.

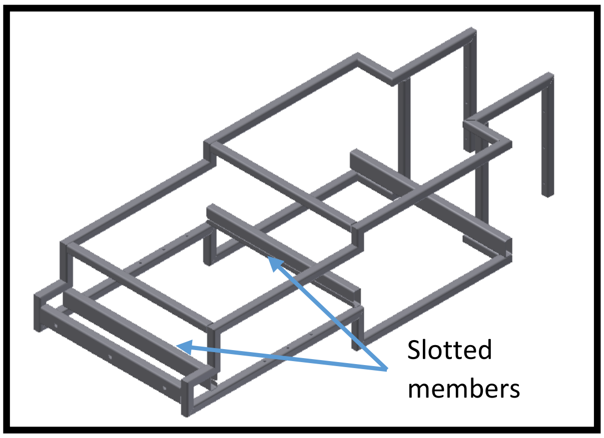


Figure 31. Basic AGV Frame

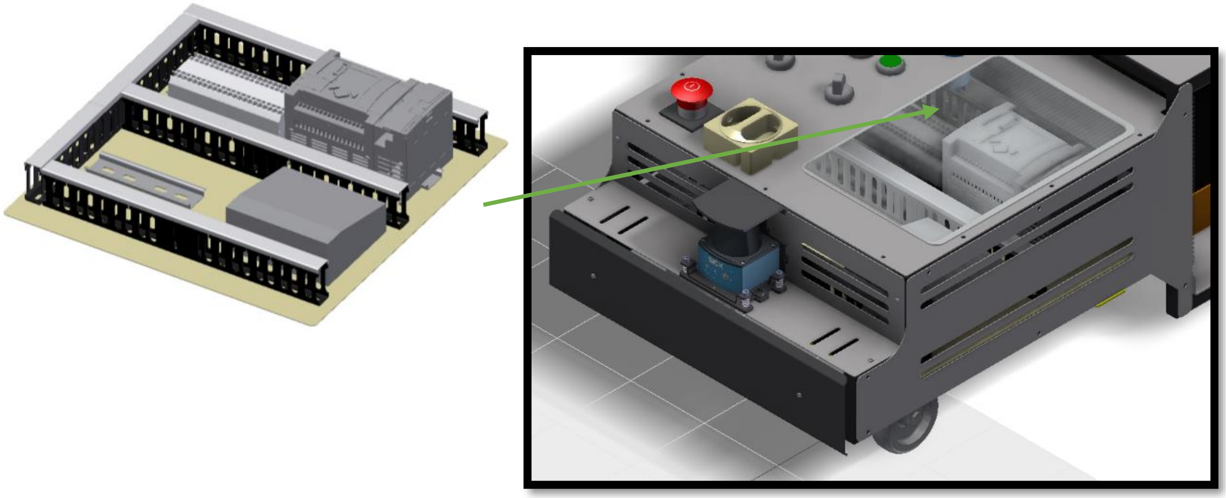


Figure 32. Placement of electrical panel

Galvanized steel plates are attached to the frame. This provides protection for the components as well as prevents users from coming into contact with potentially harmful components, such as the motors and batteries. The original design for the wheel assembly, depicted in Figure 33, remained un-changed for the final design.

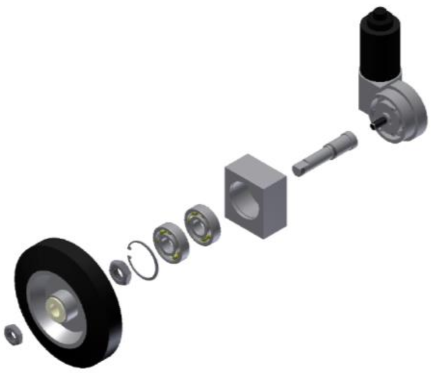


Figure 33. Original wheel assembly (Cawood, 2013)

5.2 FINAL DESIGN OF AGV

From investigations into the previous design it was found necessary to design and develop a new AGV that will:

- Improve safety
- Improve robustness, and
- Improve performance.

The basic operation and structure of the AGV will be maintained, but special attention will be given to areas such as safety, performance and maintainability.

The development of the AGV will be discussed under the headings: Mechanical design, electrical design and Programming

5.2.1 Mechanical Design

All mechanical components of the AGV was developed and analysed in Autodesk Inventor 2013. The final mechanical design of the AGV can be viewed as a collection of sub-assemblies. These sub-assemblies are the frame assembly, bumper assembly and coupling system assembly.

5.2.2 Automatic Coupling System

From the selected conceptual design the major components of the ACS are:

- Linear Actuator
- Guide System
- Mounting Bracket
- Confirmation Sensor(s)

The selected actuator was the CAHB-10-B2A-050192-AAAAP0-000 linear actuator from SKF. It is a compact actuator with a 50mm stroke and feedback potentiometer. The CAHB-10 actuator operates from a 24VDC supply and has a rated duty cycle of 25%. The actuator advances and retracts, at a constant speed, based on the polarity of the power source.

The guide system ensures that the load is correctly positioned for coupling. Furthermore the guide system must allow sufficient freedom for cornering of the AGV when a load is attached.

In addition to the design of the AGV it is also important to consider the load, i.e. the trolley, which will be towed by the AGV. The trolleys need to be modified such that the tow pin on the AGV can securely and reliably couple with the trolley. Figure 34 shows the developed coupling system along with the alterations made to the existing trolleys at GMSA. For the final product it was decided to move the control switches from the coupling housing to the control panel located at the front of the AGV. This allows for easy access when an AGV is coupled. The coupling system is secured to the AGV frame by six cap screws. Connectors were used to interface the coupling system with the AGV. Therefore, by simply removing the six screws and unplugging the connector the entire coupling system can be removed and replaced if a need arises.

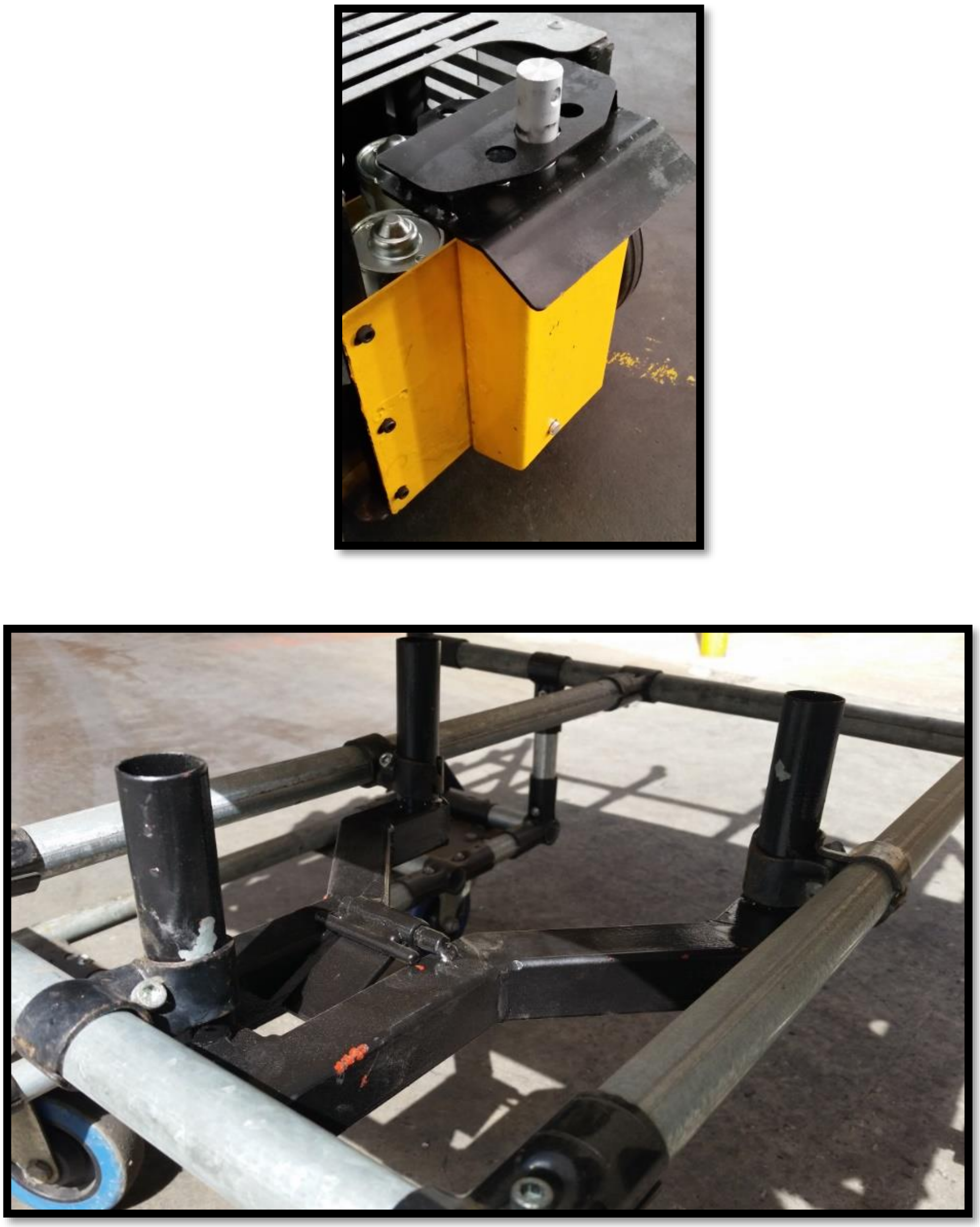


Figure 34. Final Coupling System and Trolley Modifications

The modifications to the trolleys were done using standard square tuning, pipes and brackets. This allowed GMSA to modify the trolleys in-house using existing equipment and readily available materials. The operation is as follows:

The tow-pin should be advanced as the AGV is approaching the trolley it wishes to collect. The tow-pin will then come into contact with the bracket on the trolley and guide it into place. This allows for the trolley to be placed with less accuracy and still achieve a successful coupling. The metal hinge located on the frame is used to prevent the trolley from overshooting when the AGV comes to a sudden stop. Consider an AGV travelling down a long straight track and maximum velocity. When the non-contact collision sensor is activated the AGV will come to a standstill to prevent injury. However, if the trolley is not properly attached to the AGV the trolley will continue to move down the track and potentially cause injury or damage to property.

Figure 35. AGV towing a trolley

5.2.3 Bumper Design

The mechanical bumper is located at the front of the AGV and is used to sense when the AGV physically collides with an obstacle. The design of the bumper was significantly simplified with the improved non-contact sensing abilities provided by the laser scanner. The final bumper is constructed from a steel plate that is bent on the edges to provide a smooth finish and ensure that sharp edges do not cause injury or damage if a contact collision were to occur. The bumper is secured to the AGV by two spring-loaded pins that will deform when subjected to an external force.

The gap between the frame and the inside of the bumper plate is 15mm. When selecting a compression spring with a compressed length of 5mm, there remains 10mm displacement to activate the limit switch. The selection of the compression spring is crucial, since a low compression force might give false readings as a result of vibration, whereas a high compression force might fail to activate the bumper and safely stop the AGV.

5.2.4 Frame Design

The final frame was manufactured from standard 20mm square tubing that was welded together and painted to prevent rusting. Since the AGV will constantly be exposed to unknown external influences it is important to have a frame that is robust. For this reason it was decided to make use of a welded frame, since the weld joint is a permanent joint that will not come loose during vibration experienced during normal operation. Spring washers and adhesive, such as Loctite, should be used on all non-permanent joints to ensure that they do not come loose during operation. Slots were laser cut into the galvanized panels to

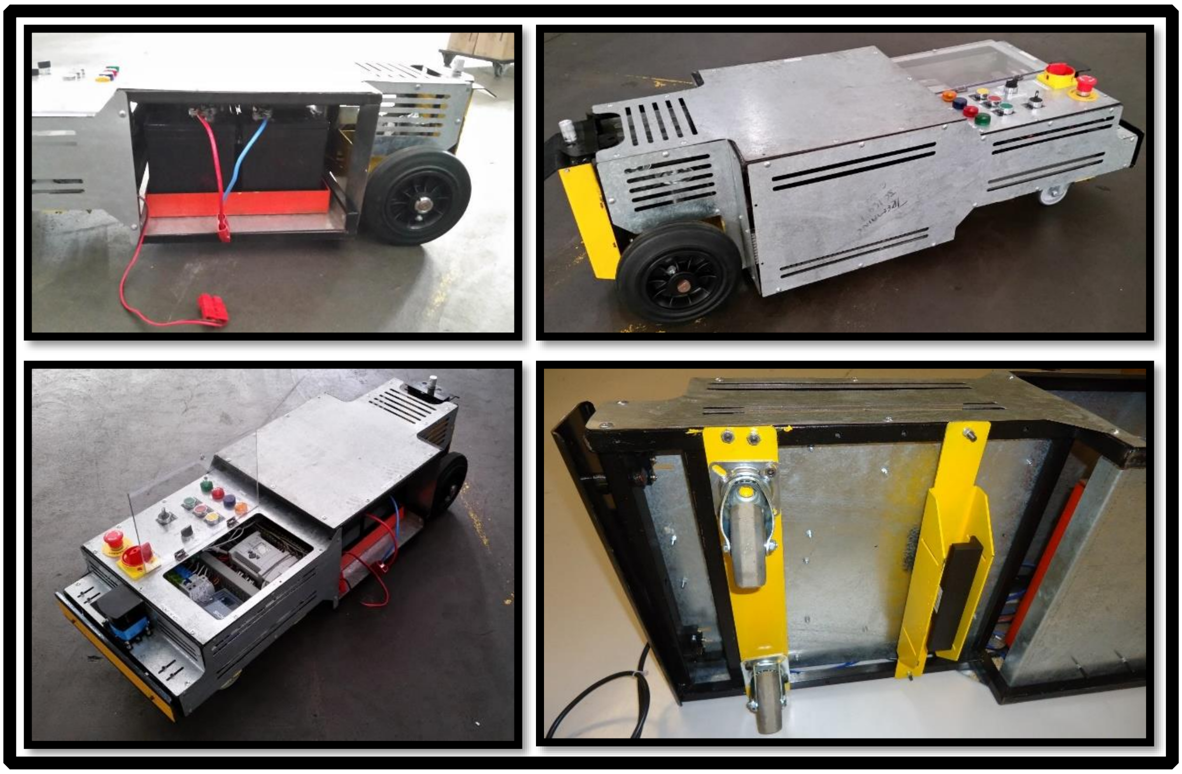


Figure 36. Overview of Mechanical Design

allow air to flow through the machine and provide ventilation that will remove heat from the system. Preliminary testing of the AGV as well as design requirements suggests that the AGV is capable of continuous operation for approximately 9 hours. For production environments that are operational 24 hours a day this suggests that the batteries should be exchanged once a day. They can also be changed, but this will render the AGV inoperable for the duration of the charging procedure. For this reason it is vital to have a procedure in place that will allow for quick replacement of the batteries. The frame was designed to accommodate two truck-sized batteries that are placed in a tray and pushed into the battery compartment of the frame. A battery tray with two batteries in it will be referred to from now on as a battery pack. When an AGV requires new batteries, the battery pack can be replaced with a new battery pack and then charged offline to ensure that it is ready for use once required. Quick-release connectors are used to connect the battery pack to the charger as well as the AGV.

The guide sensor is mounted on a bracket before being attached to the frame. The bracket also provides protection from any objects that might potentially damage the sensor.

5.2.5 Electrical Design

This section will focus on the electrical aspects of the system. The main component is the PLC, which is responsible for sending and receiving information between the devices in the system. The Allen Bradley Micrologix 1100 PLC was selected due to its low cost, availability and flexibility. The standard PLC comes with 10 digital inputs, 2 analogue inputs and 6 replay outputs. In addition to this it also allows for additional I/O expansion cards to be installed onto the PLC, thus expanding the capabilities if required. Figure 37 shows an overview of the control panel and a formal wiring diagram can be found in Annexure C.

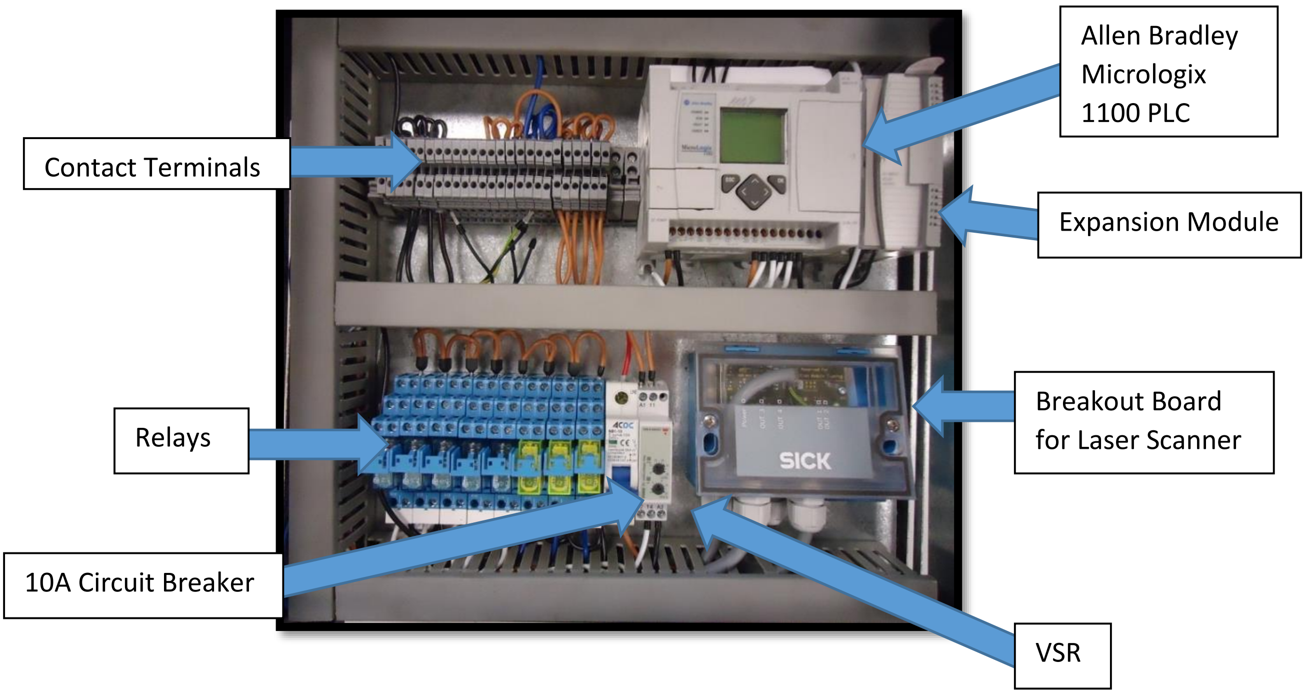


Figure 37. Overview of Control Panel

A MAX232 chip was used to convert the serial signal from the PLC to TTL level serial required by the Sabertooth motor controller. Please refer to sheet 7 of Annexure C for the wiring diagram of the MAX323 chip.

5.2.6 Battery Management System (BMS)

A battery management system is required on each AGV to inform the controller on the power level of each vehicle in the configuration. It is important to terminate operation and recharge the AGVs before a critically low supply is detected. A critically low supply may result in significant performance reduction in terms of speed, as well as sensory malfunction. Sensory malfunction may result in unreliable safety systems, such as failure to detect obstacles, hence posing a serious safety risk. The use of a BMS is therefore essential in the design of an AGV and will be considered in this section.

Power is defined as the product between current and voltage. Therefore both current and voltage measurements are required to calculate the power output of the 24V DC power supply.

$$P = I \times V$$

Due to the nature of the differential drive system the power consumption of the AGV will vary, since both motors move at different speeds and hence require different amounts of power. As shown experimentally, the voltage of the system decreases gradually with time. The range of current draw was experimentally determined to be 1.7A to 3.5A. The amount of power consumed by the motors are typically within the range 40W to 85W.

The VSR was set up by monitoring the AGV and noting when changes occur in its performance. The voltage level of the supply was measured and noted each time a decrease in performance was observed. From observation it was found that the AGV starts behaving irregularly when the supply voltage drops below 23 Volts. From the preliminary results it was found that it takes about 150 minutes for the voltage level to drop by 0.5V. The threshold of the VSR was therefore set to notify the PLC when the voltage reaches 23.5V so that the AGV stops before any performance degradation occurs.

5.2.7 Programming

Programming of the AGV involved the following IT-related tasks to be completed:

- Configuring the magnetic guide sensor
- Setting up the 2D laser scanner
- Configuration of the motor controller
- Programming of the PLC

5.2.8 Guide Sensor Configuration

The magnetic guide sensor is configured using MagSensor Control Utility, which is free RoboteQ software obtainable from their website. A “USB A” to “USB B” cable is used to connect the sensor to the PC. This section will only address the settings relevant to the configuration of the sensor for the AGV requirements.

The sensor interacts with the AGV through digital signals, therefore the command priority should be set to “Digital In”. Please refer to the MGS1600 documentation for more specific information on pinouts and available commands.

The second part of the sensor configuration is related to the magnetic tape used as well as the mechanical placement of the magnetic sensor. The developed AGV made use of 50mm magnetic tape with a south-pole polarity at the top. This sensor will only work with unipolar magnetic tape.

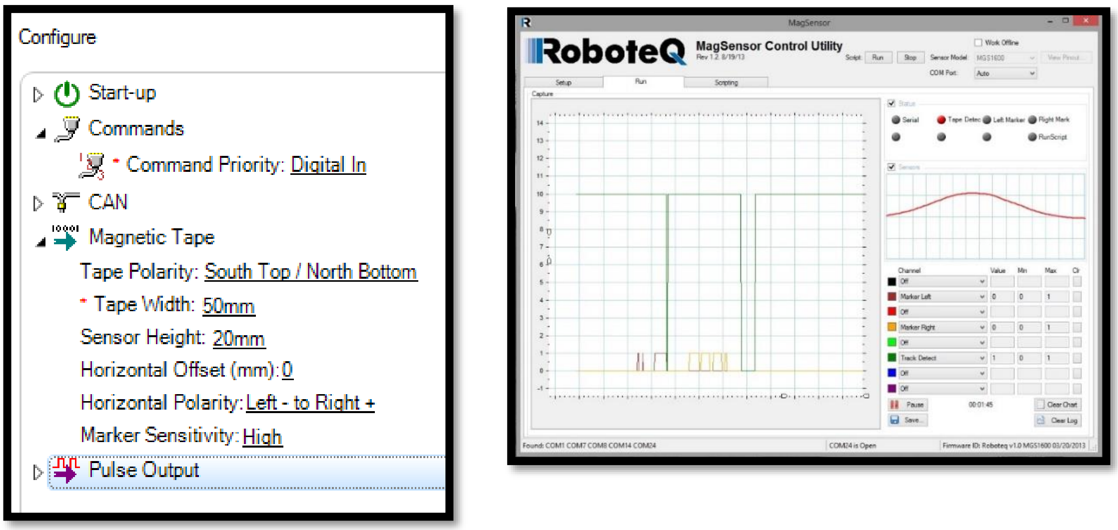


Figure 38. MagSensor Control Utility for Configuration of Guide Sensor

Sensor height refers to the physical distance between the bottom of the sensor and the top of the magnetic tape. The AGV was designed so that the sensor height is 40mm from magnetic tape, which provides sufficient range for movement during operation. The horizontal offset and horizontal polarity parameters are related to the analogue signal that will be passed to the PLC. Changing the offset will influence the mid-point of the sensor range, while the polarity parameter specifies whether the analogue value should increase, or decrease, when moving the sensor over the magnetic tape in a certain direction.

5.2.9 Configuration of the Laser Scanner

The laser scanner is configured using SOPAS software obtainable at no cost from the SICK website. The scanner is shipped with a USB cable that connects the sensor to a PC using a USB port. The scanner is automatically detected when the SOPAS software is opened and the scanner connected. There are 16 programmable zones that are available on the sensor. Each zone may be programmed according to customer requirements, but the following are recommended:

- **Wide Angle Zone** for detecting obstacles up to at least 3m – This is important for when the AGV is travelling along a long straight track at maximum speed and no nearby obstacles.
- **Loading Zone** – This zone should be selected when the AGV is attempting to collect a trolley. The zone of the scanner should have a narrow angle at short range to ensure that the trolley is not detected as an obstacle. A wide angle zone should be activated once the AGV is clear of the trolley to insure that obstacles are detected effectively.

The selection of the safety zones are made by four digital inputs to the scanner as mentioned earlier. In binary these four inputs can be noted as $(0000)_2$ where the last bit represents the least significant bit (or input 1 on the scanner breakout board). By default safety zone 1 is selected. When activating inputs 1 and 3, the binary input is $(0101)_2$. The decimal equivalent of $(0101)_2$ is 5, which means that safety zone 6 will be selected. When all inputs are high (decimal value of 15), then safety zone 16 will be selected.

5.2.10 Configuration of the Motor Controller

The Sabretooth motor controller may be operated using any of the following operating modes:

- **Analogue Input** – Uses analogue signals to send information about the speed and direction of each motor. The analogue signal may range from 0V to 5V.
- **R/C input** – Makes use of two standard remote control channels to set the speed and direction of the motors.
- **Serial Input** – Uses TTL level RS-232 serial data to set the speed and direction of the motors.

Simplified serial uses a single byte to control the motors as where packetized serial uses a packet-based communication protocol to transmit information. Simplified serial input was selected to control the motors, since it is less susceptible to noise and also provides higher accuracy in the control as opposed to analogue input signals. As per the documentation for the Sabretooth controller, sending a value of 1-127 will control motor 1 and a value of 128-255 will control motor 2. A value of 0 will stop both motors at the same time.

Due to the mechanical mounting of the motors, the LHS motor direction is opposite to the RHS motor direction. The following hexadecimal commands are used to control each motor on the AGV:

Motor 1: RHS MOTOR

Full Speed Reverse	$(1)_{10} = (1)_{16}$
Stop	$(64)_{10} = (40)_{16}$
Full Speed Forward	$(127)_{10} = (7F)_{16}$

Motor 2: LHS MOTOR

Full Speed Forward	$(128)_{10} = (80)_{16}$
Stop	$(192)_{10} = (C0)_{16}$
Full Speed Reverse	$(255)_{10} = (FF)_{16}$

To ensure optimal responsiveness of the motors, a rate of 38400 baud was selected using the DIP switches located on the controller.

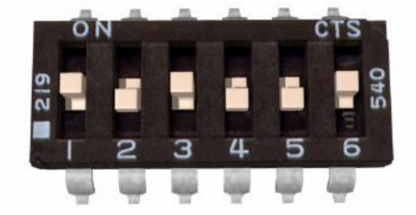


Figure 39. DIP Switch Configuration for Simplified Serial Communication at 38400 baud

5.2.11 Programming of the PLC

The Allen Bradley PLC was programmed in ladder using RSLogix Micro software, which is a free development package supplied by Allen Bradley for programming their low cost range of PLCs.

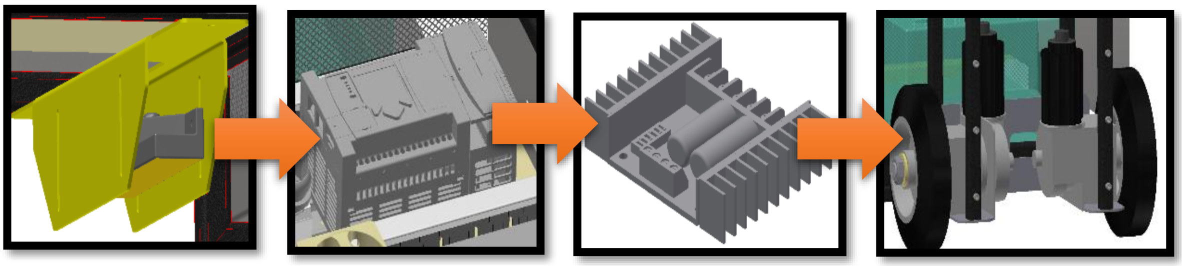


Figure 40. Overview of control system data flow

Firstly we will look at the control strategy for the navigational system depicted in Figure 40. The magnetic guide sensor reads the positional offset from the magnetic tape and transmits the information to the PLC as an analogue signal that ranges from 0V to 5V. The PLC receives the analogue signal reads the information as an integer value. The signal value is subtracted from the experimentally determined value for when the magnetic tape is in the centre of the AGV. The obtained value represents the error signal. Mathematically this can be described as:

$$\varepsilon = \partial_{Actual} - \partial_{Target}$$

Where ε represents the error, ∂_{Actual} represents the actual position of the AGV and ∂_{Target} represents the target position of the AGV. A scaling function is used to convert the error signal to a smaller range that is used by the PID function. The PID function returns a decimal value that represents the **differential speed** of each motor. This speed differential is added to one motor while subtracted from the other, depending on position of the AGV. The PID tuning parameters were experimentally determined with the assistance of a SCADA program and are shown in Figure 41. The SCADA program was created in Movicon and was used to read the error signal as well as motor command values from the PLC during runtime.

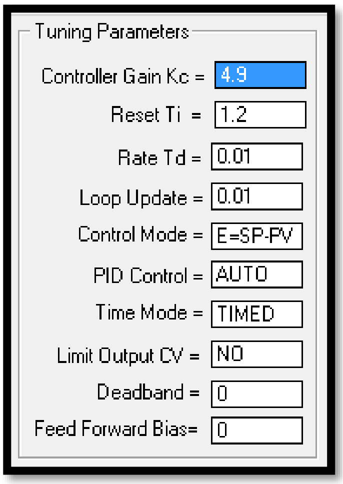


Figure 41. PID Tuning Parameters

The PID parameters were adjusted until the graph produced satisfactory results. The results will be addressed further in Section 7. The speed command of each motor is then converted from decimal to hexadecimal in the PLC program by using the move command as shown in Figure 42.

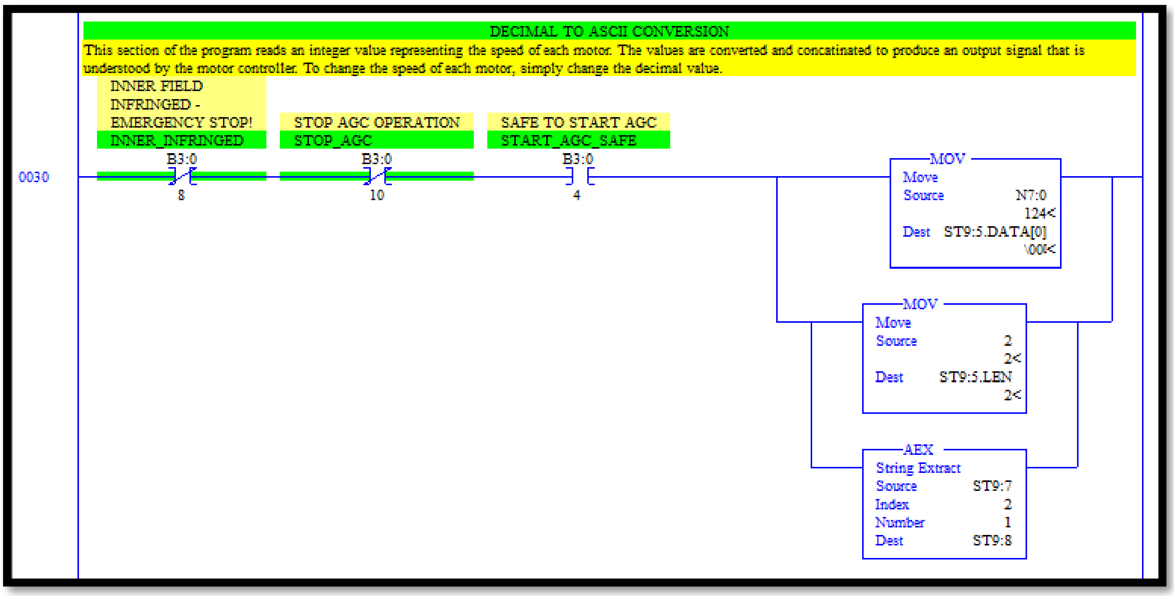


Figure 42. PLC conversion from decimal to hexadecimal

The functionality summarized in Table 8 was also implemented on the PLC.

#	Function	Description
1	Start Button	When pressed, blink the green LED three times to warn that the AGV is about to start moving. If the LED does not flash it indicates that it is not safe to start the AGV.
2	Stop Button	When pressed, the operation of the AGV will be stopped until the green button is pressed.
3	Reset Button	Resets the safety of the AGV if it is safe to do so. If the red LED does not stop flashing after the reset button is pressed it indicates that not all safety sensors are in a safe state.
4	Low Voltage Detection	The low voltage indicator LED comes on whenever a low voltage is detected by the VSR. If low voltage is detected for more than 10 minutes the AGV will come to a stop. This was implemented for safety reasons.
5	Laser Scanner Fields	PLC reads the status of the three fields (i.e. outer field, middle field and inner field) of the selected safety zone. The AGV comes to a stop as soon as the inner field of the safety zone is violated

Table 8. PLC Functionality Summary

5.2.12 Layout of the Guide-Path

The AGV considered in this research receives its control commands from markers placed on the floor. The manner in which these markers are placed determine the command received by the controller. The initial approach made use of a counter-based method that worked as follows:

A counter is activated whenever the LHS sensor detects a marker. The counter is incremented each time the RHS detects a rising edge of a marker. When the LHS sensor goes LOW, the value of the counter is evaluated and a control command is selected based on the count. For example, a count of 3 may command the AGV to slow down while a count of 5 may stop it completely. This approach required a large amount of magnetic tape and the marker array became very large as the capabilities of the AGV were improved. It was also found that the AGV intermittently drives over the edge of a control marker depending on the placement thereof. This often caused overshoot to occur and markers to not be read successfully.

As an alternative it was decided to implement a sequence-based approach in the PLC program. This method makes use of only three control markers. By placing one marker on the LHS of the track, the AGV is commanded to follow the left track if there is a branch. Similarly a marker on the RHS of the track commands the AGV to follow the right track if there is a branch. Whenever two markers are present at the same time (both LHS and RHS marker sensors active) the sequence is incremented in the PLC. This allows for less magnetic tape to be used.

CHAPTER 6

DEVELOPMENT OF INTELLIGENT CONTROL STRATEGY

From the SysML model, described in section 4, the following requirements were identified for the intelligent control strategy:

- **Intelligent AGV Coordination** – The controller is required to coordinate multiple AGVs to ensure that no collisions occur while tasks are performed. The controller must dispatch AGVs in such a way that the shortest possible cycle time is achieved.
- **Flexibility** – The controller is required to accommodate various possible working environments with variable number of AGVs in the system.
- **Centralized Control System** – The controller must be of the centralized type, which utilizes a central computer for AGV coordination.
- **Low Cost** – Low implementation cost as specified by the overall project requirement by GMSA.

A use case for the operator of the controller was created in the SysML model. The use case identifies the actions or activities that an operator can perform on the controller. The following basic functionality must be incorporated into the controller:

- Start/Stop of the Controller
- Route Teaching
- Error Identification
- Status Monitoring

The operator is required to scan each of the RFID tags they wish to utilize in the system to determine the unique identifier of each. With 2^{40} possible read-only identifier combinations it is essential that a simple assigning process is in place to ensure that a track can be created successfully in the shortest amount of time. The major advantage of the chosen strategy is that RFID tags can be reconfigured even after being placed, hence allowing the route layout to be changed effortlessly without making physical changes to the track layout.

The process illustrated in Figure 43 is to be followed by the operator when performing the teaching run.

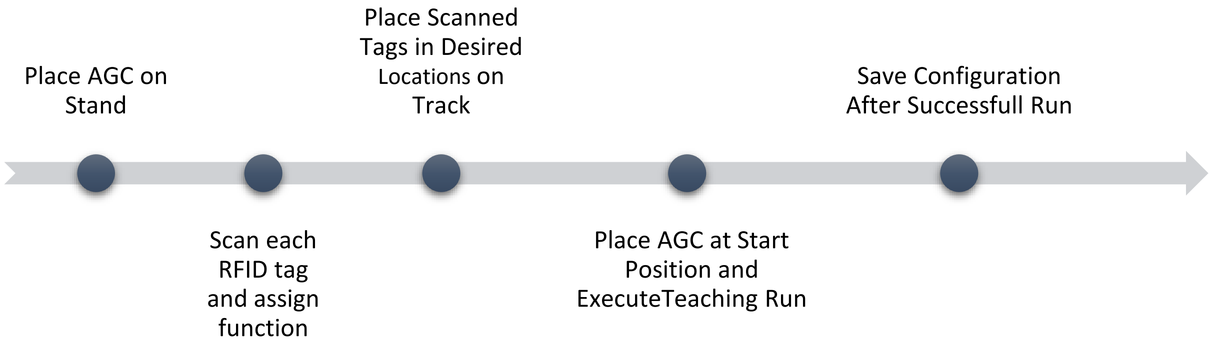


Figure 43. Process for performing teaching run

The controller obtains control information from RFID tags located along the AGV path. The identification value of each tag is transmitted to the controller for additional processing. However, additional information is required for the controller to effectively coordinate AGV. Additional information includes a delivery request and removal request signal. If the assembly worker does not request service, the AGVs will not necessarily perform the task (collection or delivery) in the shortest possible time. The request/removal signal may come from a proximity sensor, pushbutton or a digital signal from the controller of another station or process.

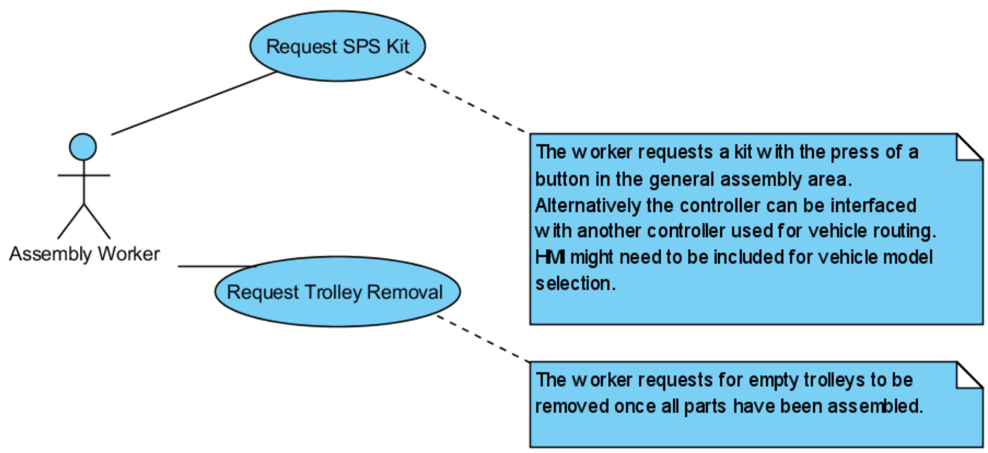


Figure 44. Use Case for Job Request

The use of a dedicated central controller is essential to establish coordination between the AGVs as to ensure that tasks are not duplicated (i.e. only a single

AGV responds to a request) and that no collisions occur when multiple AGVs make use of the same track.

6.1 ROUTE LAYOUT AND NAVIGATION

As described in section 1.2, the initial application of the AGV was to transport empty instrument panels to the end of the assembly line. This was achieved by executing a service loop. Since no specific alternative applications have been proposed for the AGVs, a general discussion will be utilized in terms of route layout and navigation.

Assume two manual assembly stations as depicted in Figure 45. Let us further assume that two AGVs are present in the service loop and that different SPS kits are delivered to each of the assembly stations.

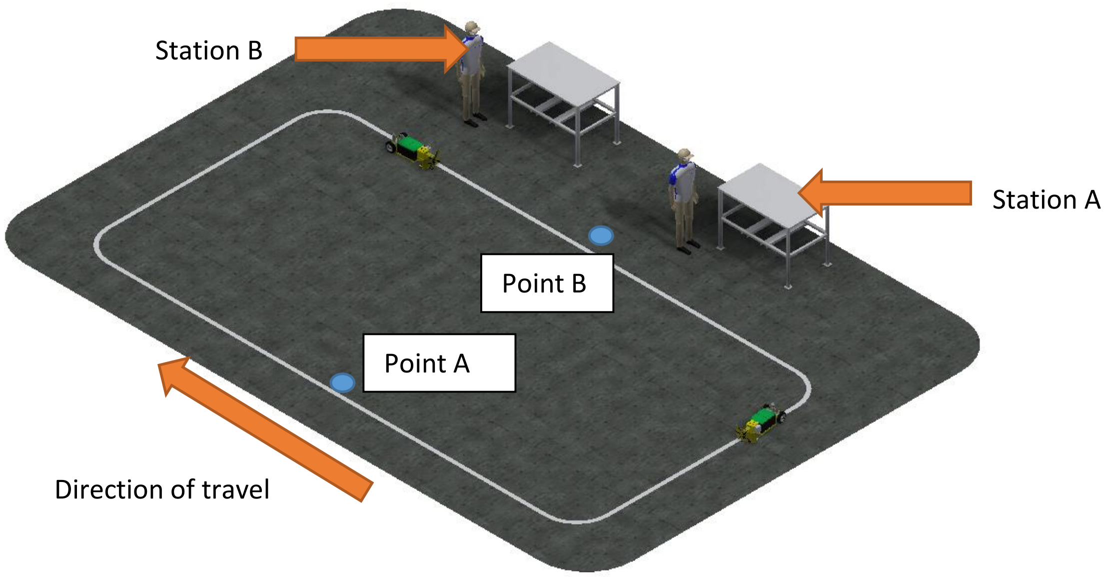


Figure 45. Multiple AGVs in a loop dispatched system

In a simple system, the AGVs will execute a service loop by first removing an empty trolley from station “A” before removing an empty trolley from station “B”. This needs to be done to avoid collisions as no alternative routing is available. Similarly, a SPS kit should first be delivered to station “A” and then to station ”B” (for the assumed direction of travel). As a result of the sequencing constraints a delay may occur in the process. To overcome the previously mentioned delay it is necessary to provide alternative routes that the AGV may follow to avoid collisions.

An example of an alternative route would be to lay tape from point “A” to point “B”. This way the intelligent controller can evaluate the position of each AGV and advice whether alternative route should be taken.

The RFID scanner is located at the bottom of the AGV and creates a magnetic field around the scanner. When a RFID tag is moved into the magnetic field the induced current produces a unique identifier value that is interpreted by the RFID reader. Meaning can be assigned to RFID tags through the intelligent controller user interface. The following control instructions are available for the developed AGV:

- **Node/Branch Selection** – The AGV can either follow the LHS or RHS track when reaching a fork in the road.
- **Reduce Speed** – Slows down the AGV. This is important for areas where humans often operate.
- **Increase Speed** – Increases the speed of the AGV. This is useful in areas where there are no obstacles.
- **Stop the AGV** – Stops the AGV until a new task is assigned
- **Safety Zone Selection** – Used to select any one of the 16 available safety zones configured for the laser scanner.
- **Work Station** – Defines a location where a trolley will be collected from or delivered to.
- **Charging Station** – Defines a location where an automatic charging station is located (Optional).
- **Activate Tow Pin** – Used to advance the tow pin and engage with a SPS trolley.
- **Starting Point** – Identifies a starting point or home position for the AGV

The next section will discuss the preliminary implementation of the intelligent controller.

6.2 DESCRIPTION OF CONTROLLER

The Micrologix 1100 PLC allows for the Modbus communication to be used to communicate with a computer. An industrial grade RFID scanner, with Modbus support, as well as a wireless transceiver is required on each of the AGVs in the system. The RFID tag reader will produce a magnetic field around the reader that will obtain a unique identifier when a valid tag is present. This information will then be transmitted via the wireless link to a transceiver on the dedicated PC for intelligent control. The transceiver should be of the many-to-one type, which means that multiple signals may be received on a single transceiver.

The first task of the operator will be to scan each of the RFID tags they wish to use in the system. Once a tag has been read, the user will be prompted to select a function for the scanned tag (see section 6.1 for available functions). This information will be logged to the SQL server database for permanent record storage. Once all tags have been scanned and placed at the relevant locations on the track, the teaching run may be carried out.

The teaching run is based on the fact that all tag values are known and it assumes that they have been configured correctly. When configuring RFID tags, it is required that a starting point, or home position, is selected. The AGV should be placed such that the front of the bumper is in the centre of the RFID tag. Once the start button is pressed the AGV will start moving in a forward direction until the first tag (i.e. starting point) is reached. When a starting point is reached, an empty record is inserted into the database. As the AGV moves in a forward direction it scans for RFID tag. Once a tag has been detected it is transmitted to the intelligent controller for processing.

The controller will log the time between each tag. This information is required when dispatching vehicles so that the shortest cycle time will be achieved. The time between tags will be updated constantly during runtime, because although a short time may be measured during the setup of the track, that particular section may experience heavy traffic during production hours that may affect the time it takes to reach its destination. This way the controller will learn the shortest route based on past experience.

When reading an RFID tag that is configured as a “node”, the AGV will first follow the LHS track at that node and then the RHS track when it scans it again later in the teaching run. An AGV will continue to drive along the track until timing information has been obtained for all RFID tags in the system as well as links between the nodes. Assume we have a simple track with a starting point, a node that splits the road into two branches, each with a work station, which later joins into a single track that leads back to the starting point. When performing a teaching run the AGV will scan the starting point and move until it reaches the node where it will first follow the LHS path that leads to the first work station. From there it will continue to drive until it reaches the starting point again. It will continue to move until it reaches the node again, at which time it will then follow the RHS track until it reaches the second work station. From there it will move in a forward direction again until it reaches the starting point. Once the starting point has been reached the teaching run will be complete, since the controller now has timing information for all the configured tags and it has also learned that it needs to branch left at the node if it wants to get to work station 1 and branch to the right if it wants to get to work station 2.

With the established communication it will be possible to access variable values directly on the PLC, as was demonstrated with the SCADA program created for determining PID tuning parameters. During operation this principle will be used to:

- Control the tow tin
- Start/Stop the AGV
- Perform branch selection
- Change the safety zone
- Activate a software ESTOP

6.3 PRELIMINARY IMPLEMENTATION OF CONTROLLER

The controller was implemented in Microsoft Visual Studio since it allows for flexible programming as well as provides simply GUI creation. The following information is conveyed between the intelligent controller and the local AGV controller:

INPUTS to Intelligent Controller	OUTPUTS from Intelligent Controller
Detected RFID Tag Value	Advance Coupling Pin
Potentiometer Feedback	Retract Coupling Pin
Coupling System: Mode Selection (Automatic/Manual)	Turn Left
Station Request for Deliver/Removal of Trolley	Turn Right
Battery Status	Stop/Start AGV
	ESTOP
	Safety Zone Selection

Table 9. Summary of Controller I/O

The AGV comes to a complete stop whenever it detects a valid RFID tag. The value of the detected tag is transmitted to the intelligent controller for further processing. The control instruction transmitted by the intelligent controller informs the AGV on which action to take. Figure 46 shows the preliminary interface that was created for the intelligent controller. The name assigned to the controller program is iSPS, which is an abbreviation for intelligent set part system. There are four main data tables displayed on the main screen.

- **Active vehicles** – Extracts information from the database regarding AGVs that have been added to the controller. The iSPS software will periodically send a status request to each of the AGVs and display the result.
- **Configured Tags** – Extracts all configured tags from the database for the selected route.
- **Routing Table** – Displays information obtained from each AGV in the system. This table will show the user where each AGV is heading as well as the expected time to destination is. The expected time is based on information obtained from past experience of the controller.
- **ETA Between Tags** – Displays information about the time it takes to get from one tag to another. The initial time is obtained from the teaching run and will be updated each time the AGV moves from one tag to another.

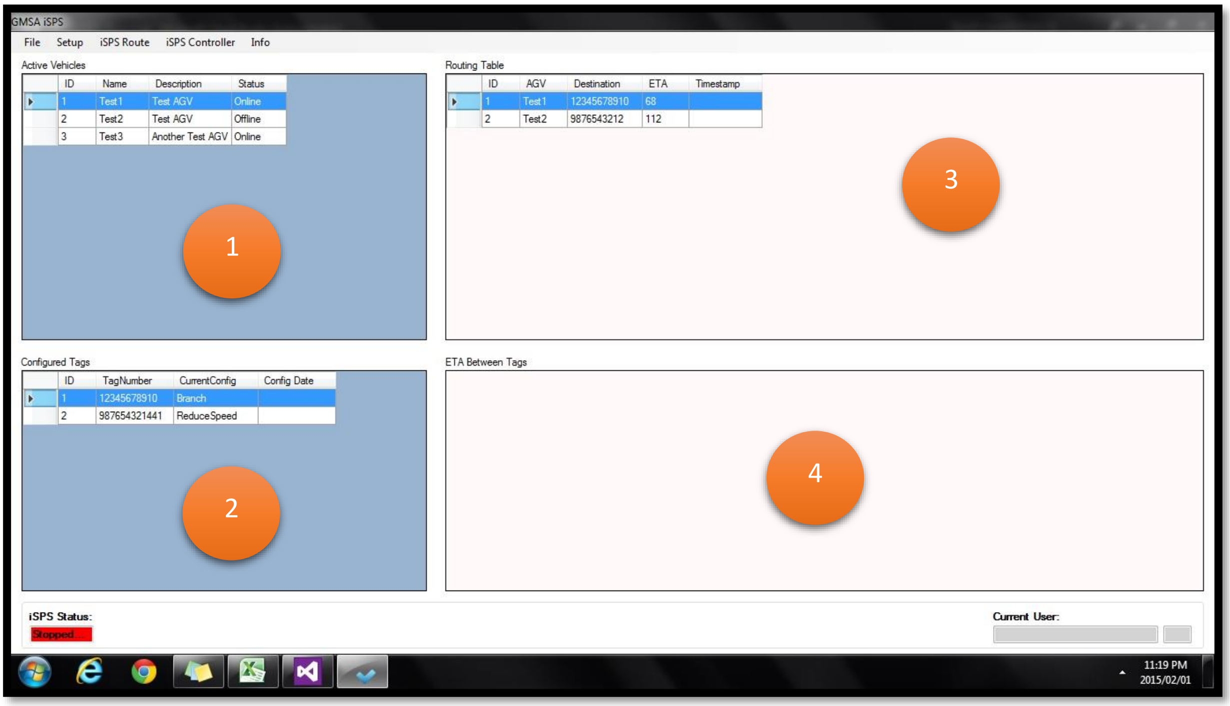


Figure 46. Preliminary Interface for the Intelligent Controller

SQL Server 2012 was used to create the database that stores the obtained information. Stored procedures were created that allow database information to be accessed from the VB.Net application.

A user management system is required by the iSPS to prevent unauthorized access to the system. Three basic access levels are recommended, namely:

- **Operator level** - An operator will only be allowed to monitor the system. They will not be allowed to make any changes.
- **Technician level** – This level account may monitor the system as well as make certain changes, such as scanning a new tag to replace an old one in the event of loss or damage
- **Administrator level** – Allowed full access to the system. This level may monitor and access all the functions of the controller

CHAPTER 7

EXPERIMENTATION AND RESULTS

This section will address the experimental procedures followed to obtain quantifiable results for the final AGV design. The intelligent controller relies heavily on the input it receives from each of the AGVs connected to it. For this reason it is important to ensure that the control of the AGV is satisfactory, since large oscillation during operation may result in command markers not being read.

7.1 TESTING OF THE CONTROL SYSTEM

The SCADA program, used for tuning the PID parameters, was also used to obtain quantifiable results for the oscillation of the AGV during operation. Figure 47 shows the decimal value of the control command transmitted to each motor as well as the decimal analogue value for the positional error. A sample was automatically recorded every 1ms using an Ethernet connection and the Modbus communication protocol. To convert the error signal to millimetres it was necessary to relate the actual measured position (using a Vernier calliper) to the error signal observed in the PLC program. This experiment revealed that one unit in the error signal equates to one millimetre of AGV displacement. From Figure 47 is can be seen that a maximum overshoot of 69mm occurred over 500 samples. The time it took the system to correct its path is calculated as follows:

$$T_{correction} = Number\ of\ samples\ \times Interval\ between\ samples$$

$$\therefore T_{correction} = 500 \times 0.001 = 0.5\ seconds$$

The average error was calculated to be 0.2mm. Overshoot was found to occur mainly around corners or in areas where the floor is uneven or not clear of small objects like nuts and bolts.

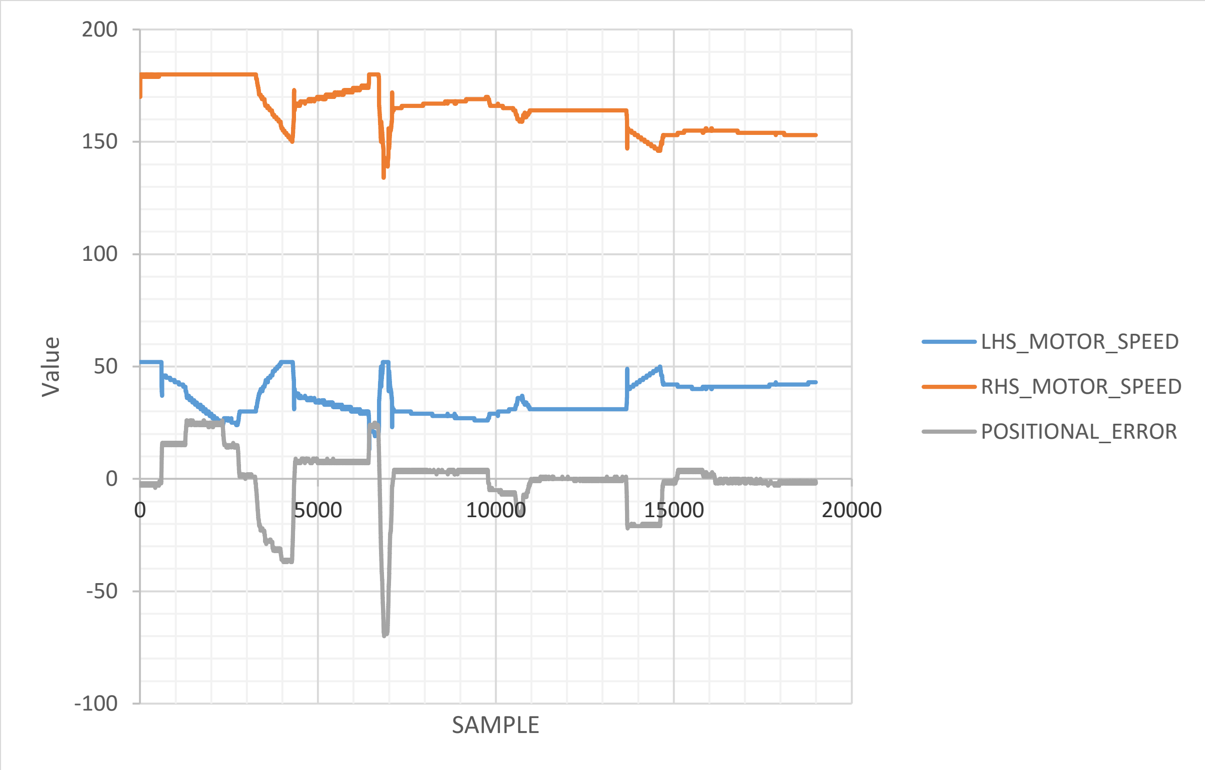


Figure 47. Summary of error signal and motor commands during operation

7.2 TESTING OF THE BATTERY MONITORING SYSTEM

As per the design requirements it is important for the AGV to stop operation whenever the supply voltage drops below a selected value. The AGV was operated and monitored continuously to determine the threshold voltage of the supply. Significant speed reduction was observed when the supply voltage drops below 23V. A threshold voltage of 23.5V was selected on the VSR. Once the VSR has been set up, the AGV was operated until the blue indicator lamp came on to indicate that a low level has been detected on the supply. The voltage was measured to be 23.5 ± 0.1 Volt, which indicates correct monitoring. Once the measurement was completed the AGV was allowed to continue with its operation until it automatically stopped due to the internal timer set by the PLC program. Once the PLC stopped the AGV it was unable to start again until the batteries were replaced. The final voltage on the PLC was measured to be 23.3 ± 0.1 Volt.

7.3 TESTING OF SAFETY DEVICES

Safety is the most important aspect of the AGV and was treated accordingly. The laser scanner proved reliable in sensing an object regardless of the material or reflectivity thereof. Scenario-based testing was carried out to ensure that:

- The AGV has sufficient time to stop when detecting obstacles.
- The AGV can detect obstacles within a 180° range
- The AGV cuts power to the motors whenever the bumper is activated. This is a mechanical safety feature in event that the software safety fails and/or an obstacle is not detected by the laser scanner.
- A voluntary action is required to reset the safety circuit

Testing revealed that the safety of the AGV is satisfactory and does not pose a threat to the operator under normal operation.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

This dissertation presented material relevant to the research and development of an intelligent AGV-based material handling system. Two AGVs were developed that were capable of:

- Autonomous retrieval and delivery of SPS trolleys
- Effective non-contact collision detection and avoidance
- Continuous operation for an entire production shift of 8 hours and 30 minutes
- Safe operation in the working environment

In addition to the above capabilities the AGVs also proved to be reliable when detecting control markers and responding to the input command received from them. When both marker sensors are active at the same time, the sequence in the PLC is incremented. This approach allowed for less magnetic tape to be used and also increased the probability of a successful read.

The improved line-sensing capabilities along with the implementation of PID control significantly improved the performance of the AGVs. The decrease in oscillation also proved to result in more reliable marker detection and improved positioning when retrieving an SPS trolley.

The use of a laser scanner allowed for multiple safety zones to be configured. This allowed the AGVs to work safely in different working environments, regardless of the space constraint. However, it is import to note that the safety field will have to be set to a short range when operating in small or narrow spaces. Safety zones should only be changed by a responsible person, since an incorrect safety zone may result in personal injury if the AGV is not allowed sufficient time to stop once an obstacle has been detected. It is recommended that an audible alarm be installed that will be activated whenever an obstacle is detected. This will ensure that passing operators are made aware when they are in close proximity to the moving vehicle.

The AGV was proven to be capable of towing a load of 200kg. However, it was found that the temperature of the motors increased significantly when a load is present. When operated with a full load over a long period of time this may cause permanent damage. It is recommended that spare motors be kept at all times to prevent downtime in event of failure.

The two AGVs functioned satisfactory when operating concurrently in a service loop. Each AGV performed tasks based on its own internal sequence, which proved that the AGVs are capable of operation even in the absence of the intelligent controller. This is a major advantage, since it eliminates downtime when the intelligent controller is down for maintenance. However, the intelligent controller would allow for more efficient operation in applications where cycle time is critical. A strategy for intelligent control has been proposed in this dissertation, but additional hardware is required before it can be implemented. In addition to the marker sensors on the AGV, an RFID scanner needs to be installed on each AGV. The RFID scanner will read an RFID tag and transmit the tag value to the intelligent controller. The intelligent controller will use the tag command to control the AGV and override the internal sequence. The intelligent controller was developed to be an optional due to the high cost of the hardware.

In conclusion, an AGV-based material handling system was developed that is: flexible, efficient, cost effective and robust enough to be used in industrial environments.

CHAPTER 9

FUTURE DEVELOPMENT

The overall performance and functionality of the developed system was satisfactory, but there are still areas that may be improved on.

The biggest problem that remains is defining the sequence of tasks that the AGV is required to perform in the absence of an intelligent controller. The current sequence of tasks are hard-coded into the PLC program and requires an experienced PLC programmer to make any modification to the sequence if the AGV is to be used for a different task to the one it was originally programmed for. It is strongly advised that an alternative method be considered in which the sequence of tasks can be configured from a GUI and transferred to the PLC using the Modbus protocol.

Future work is also required on the intelligent controller. A basic GUI and database has been created, but additional hardware and two AGVs are required for further development and implementation thereof.

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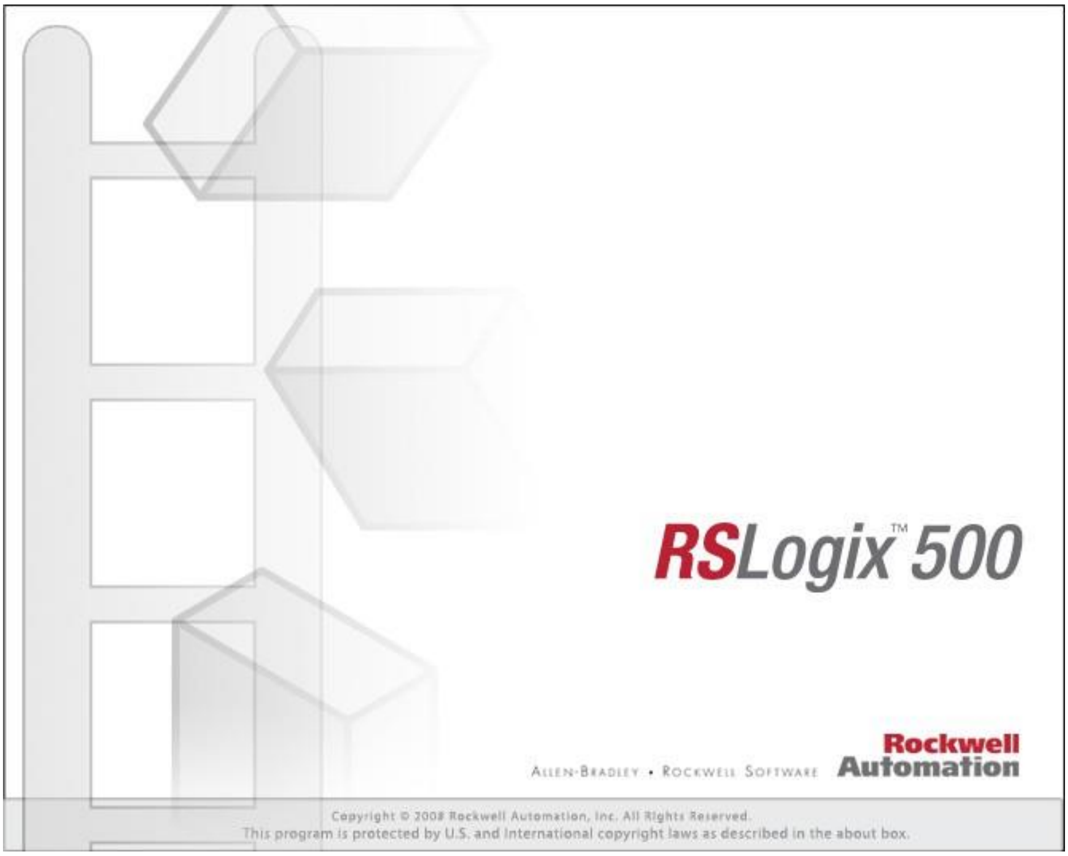
ANNEXURE A - PLC PROGRAM

RSLogix Micro Project Report



Processor Information

Processor Type: Bul.1763   MicroLogix 1100 Series B

Processor Name: ML1100

Total Memory Used: 797 Instruction Words Used - 738 Data Table Words Used

Total Memory Left: 5559 Instruction Words Left

Program Files: 3

Data Files: 11

Program ID: a16b

I/O Configuration

0	Bul.1763	MicroLogix 1100 Series B
1	1762-IQ8OW6	8-Input 10/30 VDC 6-Output (RLY)
2		
3		
4		

PID - Rung #2:33 - PD10:1

Controller Gain, Kc: 4.9	Setpoint: 200
Reset Term, Ti: 1.20	Setpoint MAX(Smax): 0
Rate Term, Td: 0.01	Setpoint MIN(Smin): 0
Loop Update Time: 0.01	Process Variable PV: 0
Control Mode: E = PV - SP	Control Output CV (%): 0
PID Control: Auto	Output Max CV(%): 100
Time Mode: Timed	Output Min CV(%): 0
Limit Output CV: No	Scaled Error: 0
Deadband: 0	Feed Forward Bias: 0

PID - Rung #2:34 - PD10:2

Controller Gain, Kc: 4.9	Setpoint: 200
Reset Term, Ti: 1.20	Setpoint MAX(Smax): 0
Rate Term, Td: 0.01	Setpoint MIN(Smin): 0
Loop Update Time: 0.01	Process Variable PV: 0
Control Mode: E = SP - PV	Control Output CV (%): 0
PID Control: Auto	Output Max CV(%): 100
Time Mode: Timed	Output Min CV(%): 0
Limit Output CV: No	Scaled Error: 0
Deadband: 0	Feed Forward Bias: 0

Channel Configuration

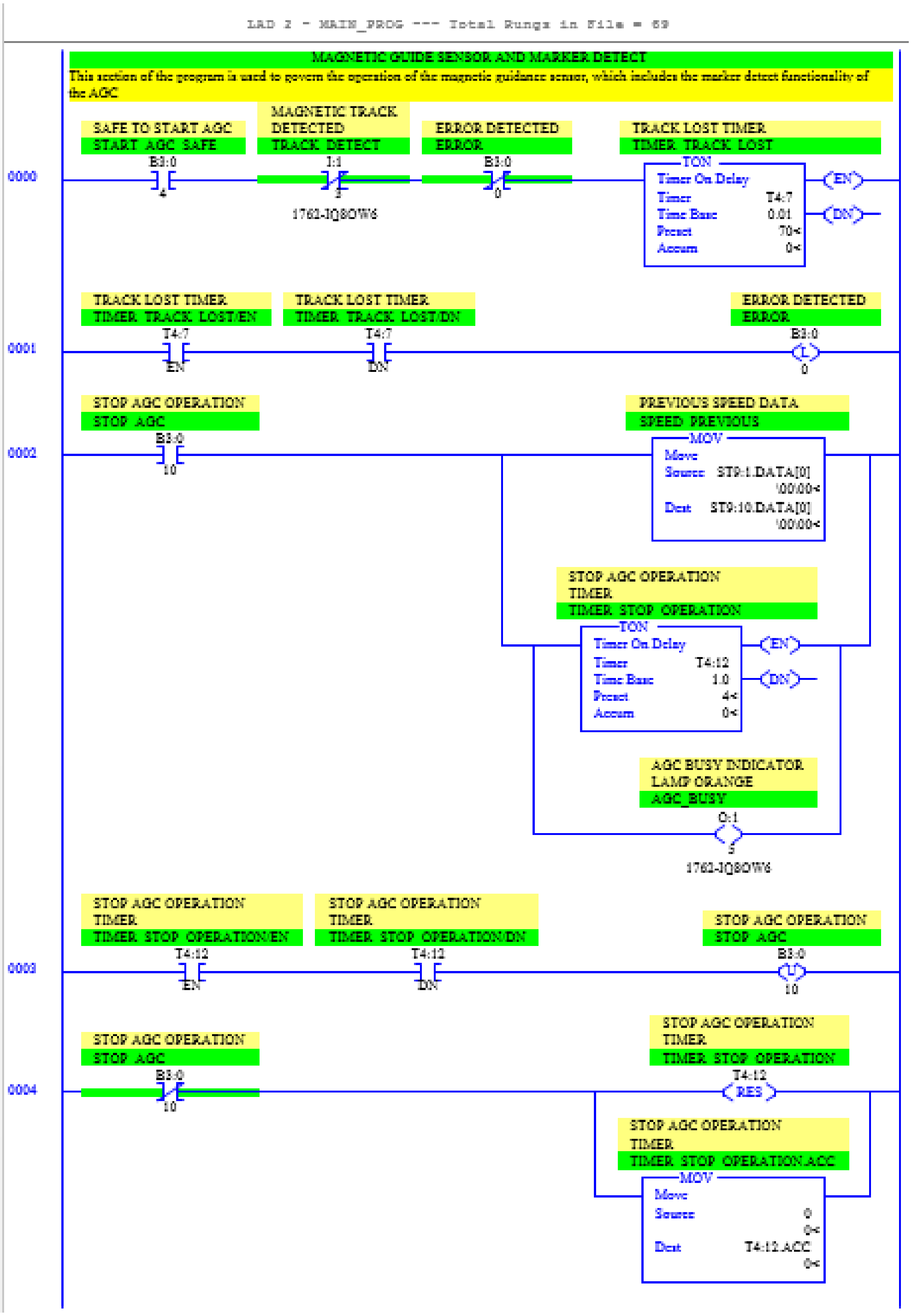
```
CHANNEL 0 (SYSTEM) - Driver: ASCII
   CHANNEL 0 (SYSTEM) - Driver: ASCII Edit Resource/Owner Timeout:   60
   CHANNEL 0 (SYSTEM) - Driver: ASCII Passthru Link ID:   1
   CHANNEL 0 (SYSTEM) - Driver: ASCII Write Protected:   No
   CHANNEL 0 (SYSTEM) - Driver: ASCII Comms Servicing Selection:   Yes
   CHANNEL 0 (SYSTEM) - Driver: ASCII Message Servicing Selection:   Yes
   CHANNEL 0 (SYSTEM) - Driver: ASCII 1st AWA Append Character:   \d
   CHANNEL 0 (SYSTEM) - Driver: ASCII 2nd AWA Append Character:   \a

   Baud:  38.4K
   Parity:  NONE
   Termination Character 1:  \ff
   Termination Character 2:  \ff
   Control Line :  No Handshaking
   Delete mode:  Ignore
   Echo:  No
   XON/XOFF:  No
   RTS Off Delay(x20 ms):  0
   RTS Send Delay(x20 ms):  0


CHANNEL 1 (SYSTEM) - Driver: Ethernet
   CHANNEL 1 (SYSTEM) - Driver: Ethernet Edit Resource/Owner Timeout:   60
   CHANNEL 1 (SYSTEM) - Driver: Ethernet Passthru Link ID:   1
   CHANNEL 1 (SYSTEM) - Driver: Ethernet Write Protected:   No
   CHANNEL 1 (SYSTEM) - Driver: Ethernet Comms Servicing Selection:   Yes
   CHANNEL 1 (SYSTEM) - Driver: Ethernet Message Servicing Selection:   Yes

   Hardware Address:  00:0F:73:03:D4:18
   IP Address:  192.168.0.2
   Subnet Mask:  255.255.255.0
   Gateway Address:  192.168.0.1
   Msg Connection Timeout (x 1mS):  15000
   Msg Reply Timeout (x mS):  3000
   Inactivity Timeout (x Min):  0
   Bootp Enable:  Yes
   Dhcp Enable  No
   SNMP Enable:  No
   HTTP Enable:  Yes
   Auto Negotiate Enable:  Yes
   Port Speed Enable:  10/100 Mbps Full Duplex/Half Duplex
   Contact:
   Location:
```

Program File List

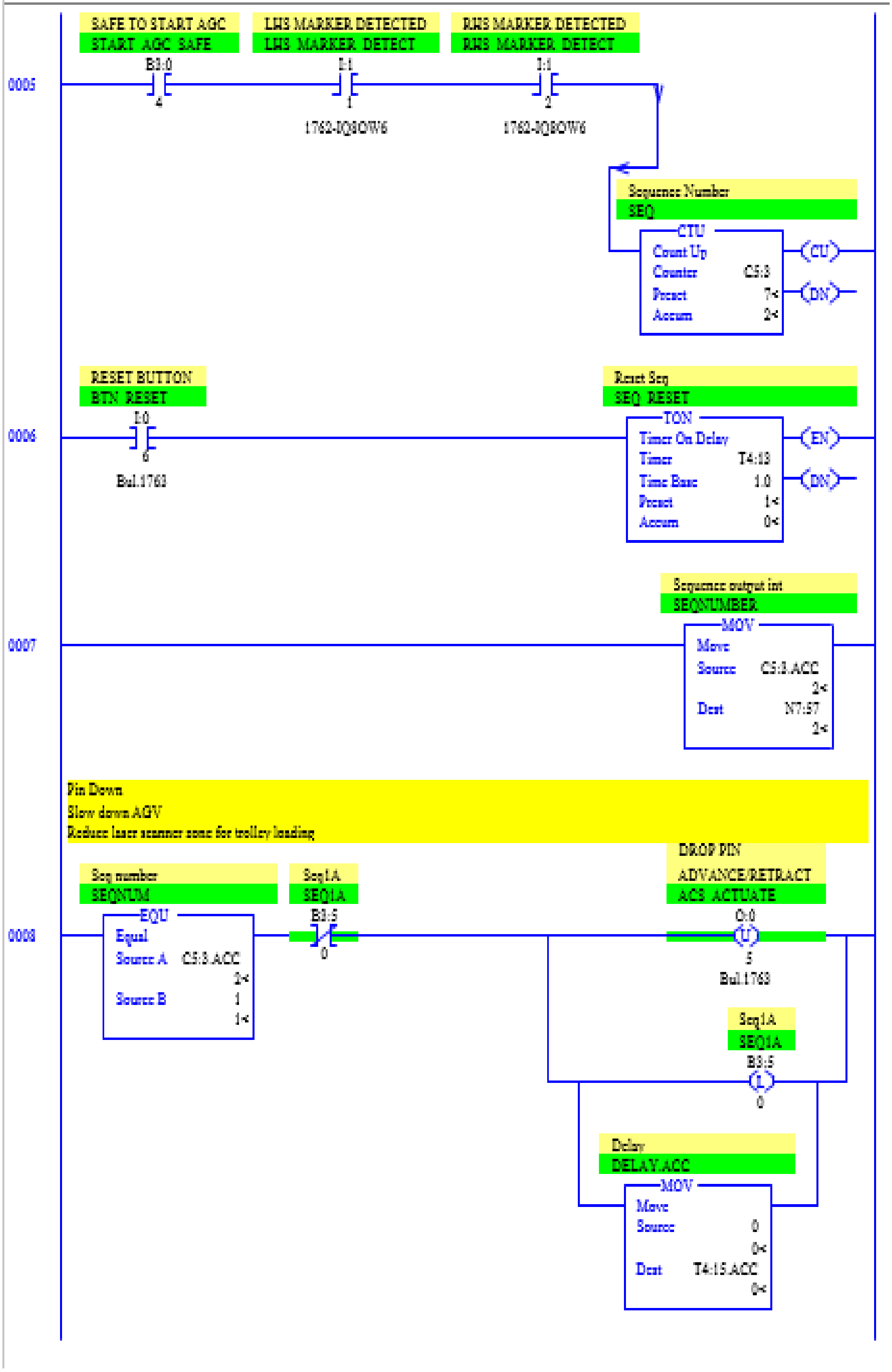
Name	Number	Type	Rungs	Debug	Bytes
[SYSTEM]	0	SYS	0	No	0
	1	SYS	0	No	0
MAIN PROG	2	LADDER	69	No	3110

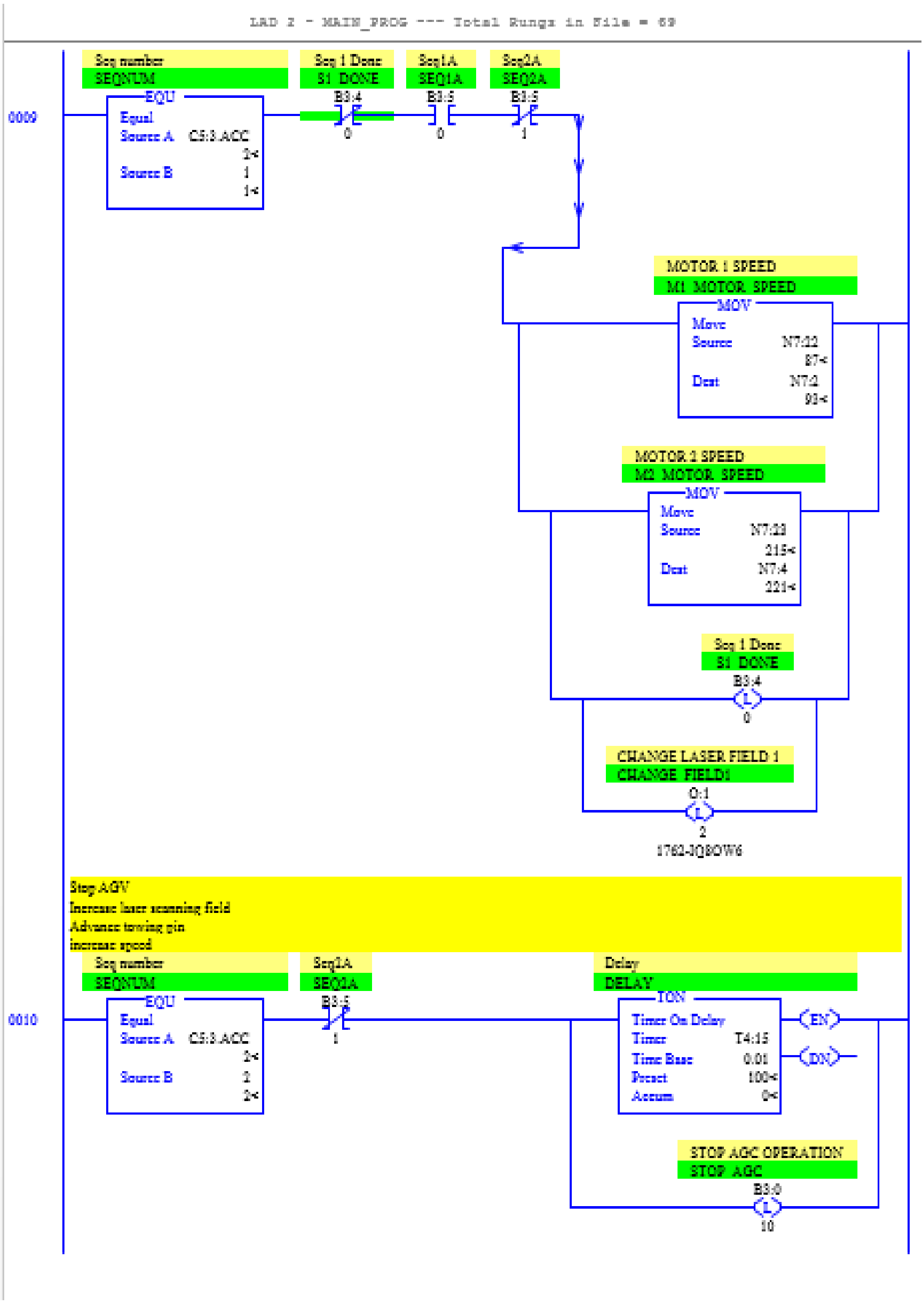
Data File List

Name	Number	Type	Scope	Debug	Words	Elements	Last
OUTPUT	0	O	Global	No	15	5	O:4
INPUT	1	I	Global	No	21	7	I:6
STATUS	2	S	Global	No	0	66	S:65
BINARY	3	B	Global	No	6	6	B3:5
TIMER	4	T	Global	No	48	16	T4:15
COUNTER	5	C	Global	No	12	4	C5:3
CONTROL	6	R	Global	No	3	1	R6:0
INTEGER	7	N	Global	No	58	58	N7:57
FLOAT	8	F	Global	No	2	1	F8:0
STRING	9	ST	Global	No	504	12	ST9:11
PID	10	PD	Global	No	69	3	PD10:2

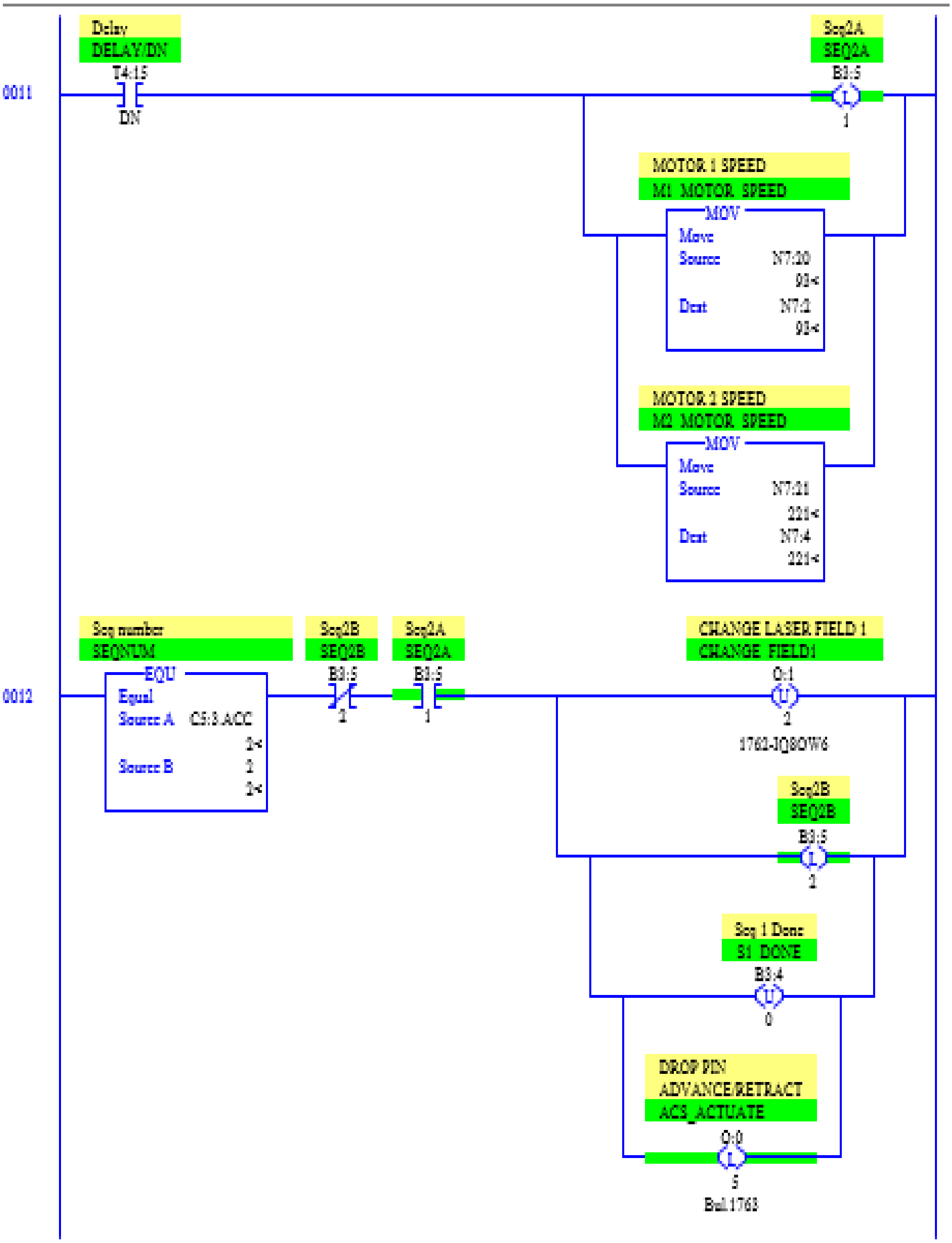

LAD 2 - MAIN_PROG --- Total Rungs in File = 69
MAGNETIC GUIDE SENSOR AND MARKER DETECT
This section of the program is used to govern the operation of the magnetic guidance sensor, which includes the marker detect functionality of the AGC
0000
SAFE TO START AGC
START_AGC_SAFE
B3:0
4
MAGNETIC TRACK DETECTED
TRACK_DETECT
I:1
3
1762-IQ8OW6
ERROR DETECTED
ERROR
B3:0
0
TRACK LOST TIMER
TIMER_TRACK_LOST
TON
Timer On Delay
Timer T4:7
Time Base 0.01
Preset 70<
Accum 0<
EN
DN
0001
TRACK LOST TIMER
TIMER_TRACK_LOST/EN
T4:7
EN
TRACK LOST TIMER
TIMER_TRACK_LOST/DN
T4:7
DN
ERROR DETECTED
ERROR
B3:0
L
0
0002
STOP AGC OPERATION
STOP_AGC
B3:0
10
PREVIOUS SPEED DATA
SPEED_PREVIOUS
MOV
Move
Source ST9:1.DATA[0]
\00\00<
Dest ST9:10.DATA[0]
\00\00<
STOP AGC OPERATION TIMER
TIMER_STOP_OPERATION
TON
Timer On Delay
Timer T4:12
Time Base 1.0
Preset 4<
Accum 0<
EN
DN
AGC BUSY INDICATOR LAMP ORANGE
AGC_BUSY
O:1
5
1762-IQ8OW6
0003
STOP AGC OPERATION TIMER
TIMER_STOP_OPERATION/EN
T4:12
EN
STOP AGC OPERATION TIMER
TIMER_STOP_OPERATION/DN
T4:12
DN
STOP AGC OPERATION
STOP_AGC
B3:0
U
10
0004
STOP AGC OPERATION
STOP_AGC
B3:0
10
STOP AGC OPERATION TIMER
TIMER_STOP_OPERATION
T4:12
RES
STOP AGC OPERATION TIMER
TIMER_STOP_OPERATION.ACC
MOV
Move
Source 0
0<
Dest T4:12.ACC
0<

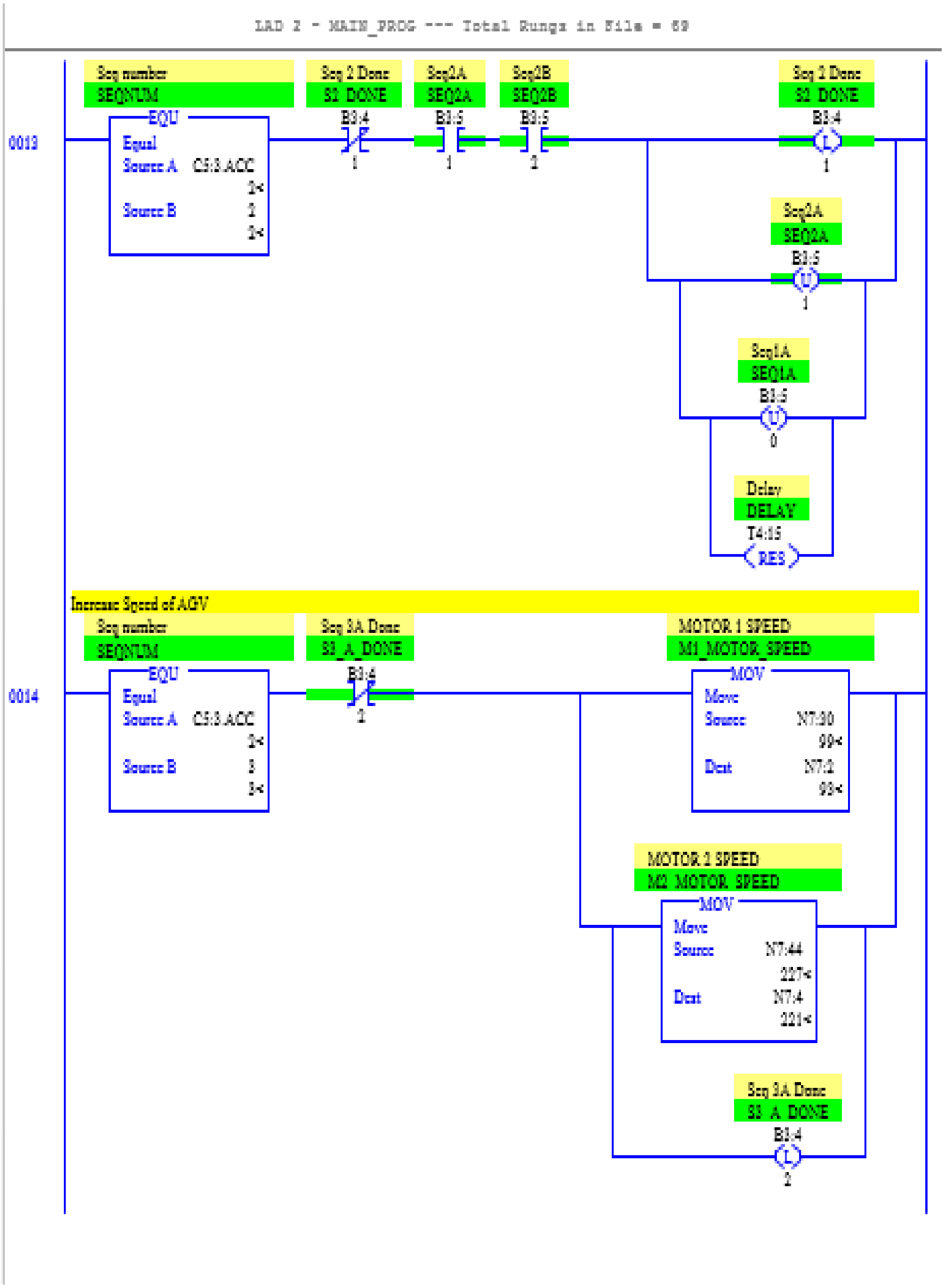
LAD 2 - MAIN_PROG --- Total Rungs in File = 69

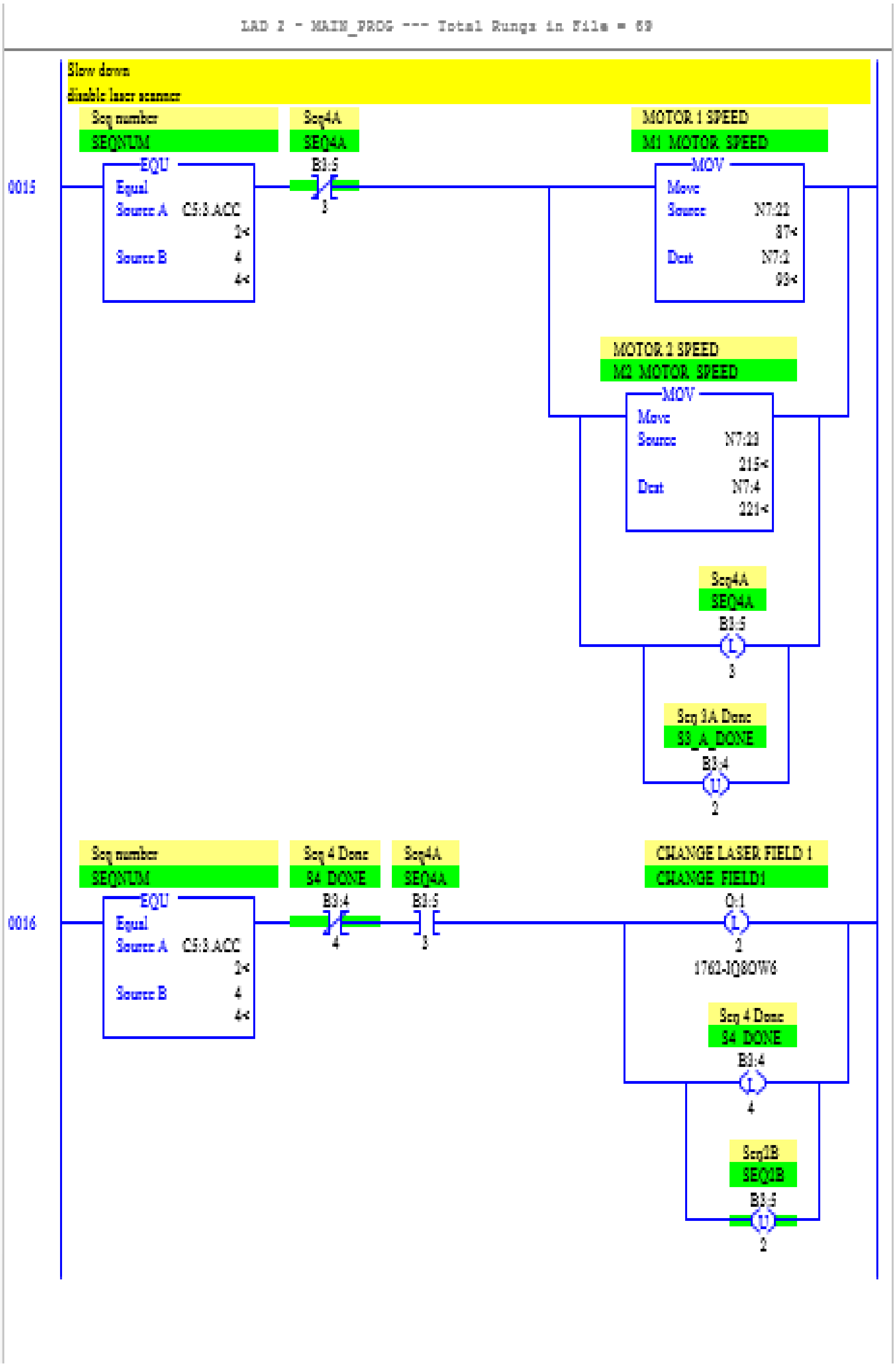


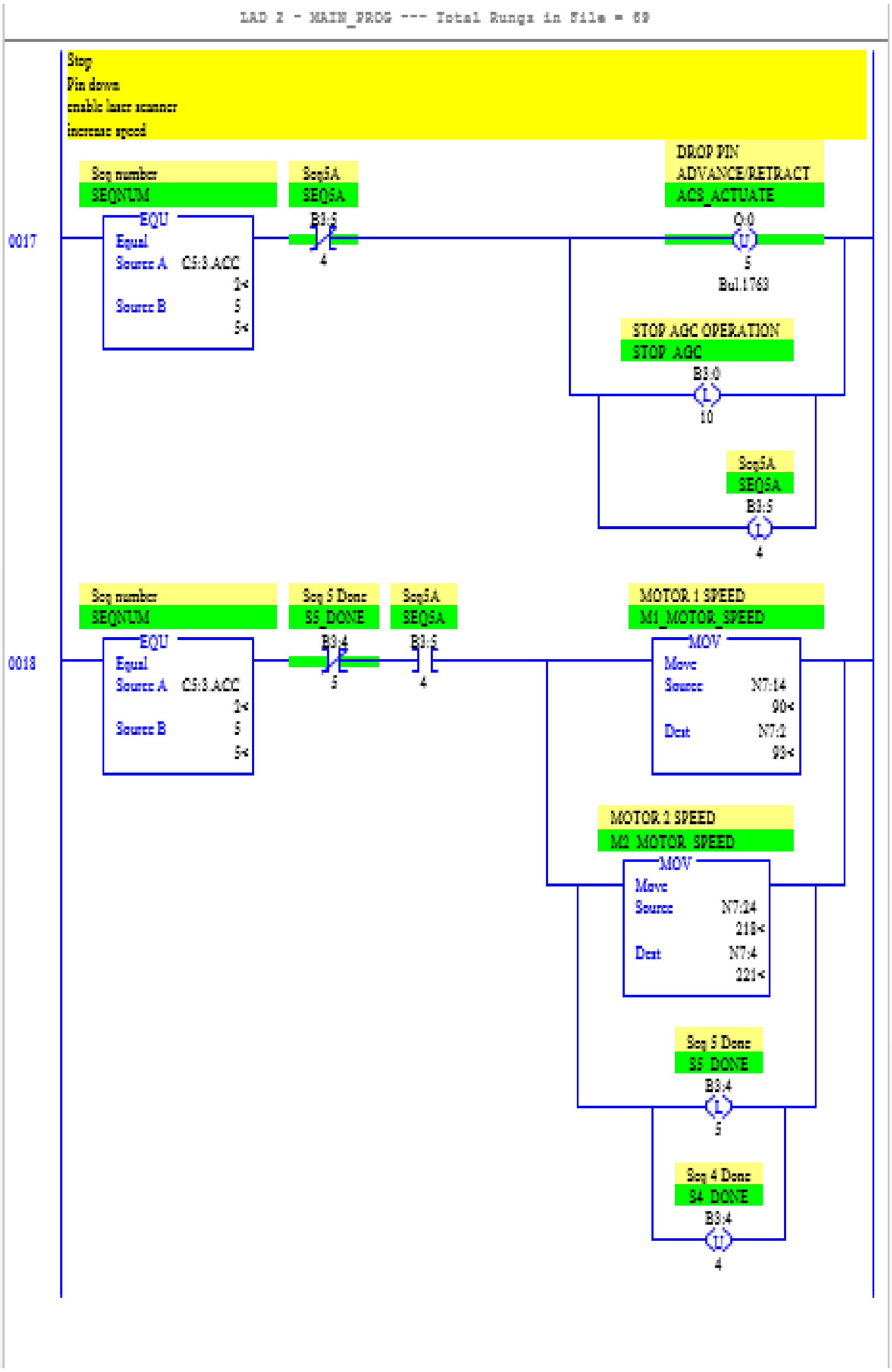

LAD 2 - MAIN_PROG --- Total Rungs in File = 69
0009
Seq number
SEQNUM
EQU
Equal
Source A C5:3.ACC
2<
Source B 1
1<
Seq 1 Done
S1 DONE
B3:4
0
Seq1A
SEQ1A
B3:5
0
Seq2A
SEQ2A
B3:5
1
MOTOR 1 SPEED
M1 MOTOR SPEED
MOV
Move
Source N7:22
87<
Dest N7:2
93<
MOTOR 2 SPEED
M2 MOTOR SPEED
MOV
Move
Source N7:23
215<
Dest N7:4
221<
Seq 1 Done
S1 DONE
B3:4
L
0
CHANGE LASER FIELD 1
CHANGE FIELD1
O:1
L
2
1762-IQ8OW6
Stop AGV
Increase laser scanning field
Advance towing pin
increase speed
0010
Seq number
SEQNUM
EQU
Equal
Source A C5:3.ACC
2<
Source B 2
2<
Seq1A
SEQ1A
B3:5
1
Delay
DELAY
TON
Timer On Delay
Timer T4:15
Time Base 0.01
Preset 100<
Accum 0<
EN
DN
STOP AGC OPERATION
STOP AGC
B3:0
L
10

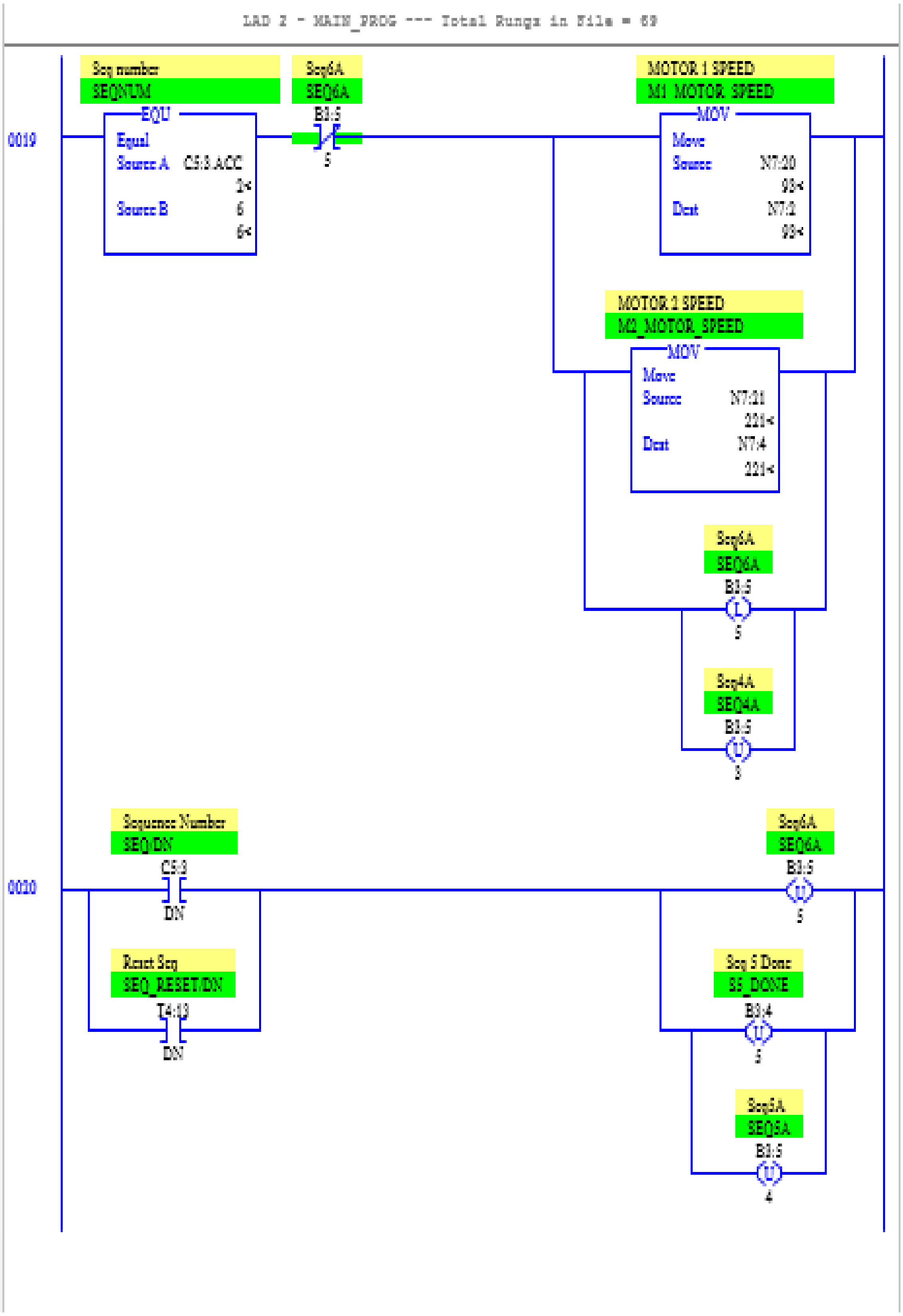
LAD 2 - MAIN_PROG --- Total Rungs in File = 69



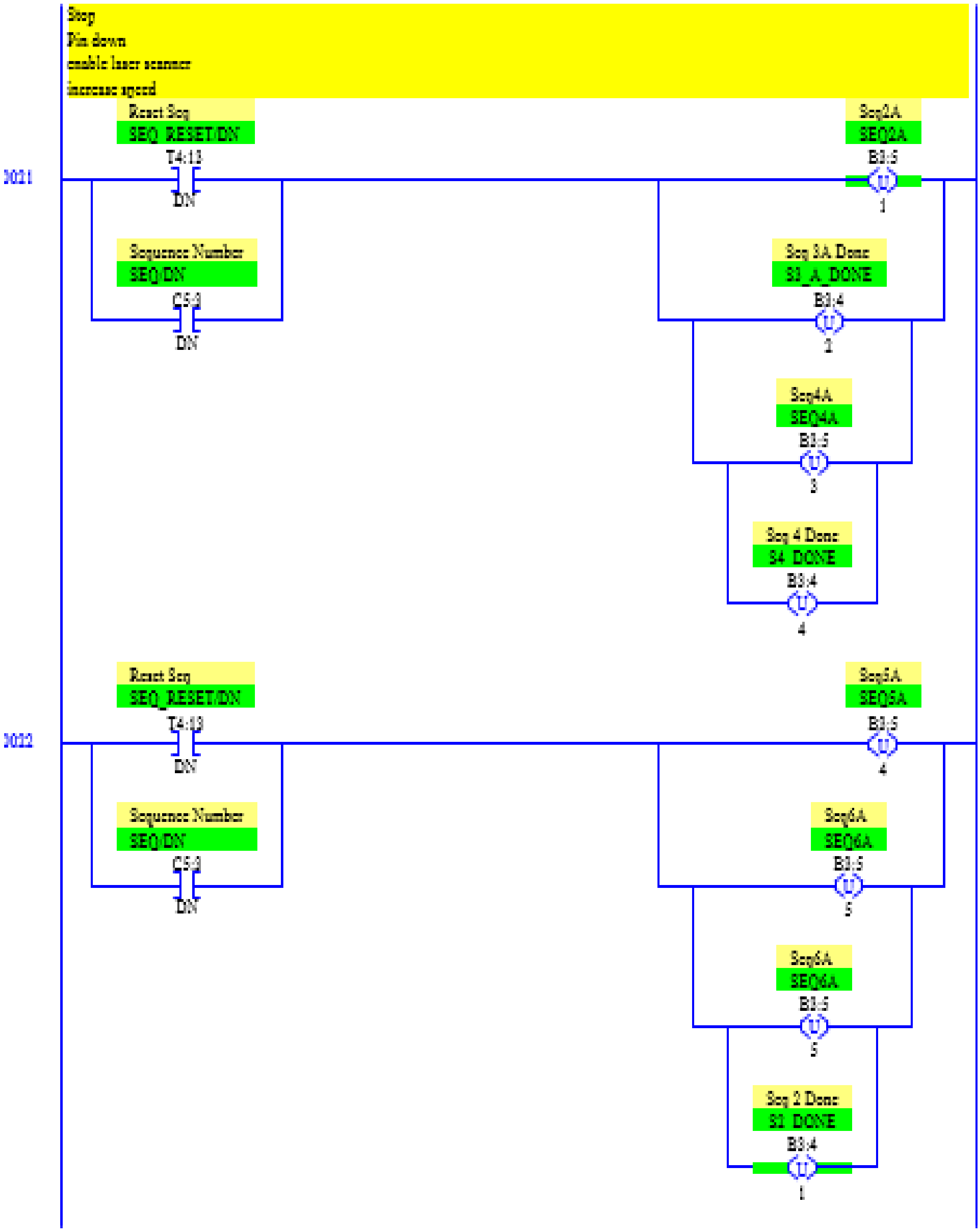

LAD 2 - MAIN_PROG --- Total Rungs in File = 69
0013
Seq number
SEQNUM
EQU
Equal
Source A C5:3.ACC
2<
Source B 2
2<
Seq 2 Done
S2_DONE
B3:4
1
Seq2A
SEQ2A
B3:5
1
Seq2B
SEQ2B
B3:5
2
Seq 2 Done
S2_DONE
B3:4
L
1
Seq2A
SEQ2A
B3:5
U
1
Seq1A
SEQ1A
B3:5
U
0
Delay
DELAY
T4:15
RES
Increase Speed of AGV
0014
Seq number
SEQNUM
EQU
Equal
Source A C5:3.ACC
2<
Source B 3
3<
Seq 3A Done
S3_A_DONE
B3:4
2
MOTOR 1 SPEED
M1_MOTOR_SPEED
MOV
Move
Source N7:30
99<
Dest N7:2
99<
MOTOR 2 SPEED
M2_MOTOR_SPEED
MOV
Move
Source N7:44
227<
Dest N7:4
221<
Seq 3A Done
S3_A_DONE
B3:4
L
2

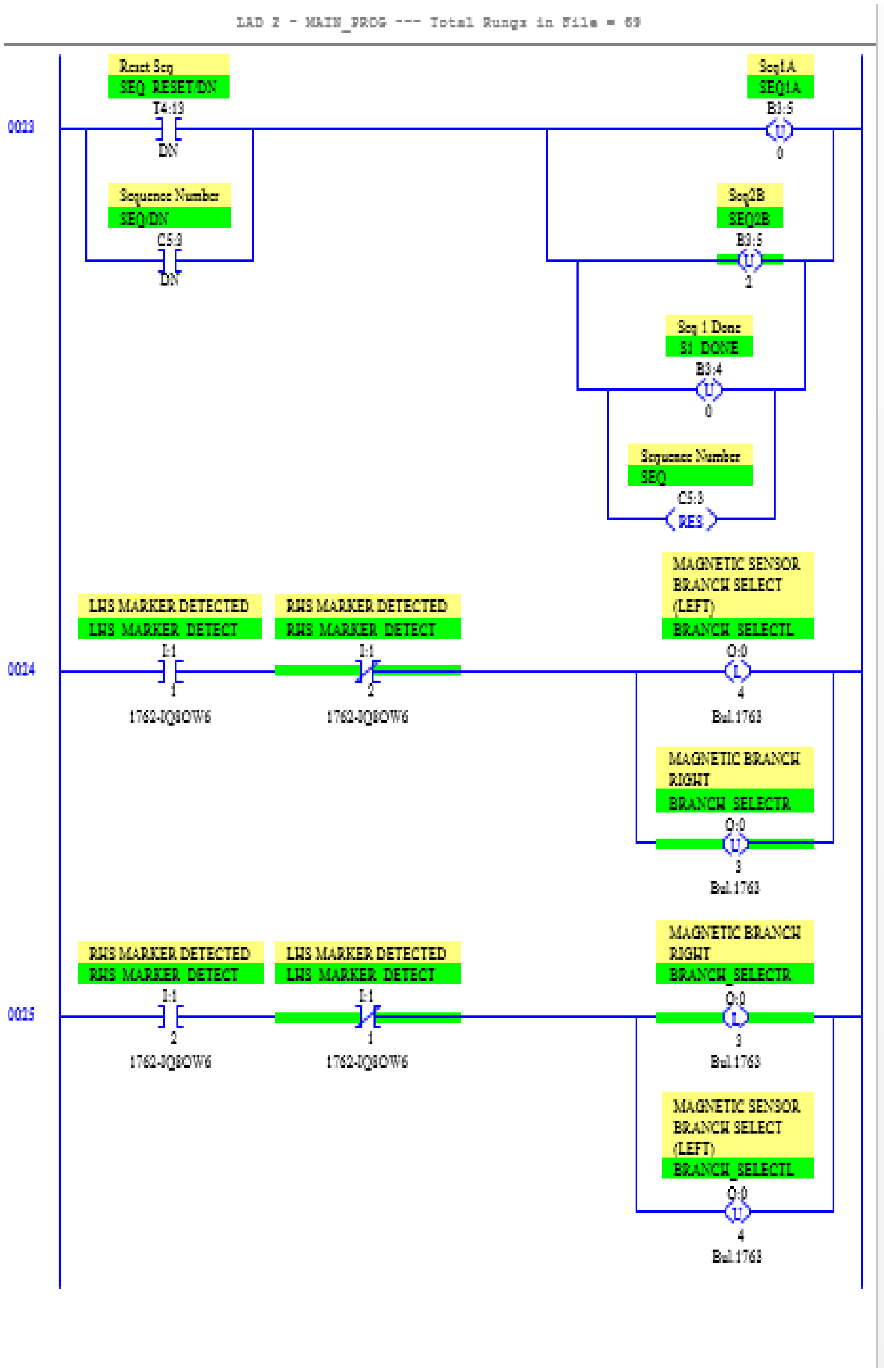

LAD 2 - MAIN_PROG --- Total Rungs in File = 69
Slow down
disable laser scanner
0015
Seq number
SEQNUM
EQU
Equal
Source A C5:3.ACC
2<
Source B 4
4<
Seq4A
SEQ4A
B3:5
3
MOTOR 1 SPEED
M1_MOTOR_SPEED
MOV
Move
Source N7:22
87<
Dest N7:2
93<
MOTOR 2 SPEED
M2_MOTOR_SPEED
MOV
Move
Source N7:23
215<
Dest N7:4
221<
Seq4A
SEQ4A
B3:5
L
3
Seq 3A Done
S3_A_DONE
B3:4
U
2
0016
Seq number
SEQNUM
EQU
Equal
Source A C5:3.ACC
2<
Source B 4
4<
Seq 4 Done
S4_DONE
B3:4
4
Seq4A
SEQ4A
B3:5
3
CHANGE LASER FIELD 1
CHANGE_FIELD1
O:1
L
2
1762-IQ8OW6
Seq 4 Done
S4_DONE
B3:4
L
4
Seq1B
SEQ1B
B3:5
U
2

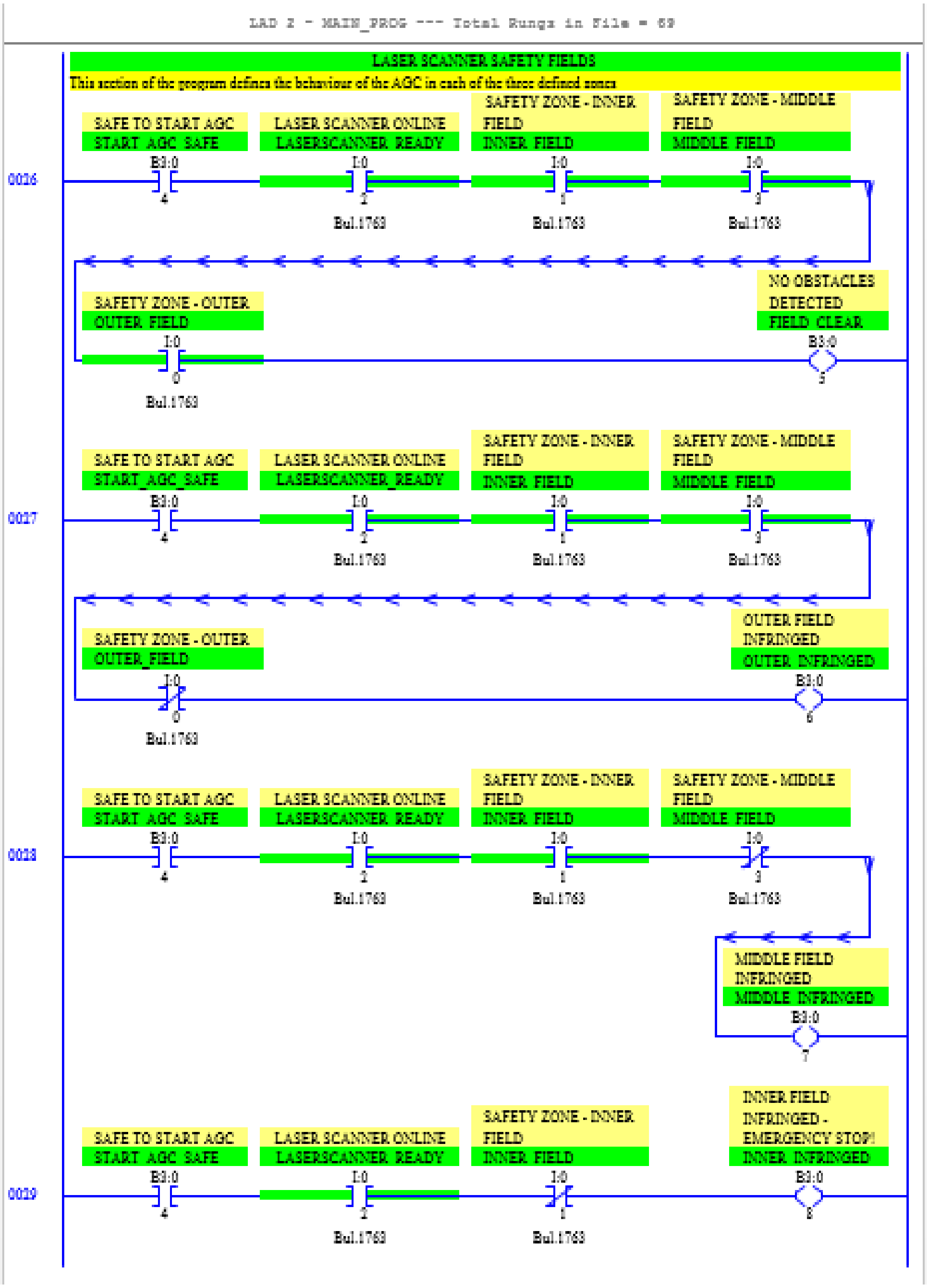

LAD 2 - MAIN_PROG --- Total Rungs in File = 69
Stop
Pin down
enable laser scanner
increase speed
0017
Seq number
SEQNUM
EQU
Equal
Source A C5:3.ACC
2<
Source B 5
5<
Seq5A
SEQ5A
B3:5
4
DROP PIN
ADVANCE/RETRACT
ACS_ACTUATE
O:0
U
5
Bul.1763
STOP AGC OPERATION
STOP_AGC
B3:0
L
10
Seq5A
SEQ5A
B3:5
L
4
0018
Seq number
SEQNUM
EQU
Equal
Source A C5:3.ACC
2<
Source B 5
5<
Seq 5 Done
S5_DONE
B3:4
5
Seq5A
SEQ5A
B3:5
4
MOTOR 1 SPEED
M1_MOTOR_SPEED
MOV
Move
Source N7:14
90<
Dest N7:2
93<
MOTOR 2 SPEED
M2_MOTOR_SPEED
MOV
Move
Source N7:24
218<
Dest N7:4
221<
Seq 5 Done
S5_DONE
B3:4
L
5
Seq 4 Done
S4_DONE
B3:4
U
4

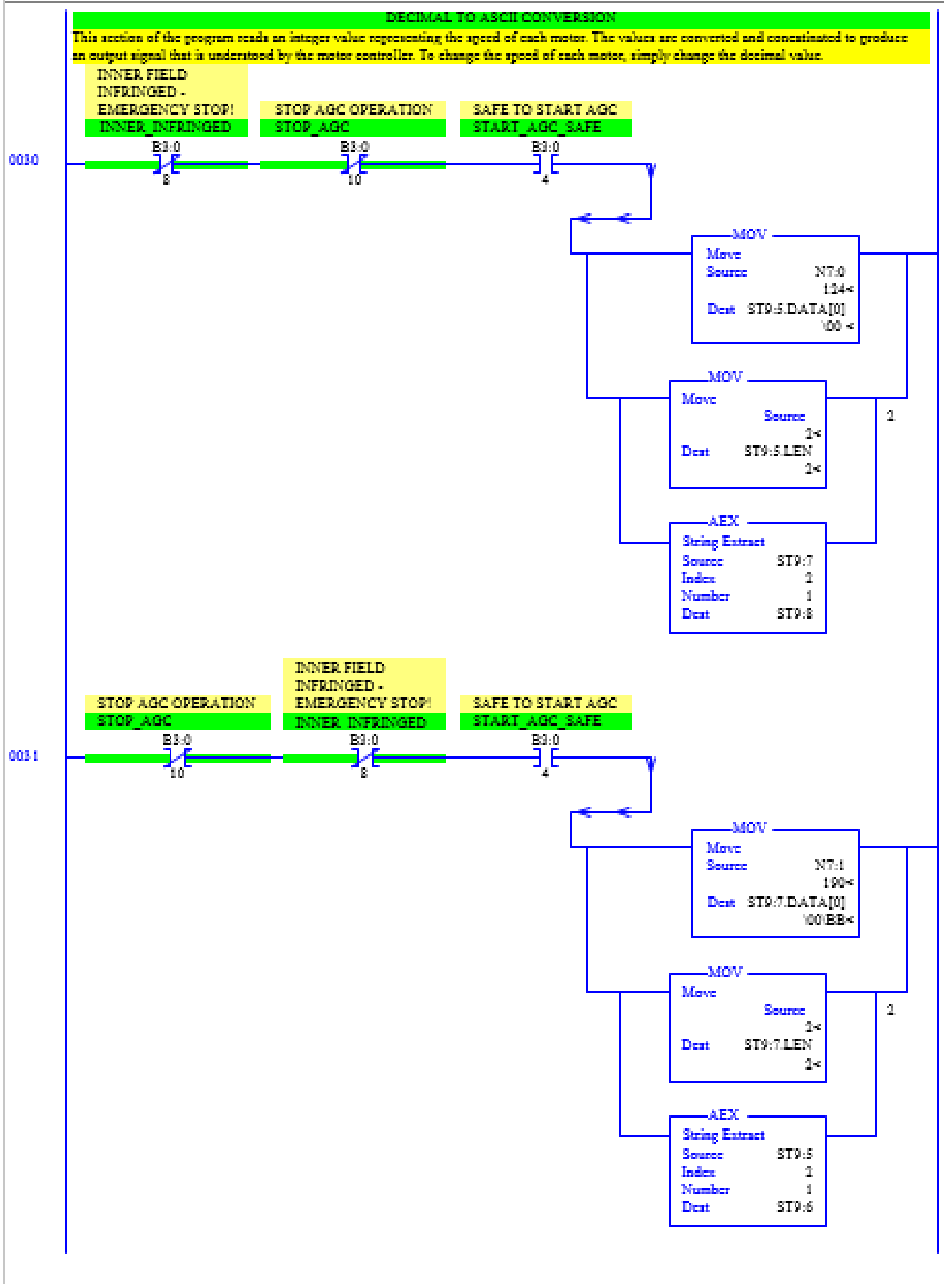


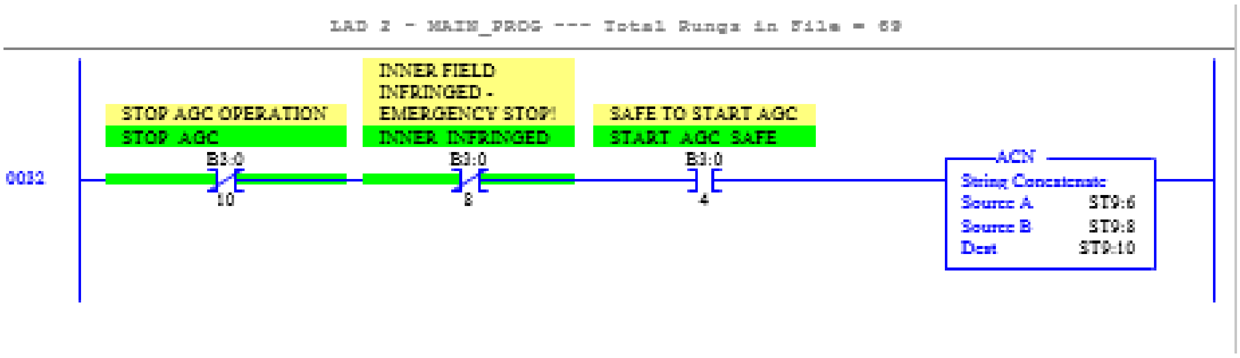
LAD 2 - MAIN_PROG --- Total Rungs in File = 69
0019
Seq number
SEQNUM
EQU
Equal
Source A C5:3.ACC
2<
Source B 6
6<
Seq6A
SEQ6A
B3:5
5
MOTOR 1 SPEED
M1_MOTOR_SPEED
MOV
Move
Source N7:20
93<
Dest N7:2
93<
MOTOR 2 SPEED
M2_MOTOR_SPEED
MOV
Move
Source N7:21
221<
Dest N7:4
221<
Seq6A
SEQ6A
B3:5
L
5
Seq4A
SEQ4A
B3:5
U
3
0020
Sequence Number
SEQ/DN
C5:3
DN
Reset Seq
SEQ_RESET/DN
T4:13
DN
Seq6A
SEQ6A
B3:5
U
5
Seq 5 Done
S5_DONE
B3:4
U
5
Seq5A
SEQ5A
B3:5
U
4

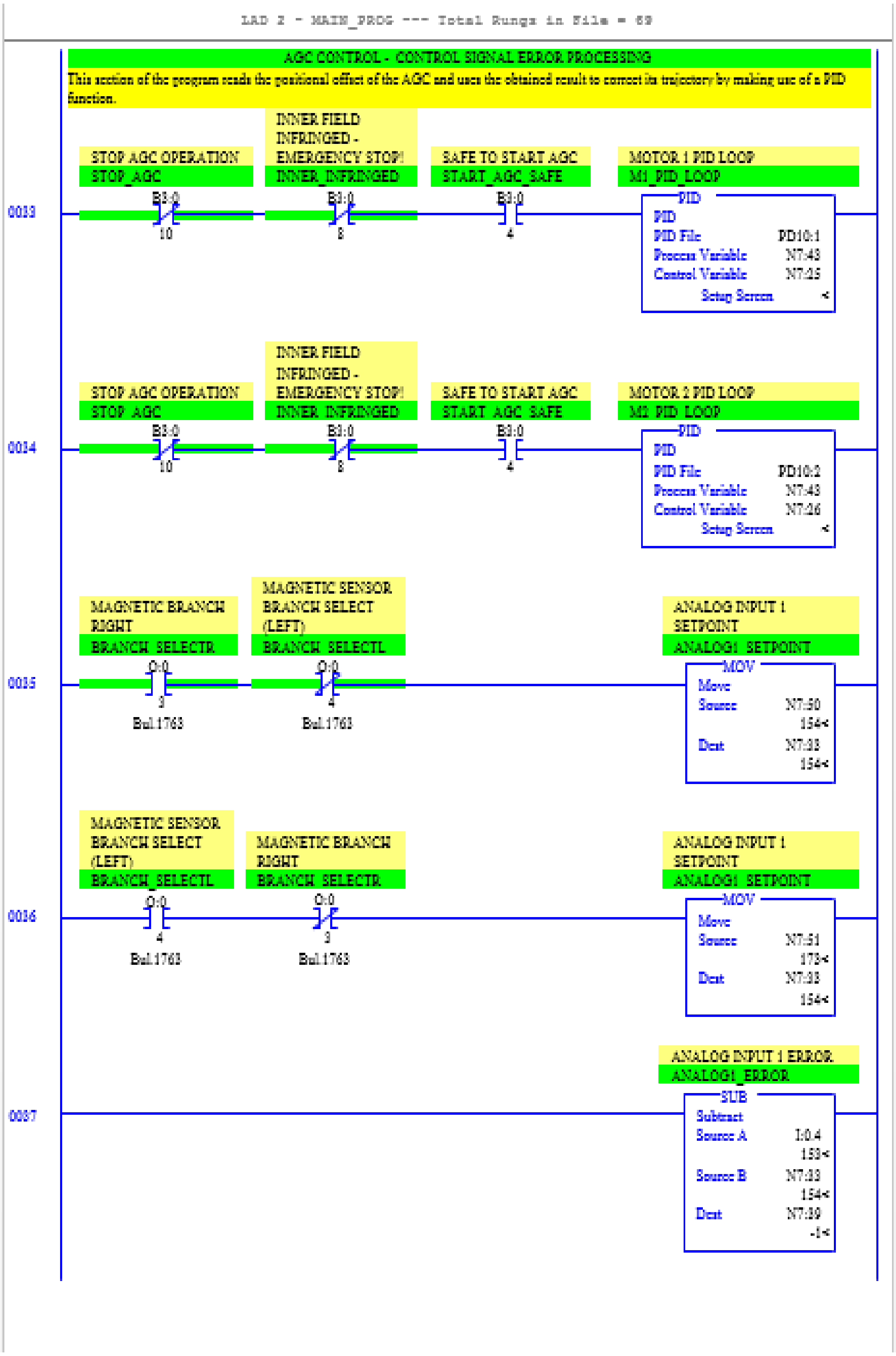

Step
Pin down
enable laser scanner
increase speed
0021
Reset Seq
SEQ_RESET/DN
T4:13
DN
Sequence Number
SEQ/DN
C5:3
DN
Seq2A
SEQ2A
B3:5
U
1
Seq 3A Done
S3_A_DONE
B3:4
U
2
Seq4A
SEQ4A
B3:5
U
3
Seq 4 Done
S4_DONE
B3:4
U
4
0022
Reset Seq
SEQ_RESET/DN
T4:13
DN
Sequence Number
SEQ/DN
C5:3
DN
Seq5A
SEQ5A
B3:5
U
4
Seq6A
SEQ6A
B3:5
U
5
Seq6A
SEQ6A
B3:5
U
5
Seq 2 Done
S2_DONE
B3:4
U
1

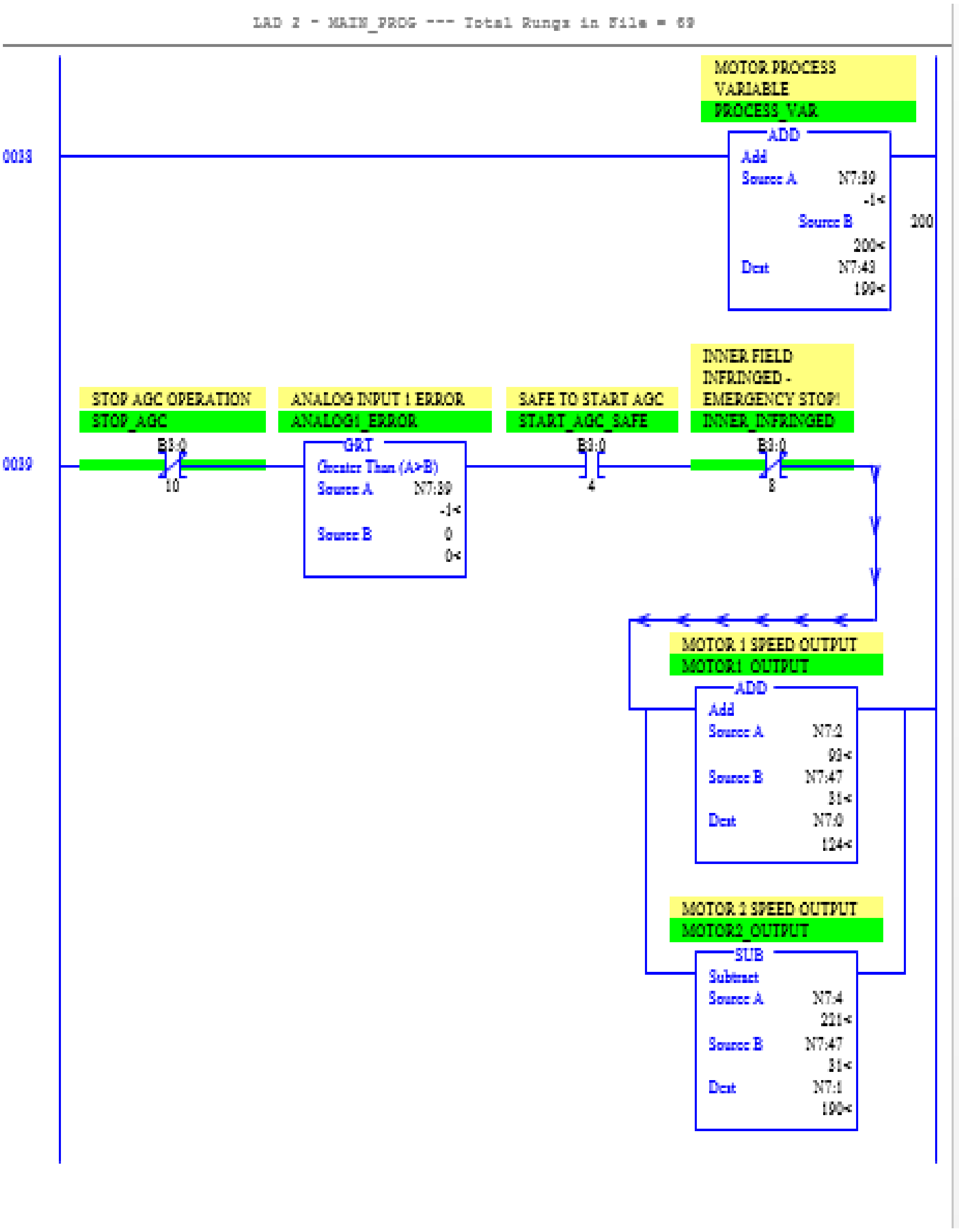

LAD 2 - MAIN_PROG --- Total Rungs in File = 69
0023
Reset Seq
SEQ_RESET/DN
T4:13
DN
Sequence Number
SEQ/DN
C5:3
DN
Seq1A
SEQ1A
B3:5
U
0
Seq2B
SEQ2B
B3:5
U
1
Seq 1 Done
S1_DONE
B3:4
U
0
Sequence Number
SEQ
C5:3
RES
0024
LHS MARKER DETECTED
LHS_MARKER_DETECT
I:1
1
1762-IQ8OW6
RHS MARKER DETECTED
RHS_MARKER_DETECT
I:1
2
1762-IQ8OW6
MAGNETIC SENSOR BRANCH SELECT (LEFT)
BRANCH_SELECTL
O:0
L
4
Bul.1763
MAGNETIC BRANCH RIGHT
BRANCH_SELECTR
O:0
U
3
Bul.1763
0025
RHS MARKER DETECTED
RHS_MARKER_DETECT
I:1
2
1762-IQ8OW6
LHS MARKER DETECTED
LHS_MARKER_DETECT
I:1
1
1762-IQ8OW6
MAGNETIC BRANCH RIGHT
BRANCH_SELECTR
O:0
L
3
Bul.1763
MAGNETIC SENSOR BRANCH SELECT (LEFT)
BRANCH_SELECTL
O:0
U
4
Bul.1763

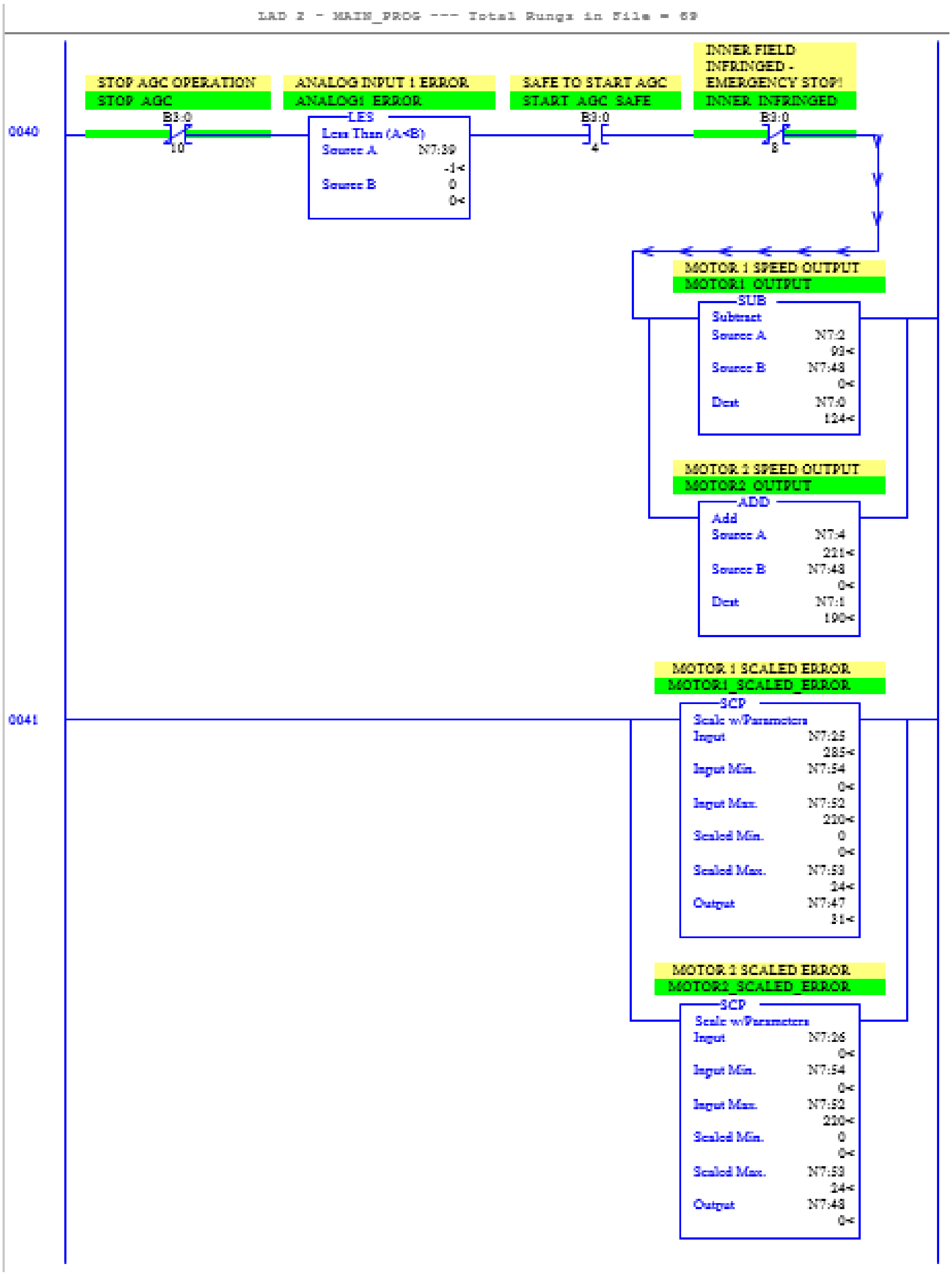

LAD 2 - MAIN_PROG --- Total Rungs in File = 69
LASER SCANNER SAFETY FIELDS
This section of the program defines the behaviour of the AGC in each of the three defined zones
0026
SAFE TO START AGC
START_AGC_SAFE
B3:0
4
LASER SCANNER ONLINE
LASERSCANNER_READY
I:0
2
Bul.1763
SAFETY ZONE - INNER FIELD
INNER_FIELD
I:0
1
Bul.1763
SAFETY ZONE - MIDDLE FIELD
MIDDLE_FIELD
I:0
3
Bul.1763
SAFETY ZONE - OUTER
OUTER_FIELD
I:0
0
Bul.1763
NO OBSTACLES DETECTED
FIELD_CLEAR
B3:0
5
0027
OUTER FIELD INFRINGED
OUTER_INFRINGED
B3:0
6
0028
MIDDLE FIELD INFRINGED
MIDDLE_INFRINGED
B3:0
7
0029
INNER FIELD INFRINGED - EMERGENCY STOP!
INNER_INFRINGED
B3:0
8

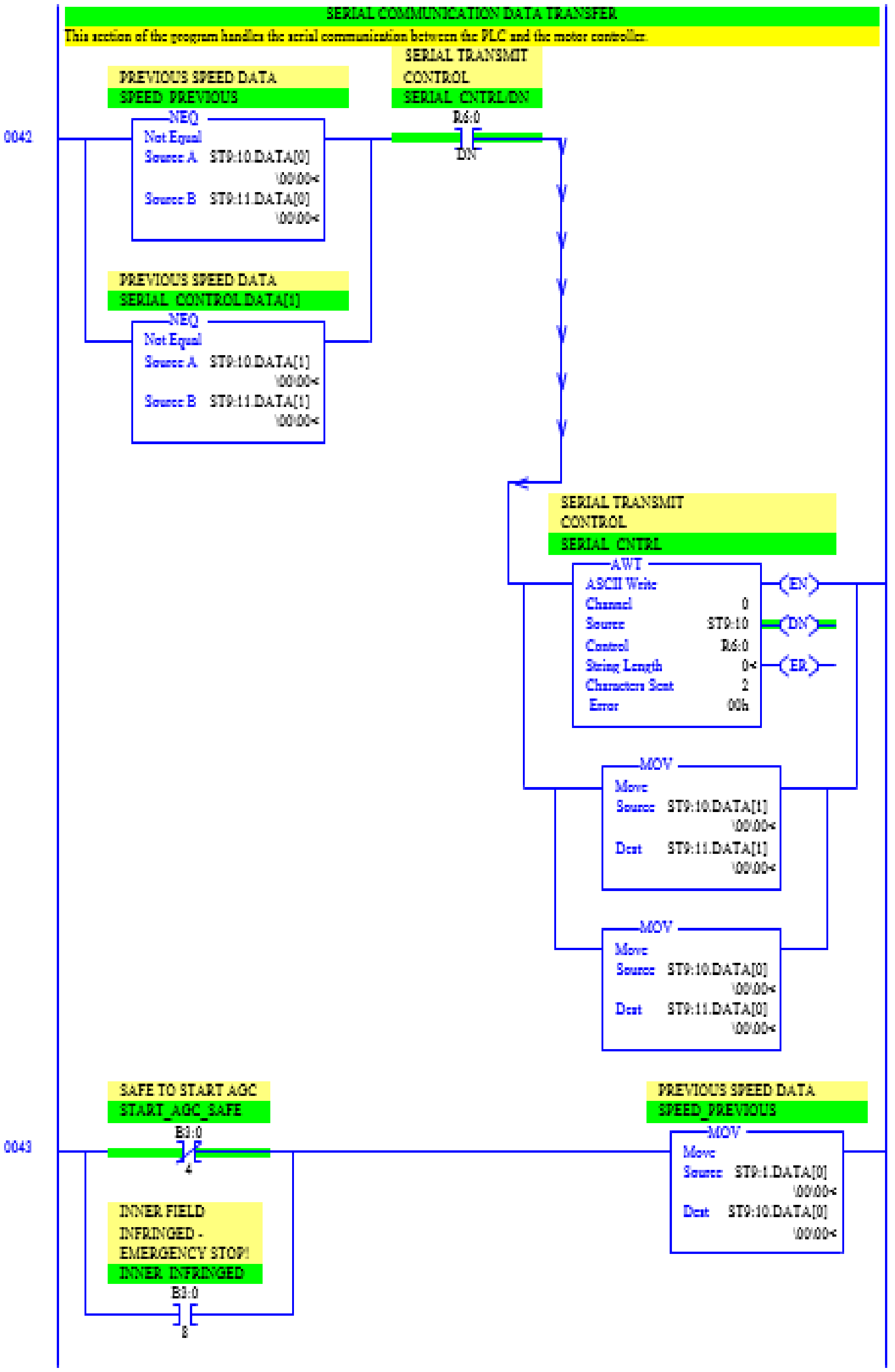

DECIMAL TO ASCII CONVERSION
This section of the program reads an integer value representing the speed of each motor. The values are converted and concatinated to produce an output signal that is understood by the motor controller. To change the speed of each motor, simply change the decimal value.
0030
INNER FIELD INFRINGED - EMERGENCY STOP!
INNER_INFRINGED
B3:0
8
STOP AGC OPERATION
STOP_AGC
B3:0
10
SAFE TO START AGC
START_AGC_SAFE
B3:0
4
MOV
Move
Source N7:0
124<
Dest ST9:5.DATA[0]
\00 <
MOV
Move
Source
2<
Dest ST9:5.LEN
2<
2
AEX
String Extract
Source ST9:7
Index 2
Number 1
Dest ST9:8
0031
STOP AGC OPERATION
STOP_AGC
B3:0
10
INNER FIELD INFRINGED - EMERGENCY STOP!
INNER_INFRINGED
B3:0
8
SAFE TO START AGC
START_AGC_SAFE
B3:0
4
MOV
Move
Source N7:1
190<
Dest ST9:7.DATA[0]
\00BB<
MOV
Move
Source
2<
Dest ST9:7.LEN
2<
2
AEX
String Extract
Source ST9:5
Index 2
Number 1
Dest ST9:6

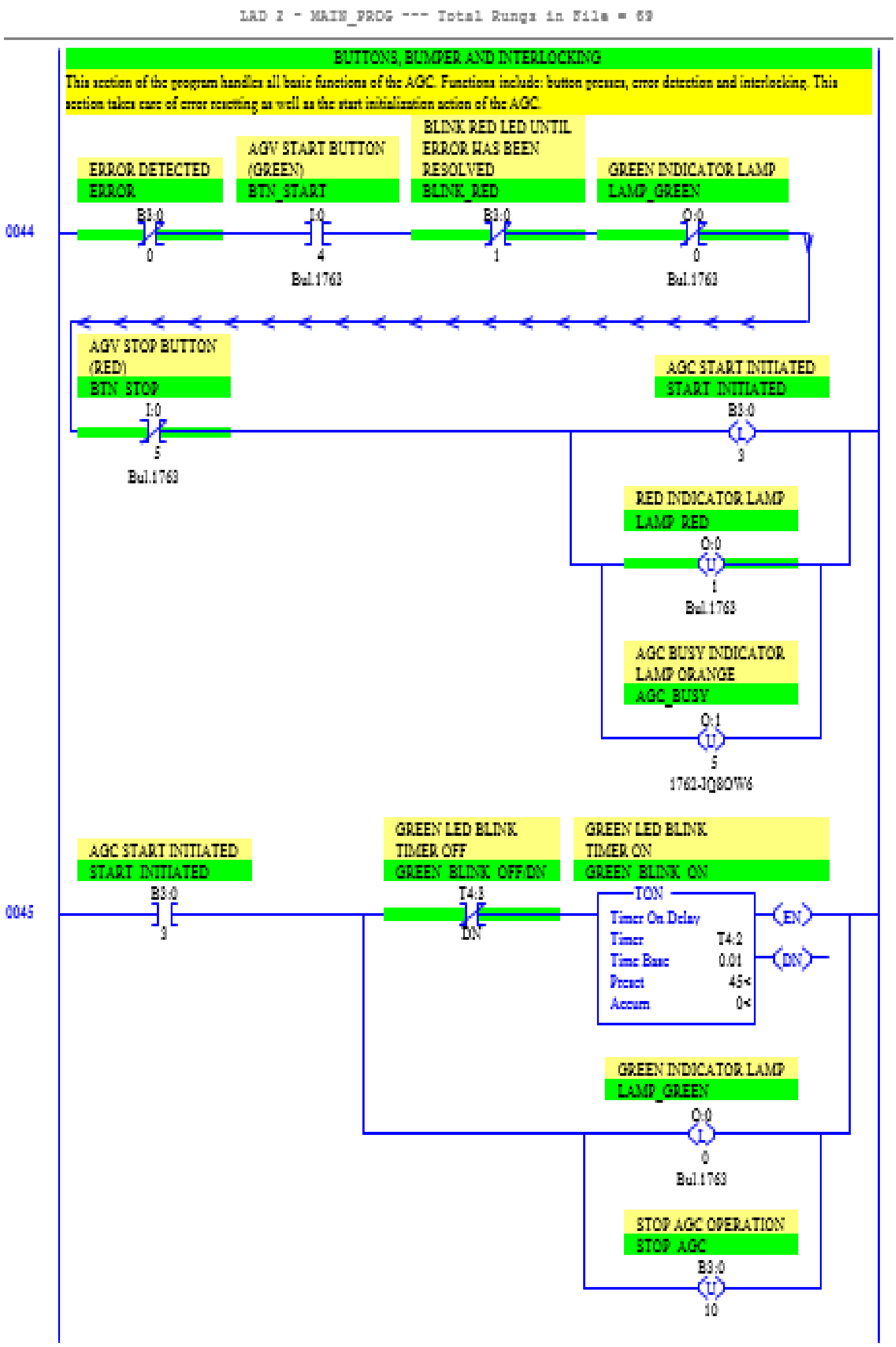

LAD 2 - MAIN_PROG --- Total Rungs in File = 69
0032
STOP AGC OPERATION
STOP AGC
B3:0
10
INNER FIELD INFRINGED - EMERGENCY STOP!
INNER INFRINGED
B3:0
8
SAFE TO START AGC
START AGC SAFE
B3:0
4
ACN
String Concatenate
Source A ST9:6
Source B ST9:8
Dest ST9:10

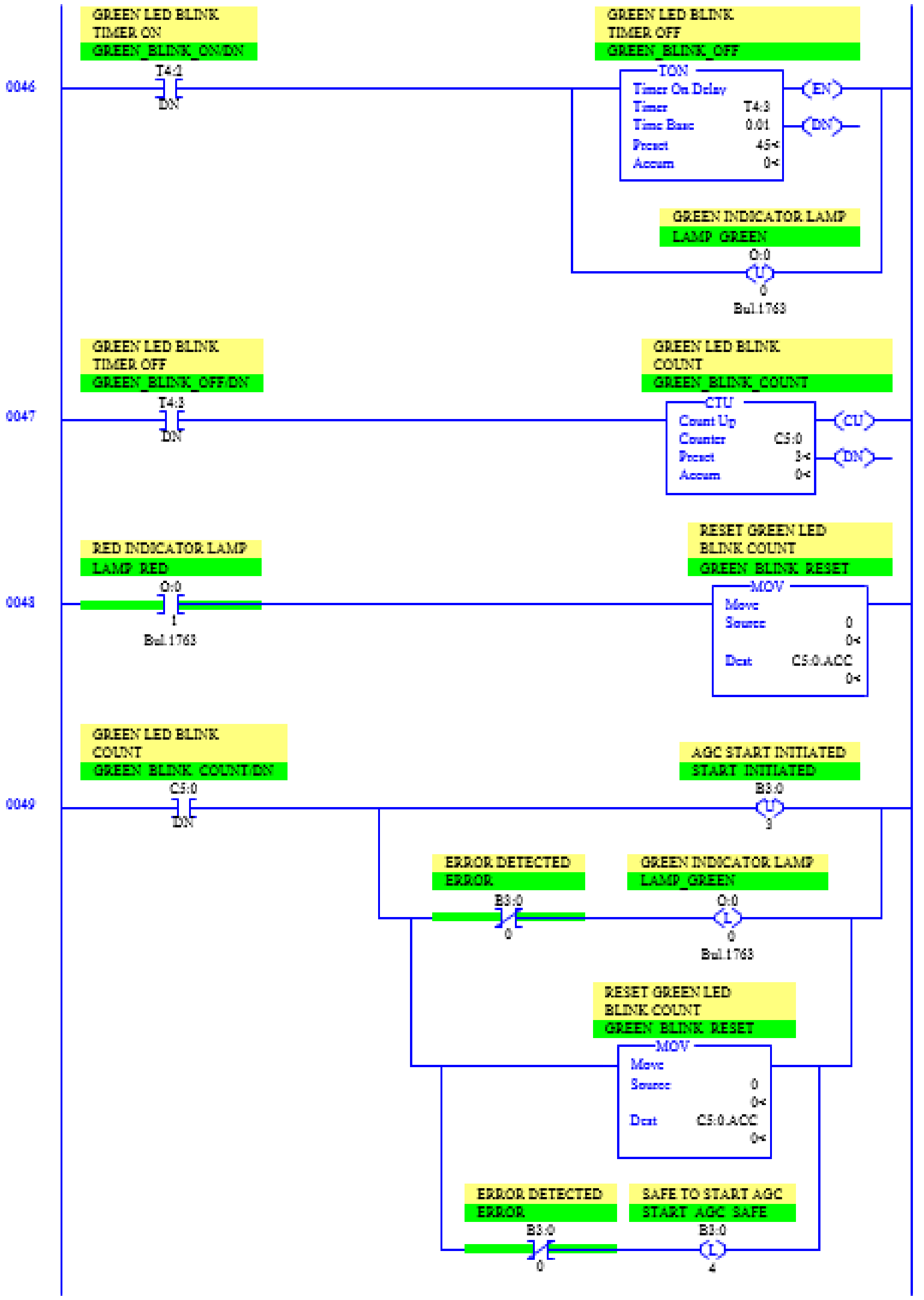

LAD 2 - MAIN_PROG --- Total Rungs in File = 69
AGC CONTROL - CONTROL SIGNAL ERROR PROCESSING
This section of the program reads the positional offset of the AGC and uses the obtained result to correct its trajectory by making use of a PID function.
0033
STOP AGC OPERATION
STOP_AGC
B3:0
10
INNER FIELD INFRINGED - EMERGENCY STOP!
INNER_INFRINGED
B3:0
8
SAFE TO START AGC
START_AGC_SAFE
B3:0
4
MOTOR 1 PID LOOP
M1_PID_LOOP
PID
PID
PID File PD10:1
Process Variable N7:43
Control Variable N7:25
Setup Screen
0034
STOP AGC OPERATION
STOP_AGC
B3:0
10
INNER FIELD INFRINGED - EMERGENCY STOP!
INNER_INFRINGED
B3:0
8
SAFE TO START AGC
START_AGC_SAFE
B3:0
4
MOTOR 2 PID LOOP
M2_PID_LOOP
PID
PID
PID File PD10:2
Process Variable N7:43
Control Variable N7:26
Setup Screen
0035
MAGNETIC BRANCH RIGHT
BRANCH_SELECTR
O:0
3
Bul.1763
MAGNETIC SENSOR BRANCH SELECT (LEFT)
BRANCH_SELECTL
O:0
4
Bul.1763
ANALOG INPUT 1 SETPOINT
ANALOG1_SETPOINT
MOV
Move
Source N7:50
154
Dest N7:33
154
0036
MAGNETIC SENSOR BRANCH SELECT (LEFT)
BRANCH_SELECTL
O:0
4
Bul.1763
MAGNETIC BRANCH RIGHT
BRANCH_SELECTR
O:0
3
Bul.1763
ANALOG INPUT 1 SETPOINT
ANALOG1_SETPOINT
MOV
Move
Source N7:51
173
Dest N7:33
154
0037
ANALOG INPUT 1 ERROR
ANALOG1_ERROR
SUB
Subtract
Source A I:0.4
153
Source B N7:33
154
Dest N7:39
-1


LAD 2 - MAIN_PROG --- Total Rungs in File = 69
0038
MOTOR PROCESS VARIABLE
PROCESS_VAR
ADD
Add
Source A N7:39
-1<
Source B 200
200<
Dest N7:43
199<
0039
STOP AGC OPERATION
STOP_AGC
B3:0
10
ANALOG INPUT 1 ERROR
ANALOG1_ERROR
GRT
Greater Than (A>B)
Source A N7:39
-1<
Source B 0
0<
SAFE TO START AGC
START_AGC_SAFE
B3:0
4
INNER FIELD INFRINGED - EMERGENCY STOP!
INNER_INFRINGED
B3:0
8
MOTOR 1 SPEED OUTPUT
MOTOR1_OUTPUT
ADD
Add
Source A N7:2
93<
Source B N7:47
31<
Dest N7:0
124<
MOTOR 2 SPEED OUTPUT
MOTOR2_OUTPUT
SUB
Subtract
Source A N7:4
221<
Source B N7:47
31<
Dest N7:1
190<


LAD 2 - MAIN_PROG --- Total Rungs in File = 69
0040
STOP AGC OPERATION
STOP_AGC
B3:0
10
ANALOG INPUT 1 ERROR
ANALOG1_ERROR
LES
Less Than (A<B)
Source A N7:39
-1<
Source B 0
0<
SAFE TO START AGC
START_AGC_SAFE
B3:0
4
INNER FIELD INFRINGED - EMERGENCY STOP!
INNER_INFRINGED
B3:0
8
MOTOR 1 SPEED OUTPUT
MOTOR1_OUTPUT
SUB
Subtract
Source A N7:2
93<
Source B N7:48
0<
Dest N7:0
124<
MOTOR 2 SPEED OUTPUT
MOTOR2_OUTPUT
ADD
Add
Source A N7:4
221<
Source B N7:48
0<
Dest N7:1
190<
0041
MOTOR 1 SCALED ERROR
MOTOR1_SCALED_ERROR
SCP
Scale w/Parameters
Input N7:25
285<
Input Min. N7:54
0<
Input Max. N7:52
220<
Scaled Min. 0
0<
Scaled Max. N7:53
24<
Output N7:47
31<
MOTOR 2 SCALED ERROR
MOTOR2_SCALED_ERROR
SCP
Scale w/Parameters
Input N7:26
0<
Input Min. N7:54
0<
Input Max. N7:52
220<
Scaled Min. 0
0<
Scaled Max. N7:53
24<
Output N7:48
0<

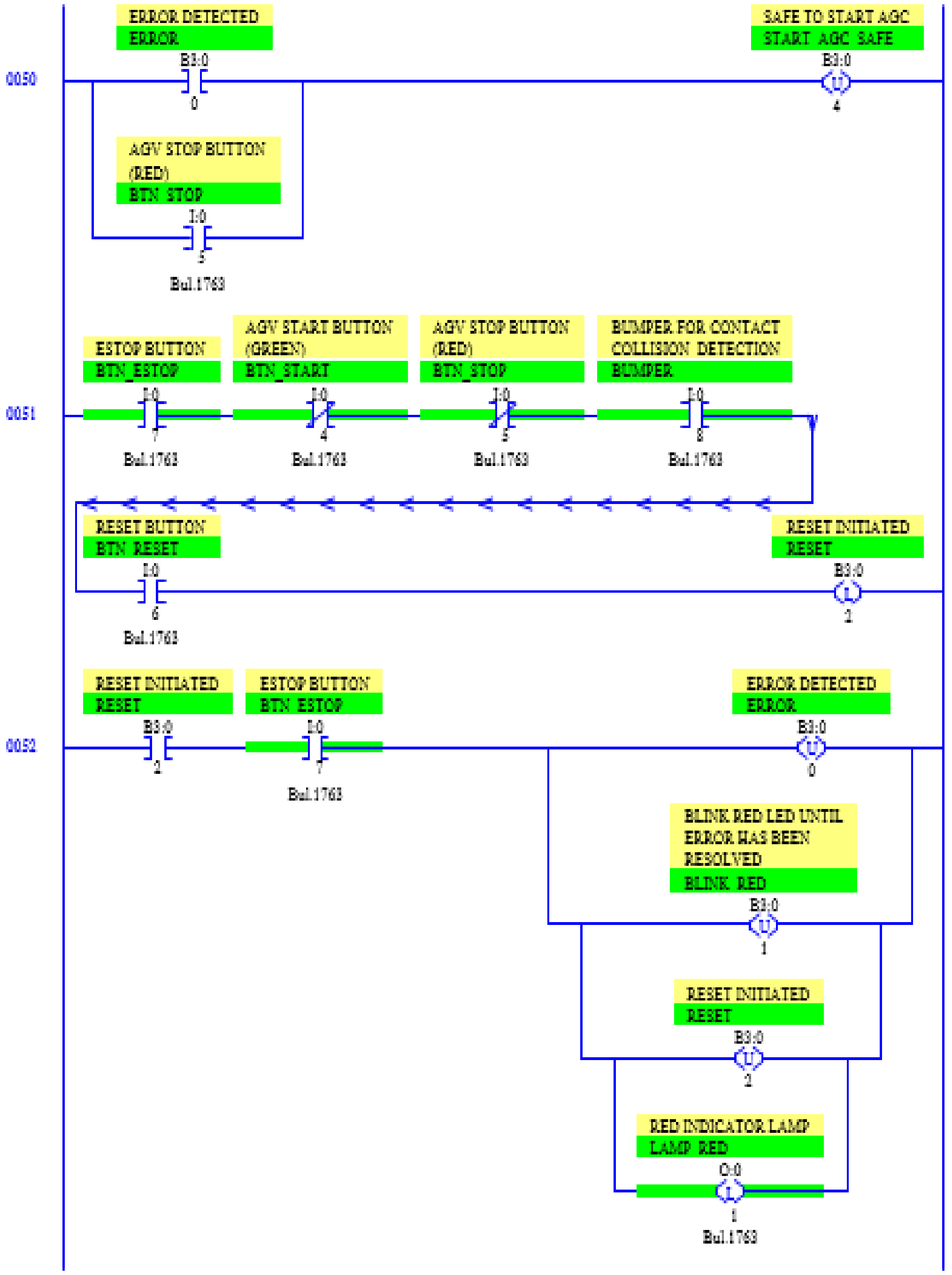

SERIAL COMMUNICATION DATA TRANSFER
This section of the program handles the serial communication between the PLC and the motor controller.
0042
PREVIOUS SPEED DATA
SPEED_PREVIOUS
NEQ
Not Equal
Source A ST9:10.DATA[0]
\00\00<
Source B ST9:11.DATA[0]
\00\00<
SERIAL TRANSMIT CONTROL
SERIAL_CNTRL/DN
R6:0
DN
PREVIOUS SPEED DATA
SERIAL_CONTROL.DATA[1]
NEQ
Not Equal
Source A ST9:10.DATA[1]
\00\00<
Source B ST9:11.DATA[1]
\00\00<
SERIAL TRANSMIT CONTROL
SERIAL_CNTRL
AWT
ASCII Write
Channel 0
Source ST9:10
Control R6:0
String Length 0<
Characters Sent 2
Error 00h
EN
DN
ER
MOV
Move
Source ST9:10.DATA[1]
\00\00<
Dest ST9:11.DATA[1]
\00\00<
MOV
Move
Source ST9:10.DATA[0]
\00\00<
Dest ST9:11.DATA[0]
\00\00<
0043
SAFE TO START AGC
START_AGC_SAFE
B3:0
4
INNER FIELD INFRINGED - EMERGENCY STOP!
INNER_INFRINGED
B3:0
8
PREVIOUS SPEED DATA
SPEED_PREVIOUS
MOV
Move
Source ST9:1.DATA[0]
\00\00<
Dest ST9:10.DATA[0]
\00\00<

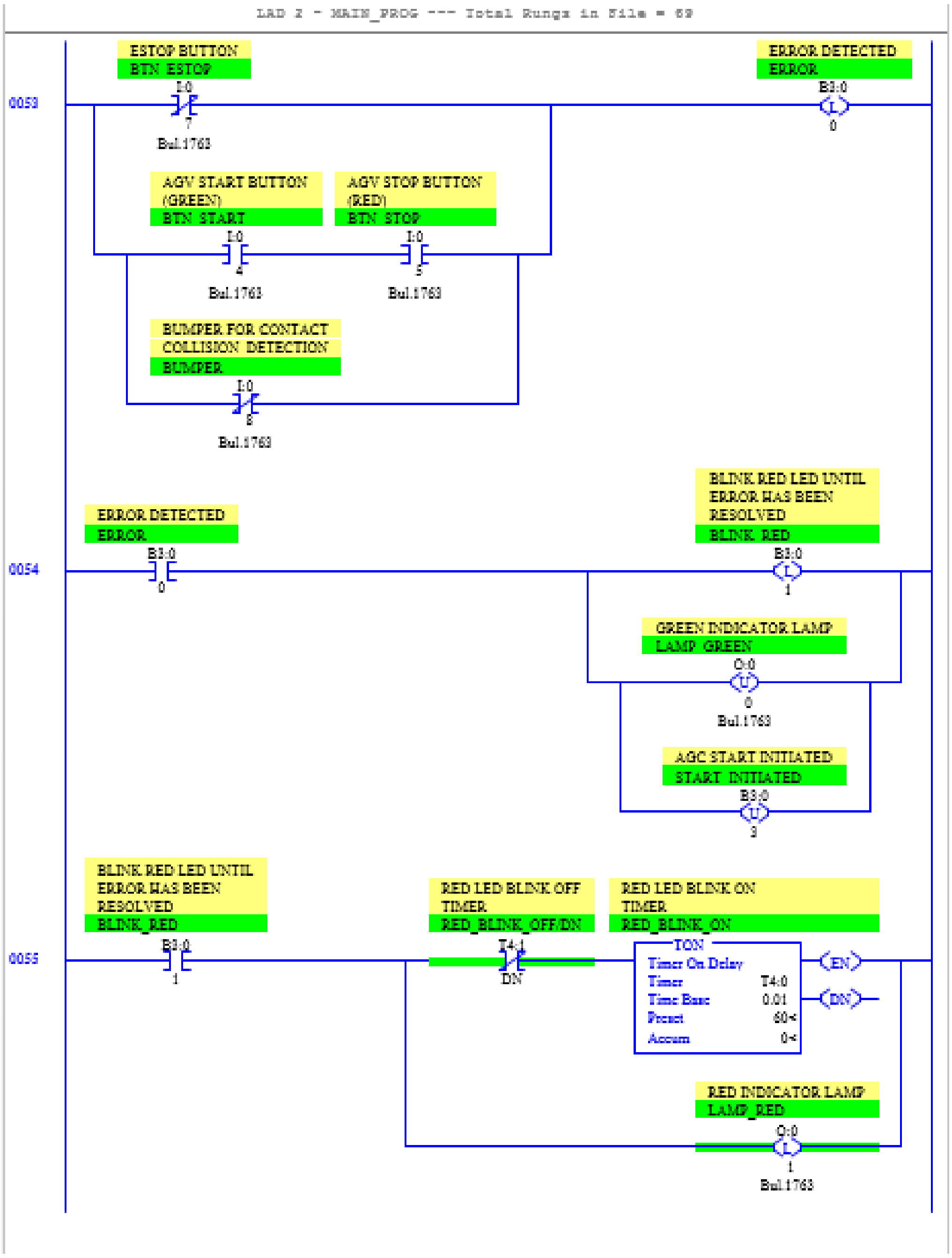

LAD 2 - MAIN_PROG --- Total Rungs in File = 69
BUTTONS, BUMPER AND INTERLOCKING
This section of the program handles all basic functions of the AGC. Functions include: button presses, error detection and interlocking. This section takes care of error resetting as well as the start initialization action of the AGC.
0044
ERROR DETECTED
ERROR
B3:0
0
AGV START BUTTON (GREEN)
BTN_START
I:0
4
Bul.1763
BLINK RED LED UNTIL ERROR HAS BEEN RESOLVED
BLINK_RED
B3:0
1
GREEN INDICATOR LAMP
LAMP_GREEN
O:0
0
Bul.1763
AGV STOP BUTTON (RED)
BTN_STOP
I:0
5
Bul.1763
AGC START INITIATED
START_INITIATED
B3:0
L
3
RED INDICATOR LAMP
LAMP_RED
O:0
U
1
Bul.1763
AGC BUSY INDICATOR LAMP ORANGE
AGC_BUSY
O:1
U
5
1762-IQ8OW6
0045
AGC START INITIATED
START_INITIATED
B3:0
3
GREEN LED BLINK TIMER OFF
GREEN_BLINK_OFF/DN
T4:3
DN
GREEN LED BLINK TIMER ON
GREEN_BLINK_ON
TON
Timer On Delay
Timer T4:2
Time Base 0.01
Preset 45<
Accum 0<
EN
DN
GREEN INDICATOR LAMP
LAMP_GREEN
O:0
L
0
Bul.1763
STOP AGC OPERATION
STOP_AGC
B3:0
U
10


0046
GREEN LED BLINK TIMER ON
GREEN_BLINK_ON/DN
T4:2
DN
GREEN LED BLINK TIMER OFF
GREEN_BLINK_OFF
TON
Timer On Delay
Timer T4:3
Time Base 0.01
Preset 45<
Accum 0<
EN
DN
GREEN INDICATOR LAMP
LAMP_GREEN
O:0
U
0
Bul.1763
0047
GREEN LED BLINK TIMER OFF
GREEN_BLINK_OFF/DN
T4:3
DN
GREEN LED BLINK COUNT
GREEN_BLINK_COUNT
CTU
Count Up
Counter C5:0
Preset 3<
Accum 0<
CU
DN
0048
RED INDICATOR LAMP
LAMP_RED
O:0
1
Bul.1763
RESET GREEN LED BLINK COUNT
GREEN_BLINK_RESET
MOV
Move
Source 0
0<
Dest C5:0.ACC
0<
0049
GREEN LED BLINK COUNT
GREEN_BLINK_COUNT/DN
C5:0
DN
AGC START INITIATED
START_INITIATED
B3:0
U
3
ERROR DETECTED
ERROR
B3:0
0
GREEN INDICATOR LAMP
LAMP_GREEN
O:0
L
0
Bul.1763
RESET GREEN LED BLINK COUNT
GREEN_BLINK_RESET
MOV
Move
Source 0
0<
Dest C5:0.ACC
0<
ERROR DETECTED
ERROR
B3:0
0
SAFE TO START AGC
START_AGC_SAFE
B3:0
L
4

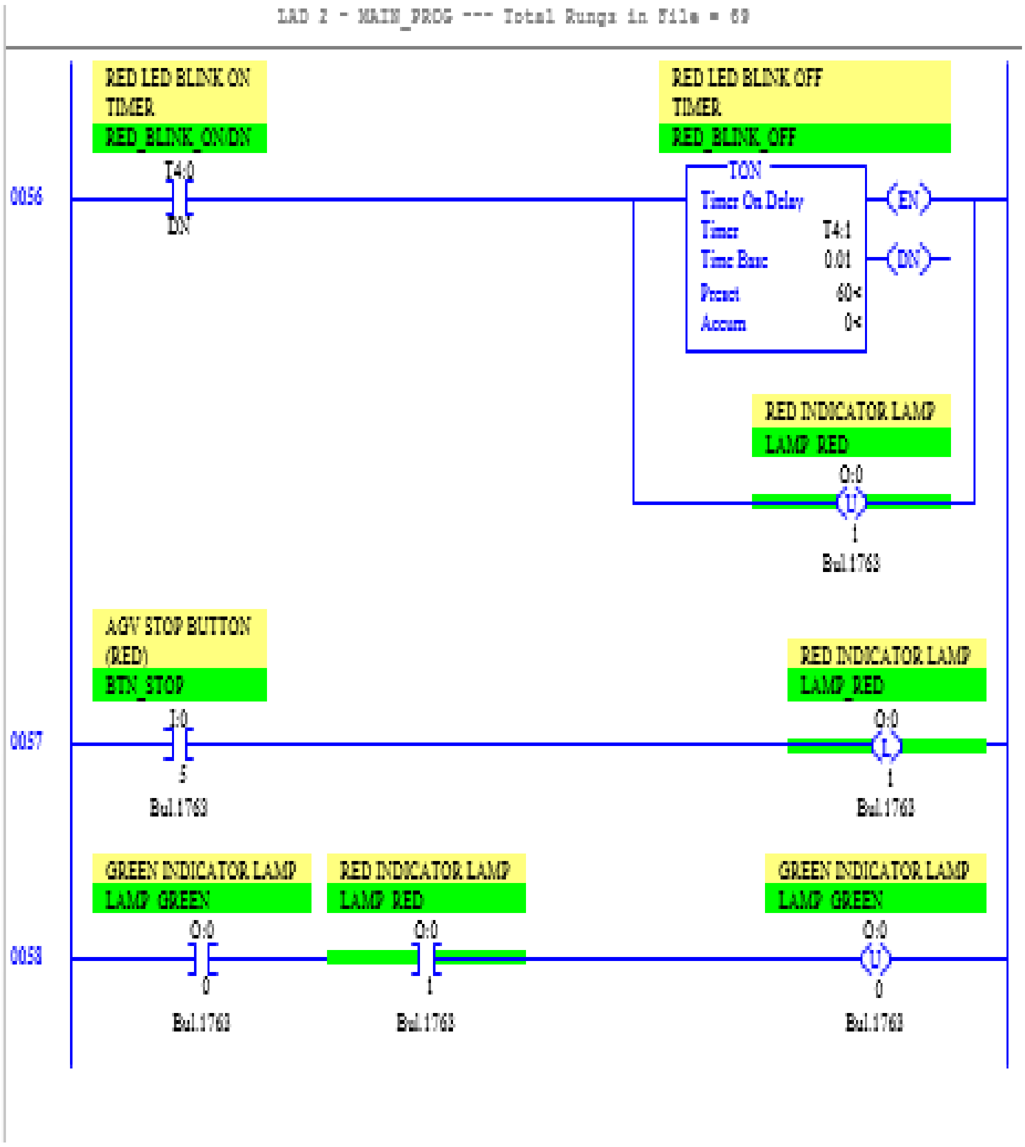
GMSA_AGV_CONTROLLER

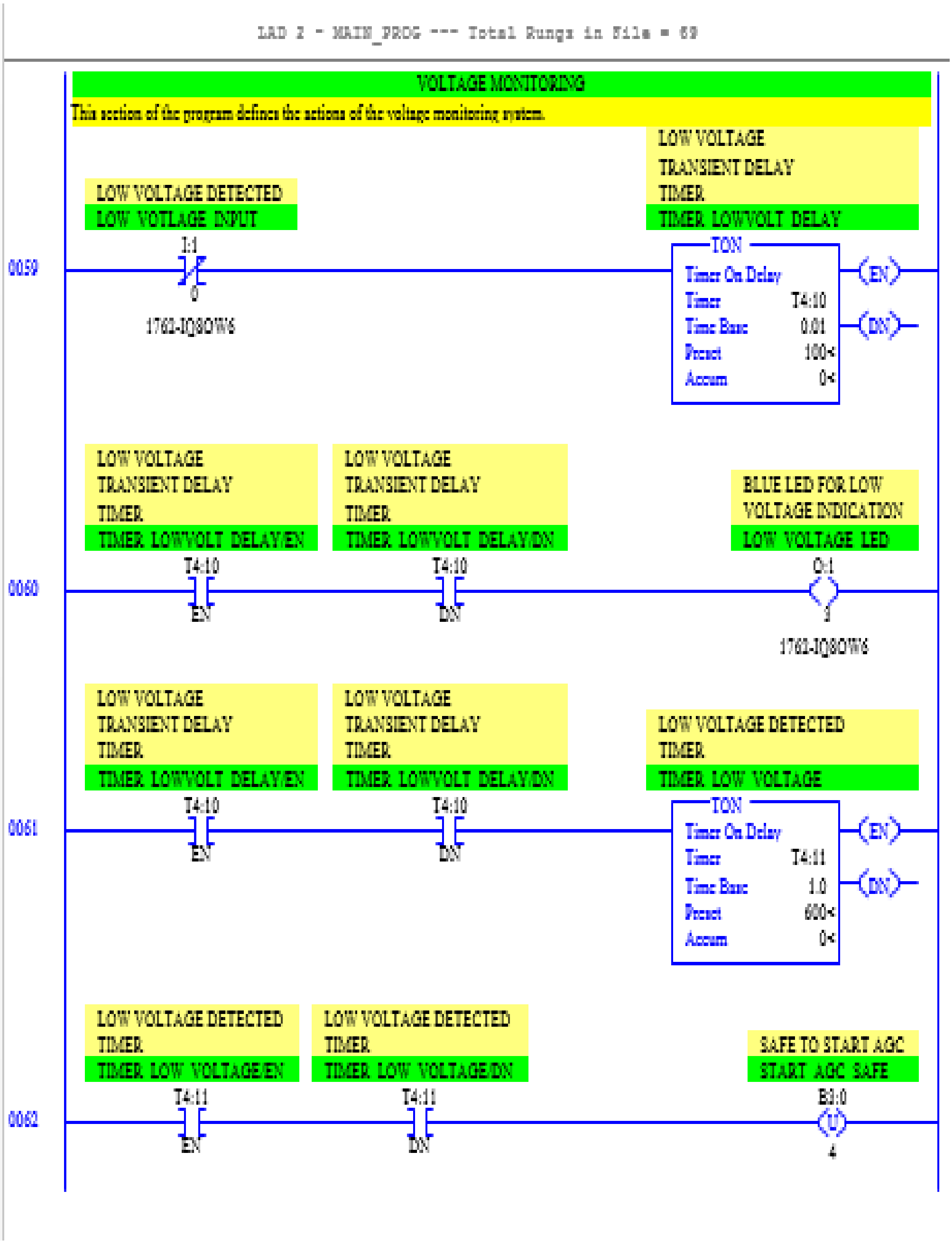
LAD 2 - MAIN_PROG --- Total Rungs in File = 69

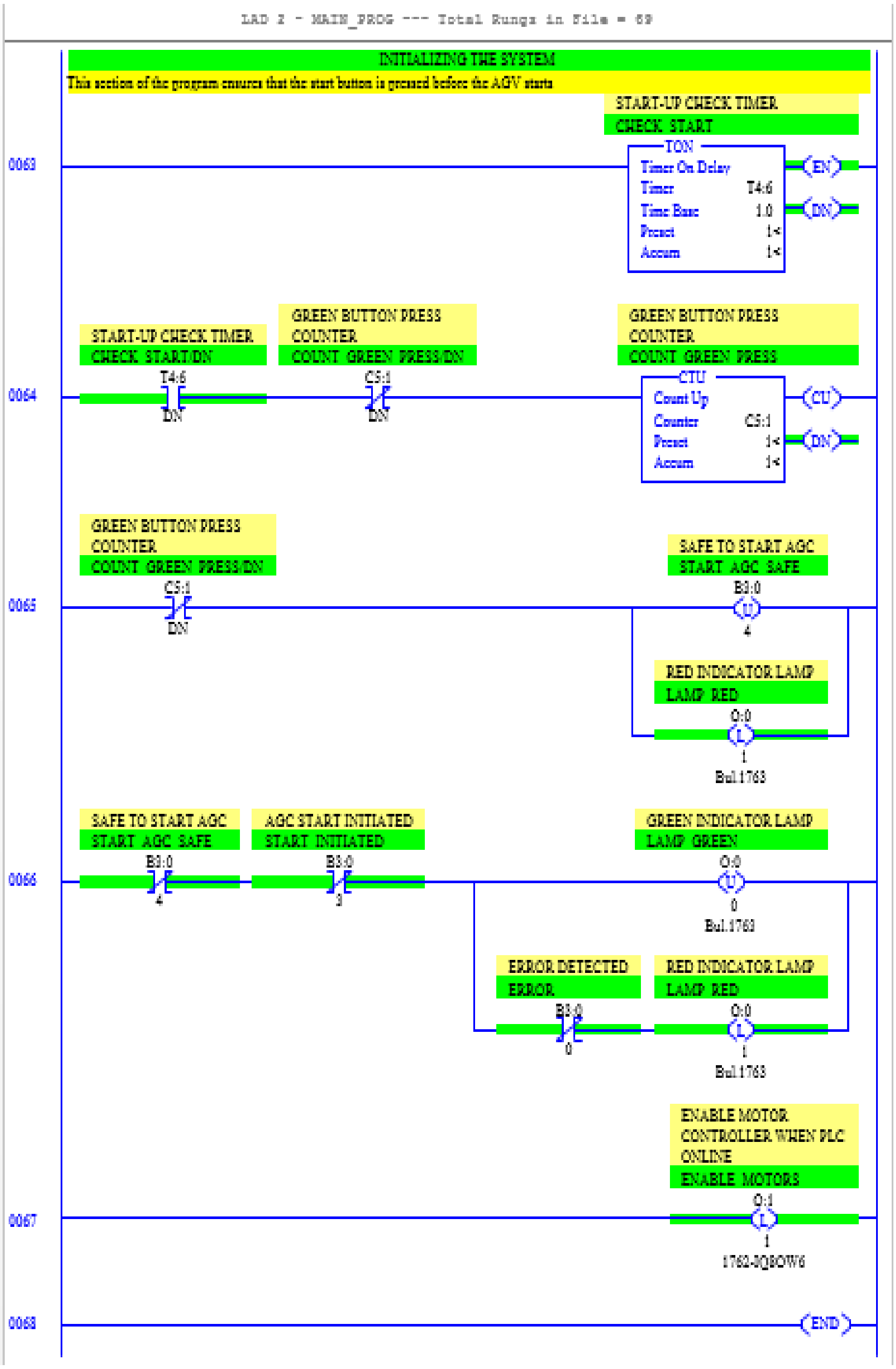




LAD 2 - MAIN_PROG --- Total Rungs in File = 69
0053
ESTOP BUTTON
BTN_ESTOP
I:0
7
Bul.1763
ERROR DETECTED
ERROR
B3:0
L
0
AGV START BUTTON (GREEN)
BTN_START
I:0
4
Bul.1763
AGV STOP BUTTON (RED)
BTN_STOP
I:0
5
Bul.1763
BUMPER FOR CONTACT COLLISION DETECTION
BUMPER
I:0
8
Bul.1763
0054
ERROR DETECTED
ERROR
B3:0
0
BLINK RED LED UNTIL ERROR HAS BEEN RESOLVED
BLINK_RED
B3:0
L
1
GREEN INDICATOR LAMP
LAMP_GREEN
O:0
U
0
Bul.1763
AGC START INITIATED
START_INITIATED
B3:0
U
3
0055
BLINK RED LED UNTIL ERROR HAS BEEN RESOLVED
BLINK_RED
B3:0
1
RED LED BLINK OFF TIMER
RED_BLINK_OFF/DN
T4:1
DN
RED LED BLINK ON TIMER
RED_BLINK_ON
TON
Timer On Delay
Timer T4:0
Time Base 0.01
Preset 60<
Accum 0<
EN
DN
RED INDICATOR LAMP
LAMP_RED
O:0
L
1
Bul.1763


LAD 2 - MAIN_PROG --- Total Rungs in File = 69
RED LED BLINK ON TIMER
RED_BLINK_ON/DN
T4:0
DN
0056
RED LED BLINK OFF TIMER
RED_BLINK_OFF
TON
Timer On Delay
Timer T4:1
Time Base 0.01
Preset 60<
Accum 0<
EN
DN
RED INDICATOR LAMP
LAMP_RED
O:0
U
1
Bul.1763
AGV STOP BUTTON (RED)
BTN_STOP
I:0
5
Bul.1763
0057
RED INDICATOR LAMP
LAMP_RED
O:0
L
1
Bul.1763
GREEN INDICATOR LAMP
LAMP_GREEN
O:0
0
Bul.1763
0058
RED INDICATOR LAMP
LAMP_RED
O:0
1
Bul.1763
GREEN INDICATOR LAMP
LAMP_GREEN
O:0
U
0
Bul.1763


LAD 2 - MAIN_PROG --- Total Rungs in File = 69
VOLTAGE MONITORING
This section of the program defines the actions of the voltage monitoring system.
0059
LOW VOLTAGE DETECTED
LOW VOTLAGE INPUT
I:1
0
1762-IQ8OW6
LOW VOLTAGE TRANSIENT DELAY TIMER
TIMER LOWVOLT DELAY
TON
Timer On Delay
Timer T4:10
Time Base 0.01
Preset 100<
Accum 0<
EN
DN
0060
LOW VOLTAGE TRANSIENT DELAY TIMER
TIMER LOWVOLT DELAY/EN
T4:10
EN
LOW VOLTAGE TRANSIENT DELAY TIMER
TIMER LOWVOLT DELAY/DN
T4:10
DN
BLUE LED FOR LOW VOLTAGE INDICATION
LOW VOLTAGE LED
O:1
1
1762-IQ8OW6
0061
LOW VOLTAGE TRANSIENT DELAY TIMER
TIMER LOWVOLT DELAY/EN
T4:10
EN
LOW VOLTAGE TRANSIENT DELAY TIMER
TIMER LOWVOLT DELAY/DN
T4:10
DN
LOW VOLTAGE DETECTED TIMER
TIMER LOW VOLTAGE
TON
Timer On Delay
Timer T4:11
Time Base 1.0
Preset 600<
Accum 0<
EN
DN
0062
LOW VOLTAGE DETECTED TIMER
TIMER LOW VOLTAGE/EN
T4:11
EN
LOW VOLTAGE DETECTED TIMER
TIMER LOW VOLTAGE/DN
T4:11
DN
SAFE TO START AGC
START AGC SAFE
B3:0
U
4


LAD 2 - MAIN_PROG --- Total Rungs in File = 69
INITIALIZING THE SYSTEM
This section of the program ensures that the start button is pressed before the AGV starts
START-UP CHECK TIMER
CHECK_START
0063
TON
Timer On Delay
Timer T4:6
Time Base 1.0
Preset 1<
Accum 1<
EN
DN
0064
START-UP CHECK TIMER
CHECK_START/DN
T4:6
DN
GREEN BUTTON PRESS COUNTER
COUNT_GREEN_PRESS/DN
C5:1
DN
GREEN BUTTON PRESS COUNTER
COUNT_GREEN_PRESS
CTU
Count Up
Counter C5:1
Preset 1<
Accum 1<
CU
DN
0065
GREEN BUTTON PRESS COUNTER
COUNT_GREEN_PRESS/DN
C5:1
DN
SAFE TO START AGC
START_AGC_SAFE
B3:0
U
4
RED INDICATOR LAMP
LAMP_RED
O:0
L
1
Bul.1763
0066
SAFE TO START AGC
START_AGC_SAFE
B3:0
4
AGC START INITIATED
START_INITIATED
B3:0
3
GREEN INDICATOR LAMP
LAMP_GREEN
O:0
U
0
Bul.1763
ERROR DETECTED
ERROR
B3:0
0
RED INDICATOR LAMP
LAMP_RED
O:0
L
1
Bul.1763
0067
ENABLE MOTOR CONTROLLER WHEN PLC ONLINE
ENABLE_MOTORS
O:1
L
1
1762-IQ8OW6
0068
END

Data File O0 (bin) -- OUTPUT

Offset	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	
O:0.0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	Bul.1763 MicroLogix 1100 Series B
O:0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Bul.1763 MicroLogix 1100 Series B
O:0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Bul.1763 MicroLogix 1100 Series B
O:0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Bul.1763 MicroLogix 1100 Series B
O:1.0											0	0	0	0	1	0	1762-IQ8OW6 - 8-Input 10/30 VDC 6-Output

Data File I1 (bin) -- INPUT

Offset	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0		
I:0.0	0	0	0	0	0	0	0	1	1	0	0	0	1	1	1	1	Bul.1763	MicroLogix 1100 Series B
I:0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Bul.1763	MicroLogix 1100 Series B
I:0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Bul.1763	MicroLogix 1100 Series B
I:0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Bul.1763	MicroLogix 1100 Series B
I:0.4	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0	1	Bul.1763	MicroLogix 1100 Series B-Anal
I:0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	Bul.1763	MicroLogix 1100 Series B-Anal
I:1.0									0	0	0	0	0	0	0	1	1762-IQ8OW6 - 8-Input 10/30 VDC 6-Output (	

Data File S2 (hex) -- STATUS

Main

Processor Mode S:1/0 - S:1/4 = Remote Run
On Power up Go To Run (Mode Behavior) S:1/12 = 0
First Pass S:1/15 = No
Free Running Clock S:4 = 0110-1101-0010-0100

Proc

OS Catalog Number S:57 = 1100
OS Series S:58 = B
OS FRS S:59 =
Processor Catalog Number S:60 =
Processor Series S:61 = B
Processor FRN S:62 =

User Program Type S:63 = 8108h
Compiler Revision Number S:64 =

Scan Times

Maximum (x10 ms) S:22 = 40
Watchdog (x10 ms) S:3 (high byte) = 10
Last 100 uSec Scan Time S:35 = 23
Scan Toggle Bit S:33/9 = 1

Math

Math Overflow Selected S:2/14 = 0
Overflow Trap S:5/0 = 0
Carry S:0/0 = 0
Overflow S:0/1 = 0
Zero Bit S:0/2 = 1
Sign Bit S:0/3 = 0

Math Register (lo word) S:13 = 0
Math Register (high word) S:14-S:13 = 0
Math Register (32 Bit) S:14-S:13 = 0

Chan 0

Processor Mode S:1/0- S:1/4 = Remote Run
Node Address S:15 (low byte) = 0
Baud Rate S:15 (high byte) = 7
Channel Mode S:33/3 = 0
Comms Active S:33/4 = 0
Incoming Cmd Pending S:33/0 = 0
Msg Reply Pending S:33/1 = 0

Outgoing Msg Cmd Pending S:33/2 = 0

Debug

Suspend Code S:7 = 0
Suspend File S:8 = 0

Errors

Fault Override At Power Up S:1/8 = 0
Startup Protection Fault S:1/9 = 0
Major Error Halt S:1/13 = 0
Overflow Trap S:5/0 = 0
Control Register Error S:5/2 = 0
Major Error Executing User Fault Rtn. S:5/3 = 0
Battery Low S:5/11 = 0
Input Filter Selection Modified S:5/13 = 0
ASCII String Manipulation error S:5/15 = 0

Fault Routine S:29 = 0
Major Error S:6 = 0h
Error Description:

Protection

Deny Future Access S:1/14 = No
Data File Overwrite Protection Lost S:36/10 = False

Mem Module

Memory Module Loaded On Boot S:5/8 = 0
Password Mismatch S:5/9 = 0
Load Memory Module On Memory Error S:1/10 = 0
Load Memory Module Always S:1/11 = 0
On Power up Go To Run (Mode Behavior) S:1/12 = 0
Program Compare S:2/9 = 0
Data File Overwrite Protection Lost S:36/10 = 0

Forces

Forces Enabled S:1/5 = Yes
Forces Installed S:1/6 = No

Data File B3 (bin) -- BINARY

Offset	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	(Symbol)	Description
B3:0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
B3:1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
B3:2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0		
B3:3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
B3:4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0		
B3:5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0		

Data File T4 -- TIMER

Offset	EN	TT	DN	BASE	PRE	ACC	(Symbol) Description
T4:0	0	0	0	.01 sec	60	0	(RED_BLINK_ON) RED LED BLINK ON TIMER
T4:1	0	0	0	.01 sec	60	0	(RED_BLINK_OFF) RED LED BLINK OFF TIMER
T4:2	0	0	0	.01 sec	45	0	(GREEN_BLINK_ON) GREEN LED BLINK TIMER ON
T4:3	0	0	0	.01 sec	45	0	(GREEN_BLINK_OFF) GREEN LED BLINK TIMER OFF
T4:4	0	0	0	.01 sec	0	0	
T4:5	0	0	0	.01 sec	0	0	
T4:6	1	0	1	1.0 sec	1	1	(CHECK_START) START-UP CHECK TIMER
T4:7	0	0	0	.01 sec	70	0	(TIMER_TRACK_LOST) TRACK LOST TIMER
T4:8	0	0	0	.01 sec	0	0	
T4:9	0	0	0	.01 sec	0	0	
T4:10	0	0	0	.01 sec	100	0	(TIMER_LOWVOLT_DELAY) LOW VOLTAGE TRANSIENT DELAY TIMER
T4:11	0	0	0	1.0 sec	600	0	(TIMER_LOW_VOLTAGE) LOW VOLTAGE DETECTED TIMER
T4:12	0	0	0	1.0 sec	4	0	(TIMER_STOP_OPERATION) STOP AGC OPERATION TIMER
T4:13	0	0	0	1.0 sec	1	0	(SEQ_RESET) Reset Seq
T4:14	0	0	0	1.0 sec	1	0	(STOPTIMERRESET) Reset stop timer
T4:15	0	0	0	.01 sec	100	0	(DELAY) Delay

Data File C5 -- COUNTER

Offset	CU	CD	DN	OV	UN	UA	PRE	ACC	(Symbol) Description
C5:0	0	0	0	0	0	0	3	0	(GREEN_BLINK_COUNT) GREEN LED BLINK COUNT
C5:1	0	0	1	0	0	0	1	1	(COUNT_GREEN_PRESS) GREEN BUTTON PRESS COUNTER
C5:2	0	0	1	0	0	0	0	0	(RHS_MARK_COUNT) RHS MARKER DETECT COUNTER
C5:3	0	0	0	0	0	0	7	2	(SEQ) Sequence Number

Data File R6 -- CONTROL

Offset	EN	EU	DN	EM	ER	UL	IN	FD	LEN	POS	(Symbol) Description
R6:0	0	0	1	0	0	0	0	0	0	2	(SERIAL_CNTRL) SERIAL TRANSMIT CONTROL

Data File N7 (dec) -- INTEGER

Offset	0	1	2	3	4	5	6	7	8	9
N7:0	124	190	93	-3	221	-1	-2	0	60	180
N7:10	55	183	52	180	90	10	-9	3	7	-4
N7:20	93	221	87	215	218	285	0	-5	205	31
N7:30	99	410	123	154	100	-95	8	3	1	-1
N7:40	3	2	1	199	227	-11	-8	31	0	0
N7:50	154	173	220	24	0	35	35	2		

Data File F8 -- FLOAT

Offset	0	1	2	3	4
F8:0	0				

Data File ST9 -- STRING

Offset	LEN	String Text	(Symbol)	Description
ST9:0	2	\00\00		
ST9:1	1	\00		
ST9:2	2	,\AC		
ST9:3	0			
ST9:4	0			
ST9:5	2	\00		
ST9:6	1			
ST9:7	2	\00\BB		
ST9:8	1	\BB		
ST9:9	0			
ST9:10	2	\00\00		
ST9:11	2	\00\00		

Data File PD10 -- PID

Offset	TM	AM	CM	OL	RG	SC	TF	DA	DB	UL	LL	SP	PV	DN	EN	SPS	KC	Ti	TD	MAXS	MINS	ZC
PD10:0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
PD10:1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	200	49	12	1	0	0	
PD10:2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	200	49	12	1	0	0	

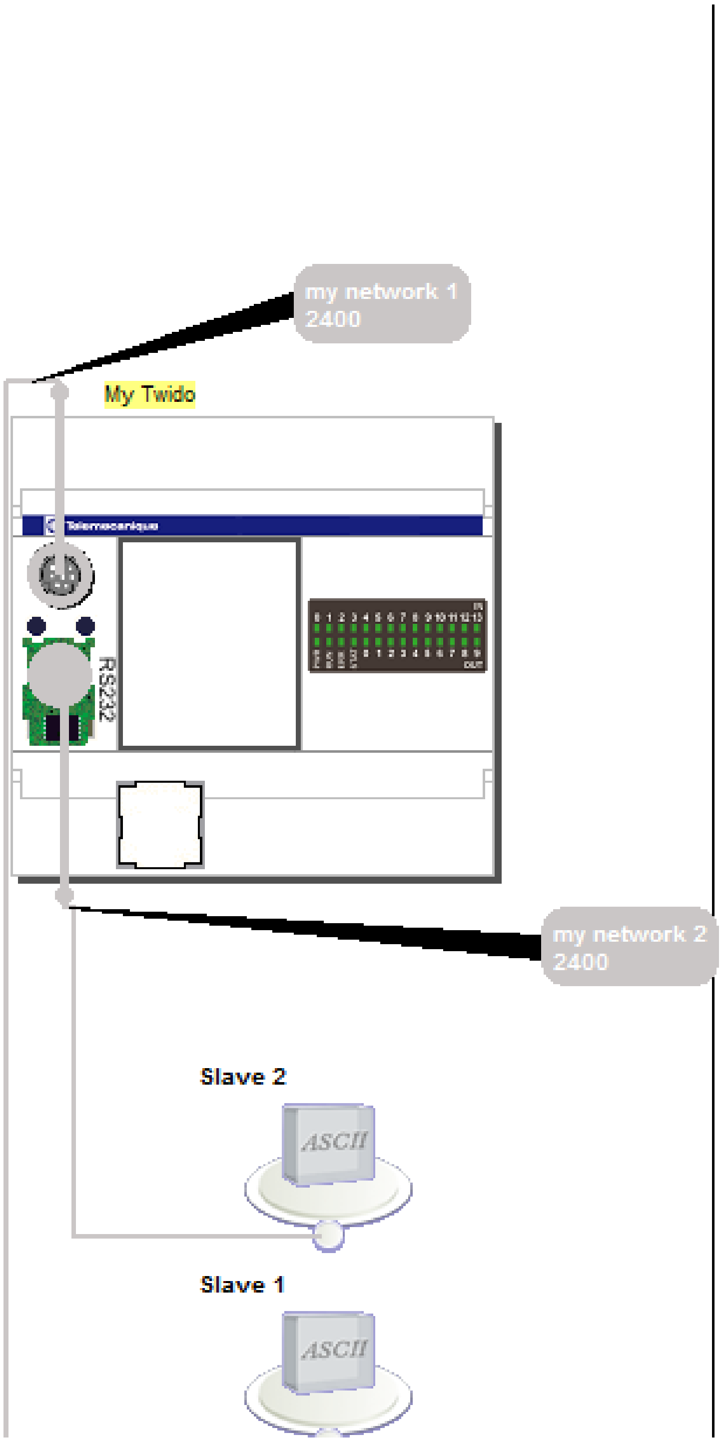
Report
PID_Improvements_AGC

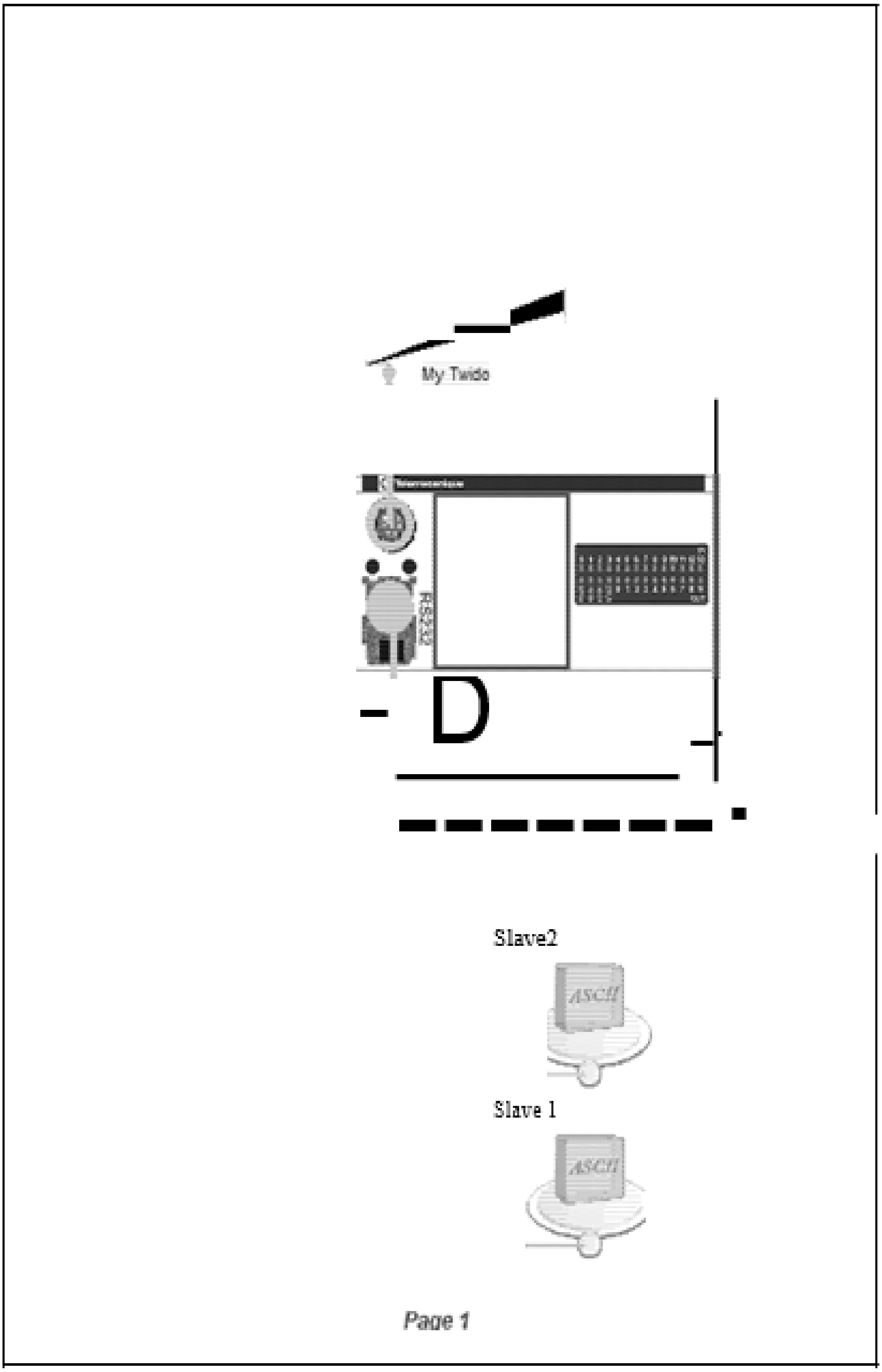
Project Information

Print date	06/03/2013
Author	Tremaine
Department	Mechatronics
Index	
Industrial Property	

Comment

Contents


my network 1
2400
My Twido
RS232
my network 2
2400
Slave 2
ASCII
Slave 1
ASCII


My Twido
RS232
D
Slave2
ASCII
Slave 1
ASCII
Page 1

Bill of material

Family	Reference number	Quantity
Twido	TWDLC-A24DRF	1
Twido	TWDNAC232D	1
ASCII elements	Generic Ascii element	2

Hardware configuration

Base

TWDLC-A24DRF

Memory objects configuration

Timer configuration (%TM)

Used	%TM	Symbol	Type	Adjustable	Time Base	Preset
Yes	%TM0		TON	Yes	1 s	2
Yes	%TM1		TON	Yes	100 ms	3
Yes	%TM2		TON	Yes	100 ms	3
Yes	%TM3		TON	Yes	100 ms	25
Yes	%TM4		TON	Yes	100 ms	3
Yes	%TM5		TON	Yes	100 ms	3

Counter configuration (%C)

Register configuration (%R)

Drum configuration (%DR)

Scheduler block configuration (%SCH)

Fast counters configuration (%FC)

Very fast counters configuration (%VFC)

Memory words (%MD)

Memory words (%MW)

Used	%MW	Symbol	Allocated
Yes	%MW2		Yes
Yes	%MW10		Yes
Yes	%MW11		Yes
Yes	%MW12		Yes
Yes	%MW14		Yes
Yes	%MW15		Yes
Yes	%MW16		Yes
Yes	%MW17		Yes
Yes	%MW18		Yes
Yes	%MW19		Yes
Yes	%MW40		Yes
Yes	%MW41		Yes
Yes	%MW50		Yes
Yes	%MW51		Yes

Memory words (%MF)

Memory bits (%M)

Used	%M	Symbol	Allocated
Yes	%M0		Yes
Yes	%M1		Yes
Yes	%M4		Yes
Yes	%M5		Yes
Yes	%M6		Yes
Yes	%M7		Yes
Yes	%M8		Yes
Yes	%M9		Yes
Yes	%M10		Yes
Yes	%M11		Yes
Yes	%M12		Yes
Yes	%M13		Yes

Used	%M	Symbol	Allocated
Yes	%M15		Yes
Yes	%M20		Yes
Yes	%M21		Yes

PID configuration (PID)

PID 0 : configured

General			
Operating mode : PID			
PID Status : Inhibit			
Input			
Measure : %MW40			
Conversion : Inhibit	Min :	Max :	
Alarms : Inhibit	Low :	Output :	
	High :	Output :	
PID			
Setpoint : 0			
Kp : %MW14	Ti : %MW15	Td : %MW16	
Sampling Period : 100			
AT			
AT mode : Inhibit	Limit :	Output :	
Output			
Action : Direct			
Limits : Allow	Min : 1	Max : 63	
Manual mode : Inhibit	Output :		
Output analog : %MW50			
PWM : Inhibit	Period :	Output :	

PID 1 : configured

General			
Operating mode : PID			
PID Status : Inhibit			
Input			
Measure : %MW41			
Conversion : Inhibit	Min :	Max :	
Alarms : Inhibit	Low :	Output :	
	High :	Output :	
PID			
Setpoint : 0			
Kp : %MW17	Ti : %MW18	Td : %MW19	
Sampling Period : 100			
AT			
AT mode : Inhibit	Limit :	Output :	
Output			
Action : Direct			
Limits : Allow	Min : 1	Max : 63	
Manual mode : Inhibit	Output :		
Output analog : %MW51			
PWM : Inhibit	Period :	Output :	

Constant configuration (%KD)

Constant configuration (%KW)

Configuration of external objects Comm

Configuration of external objects Drive

Configuration of external objects Tesys

Configuration of external objects Advantys OTB

Memory

Memory usage statistic

User data			
Memory bits	:	22 Bits	0.1%
Memory words	:	52 Words	1.5%
Backed up	:	52 Words	
RAM = EEPROM	:	Yes	
Constants	:	0 Words	0.0%
Configuration	:	551 Words	16.0%
Avail. mem. data	:	2755 Words	79.8%

User program			
Executable code	:	549 Words	3.4%
Prog. data	:	4 Words	0.1%
Online modif.	:	28 Words	0.2%
Avail. code mem.	:	15808 Words	96.4%

Other			
Execution data	:	85 Words	2.5%

Configure the behavior

Functional levels

Functional levels management

Management :	Automatic
Level :	The highest possible

Scan mode

Scan mode

Mode :	Normal
Duration (ms) :	-

Watchdog

Duration (ms) :	250

Periodic event

Not used :	Yes

Startup

Parameters

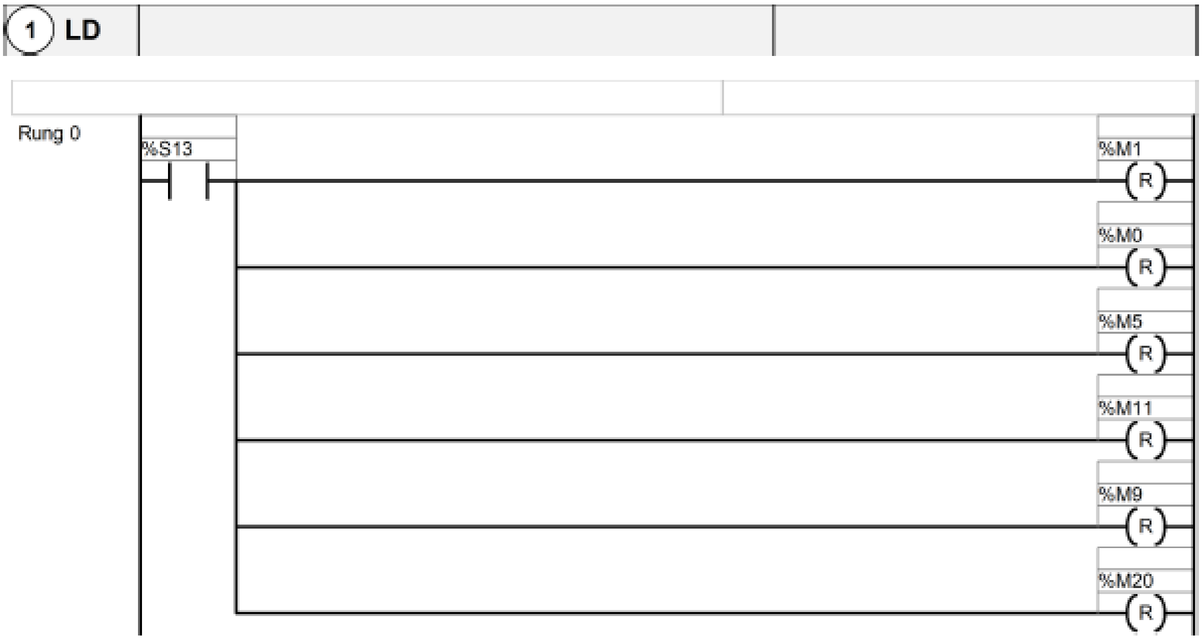
Automatic start in Run :	Yes
Run/Stop Input:	%I0.0

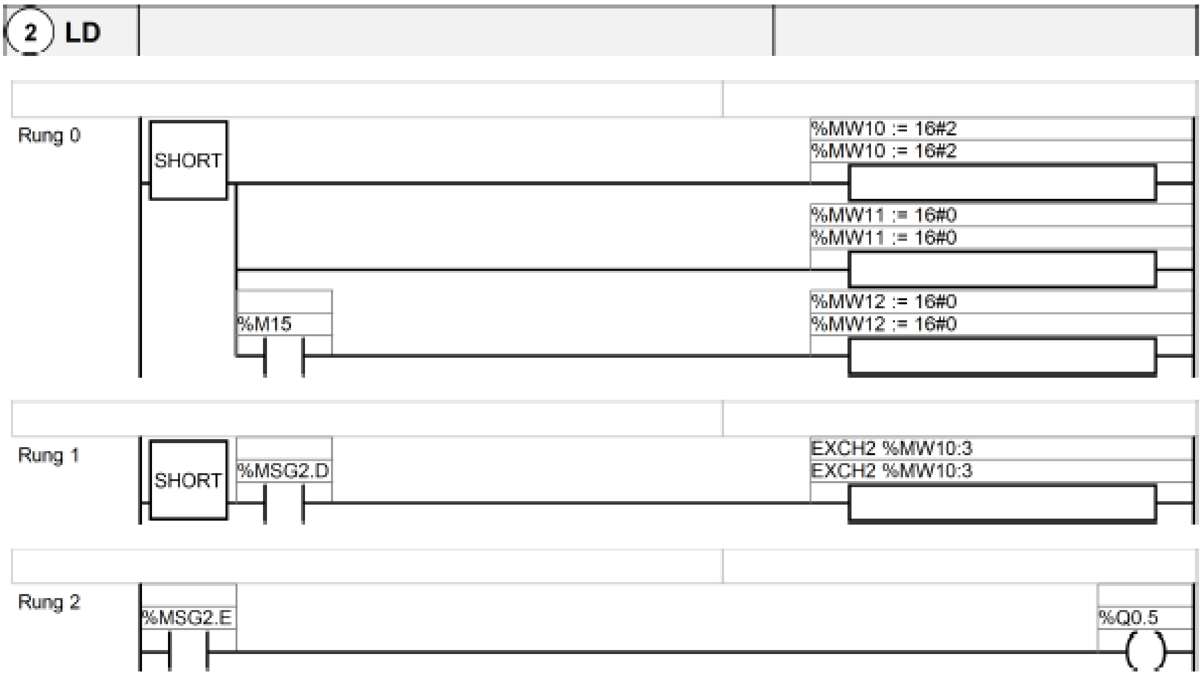
Autosave

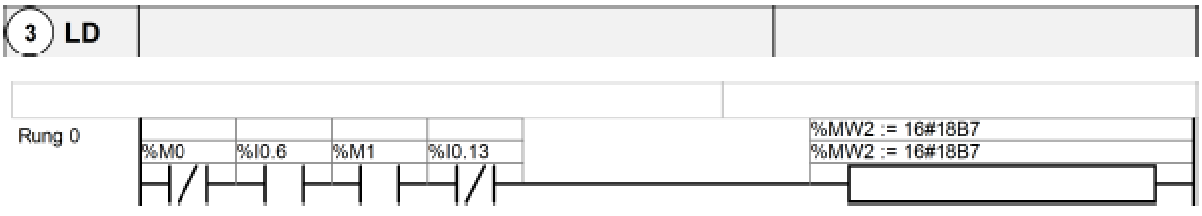
Parameters

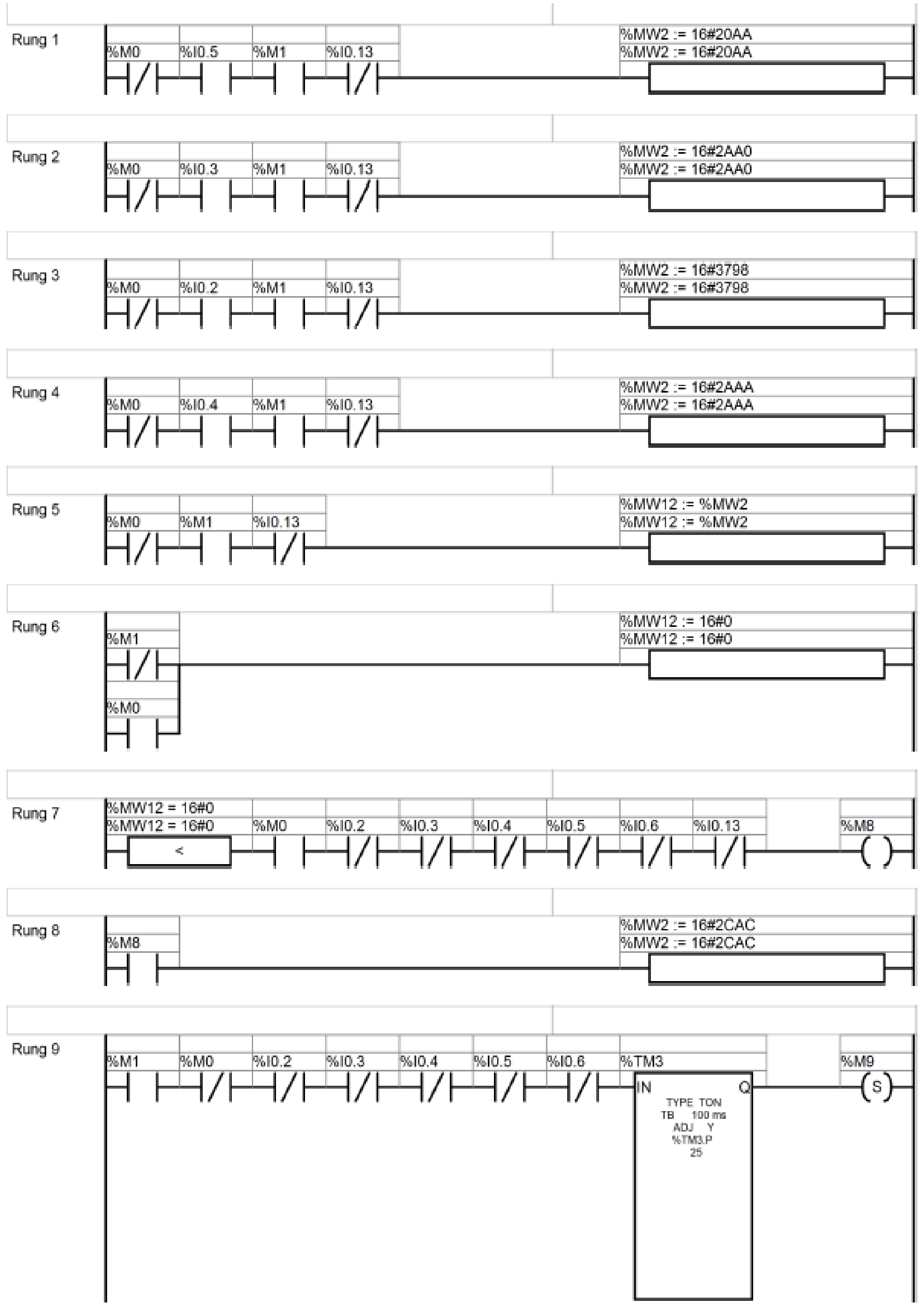
Autosave RAM=>EEPROM :	Yes

Program lists and diagrams



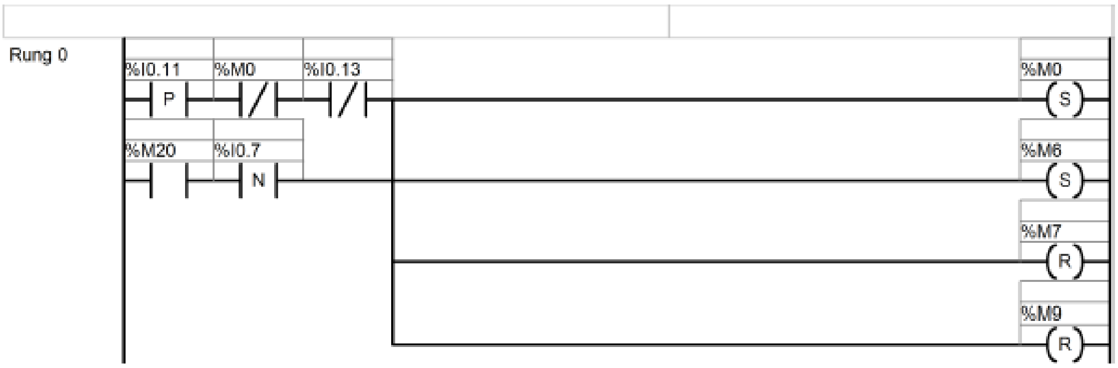




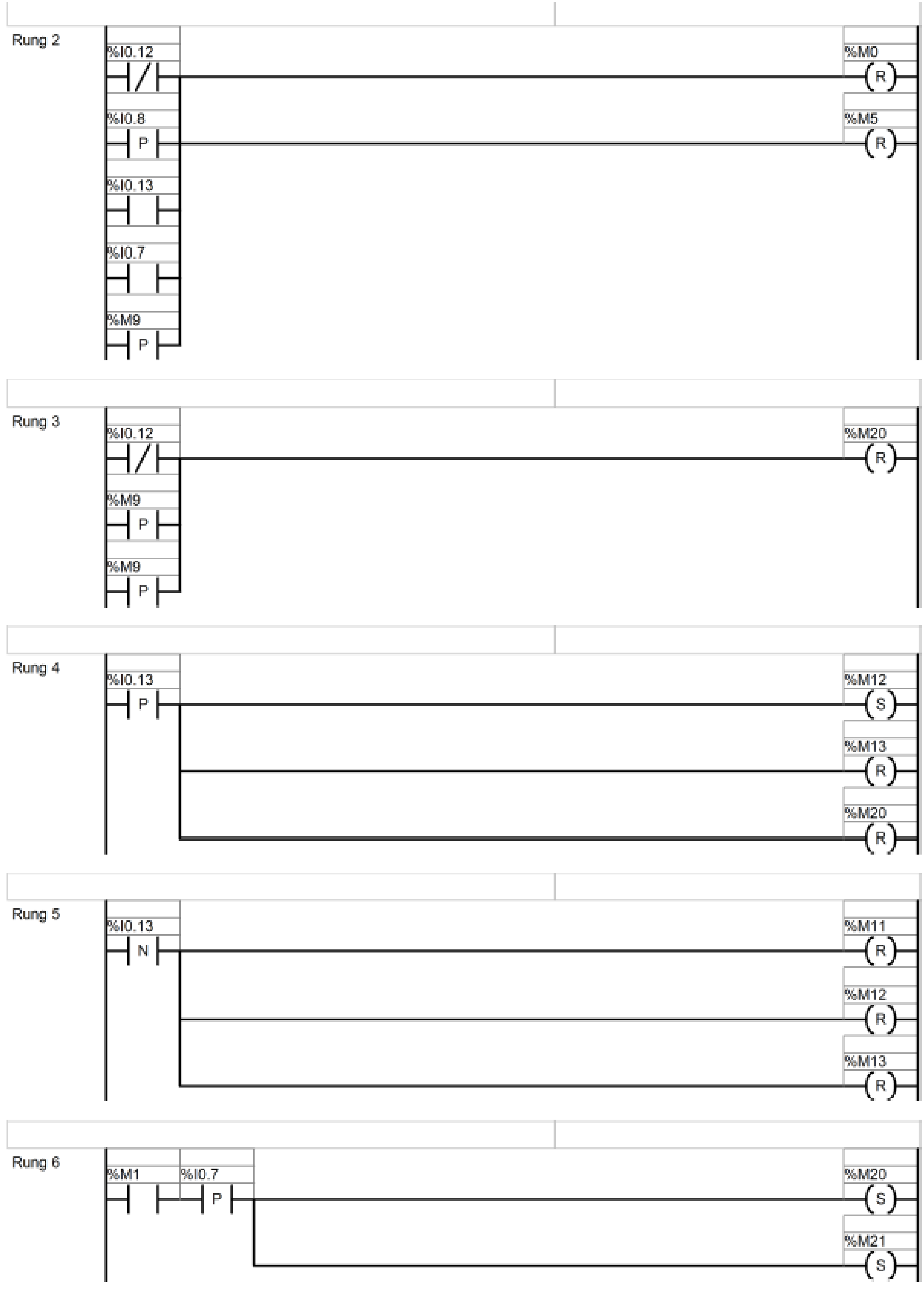

Rung 1
%M0
%I0.5
%M1
%I0.13
%MW2 := 16#20AA
%MW2 := 16#20AA
Rung 2
%M0
%I0.3
%M1
%I0.13
%MW2 := 16#2AA0
%MW2 := 16#2AA0
Rung 3
%M0
%I0.2
%M1
%I0.13
%MW2 := 16#3798
%MW2 := 16#3798
Rung 4
%M0
%I0.4
%M1
%I0.13
%MW2 := 16#2AAA
%MW2 := 16#2AAA
Rung 5
%M0
%M1
%I0.13
%MW12 := %MW2
%MW12 := %MW2
Rung 6
%M1
%M0
%MW12 := 16#0
%MW12 := 16#0
Rung 7
%MW12 = 16#0
%MW12 = 16#0
<
%M0
%I0.2
%I0.3
%I0.4
%I0.5
%I0.6
%I0.13
%M8
Rung 8
%M8
%MW2 := 16#2CAC
%MW2 := 16#2CAC
Rung 9
%M1
%M0
%I0.2
%I0.3
%I0.4
%I0.5
%I0.6
%TM3
IN
Q
TYPE TON
TB 100 ms
ADJ Y
%TM3.P
25
%M9
S

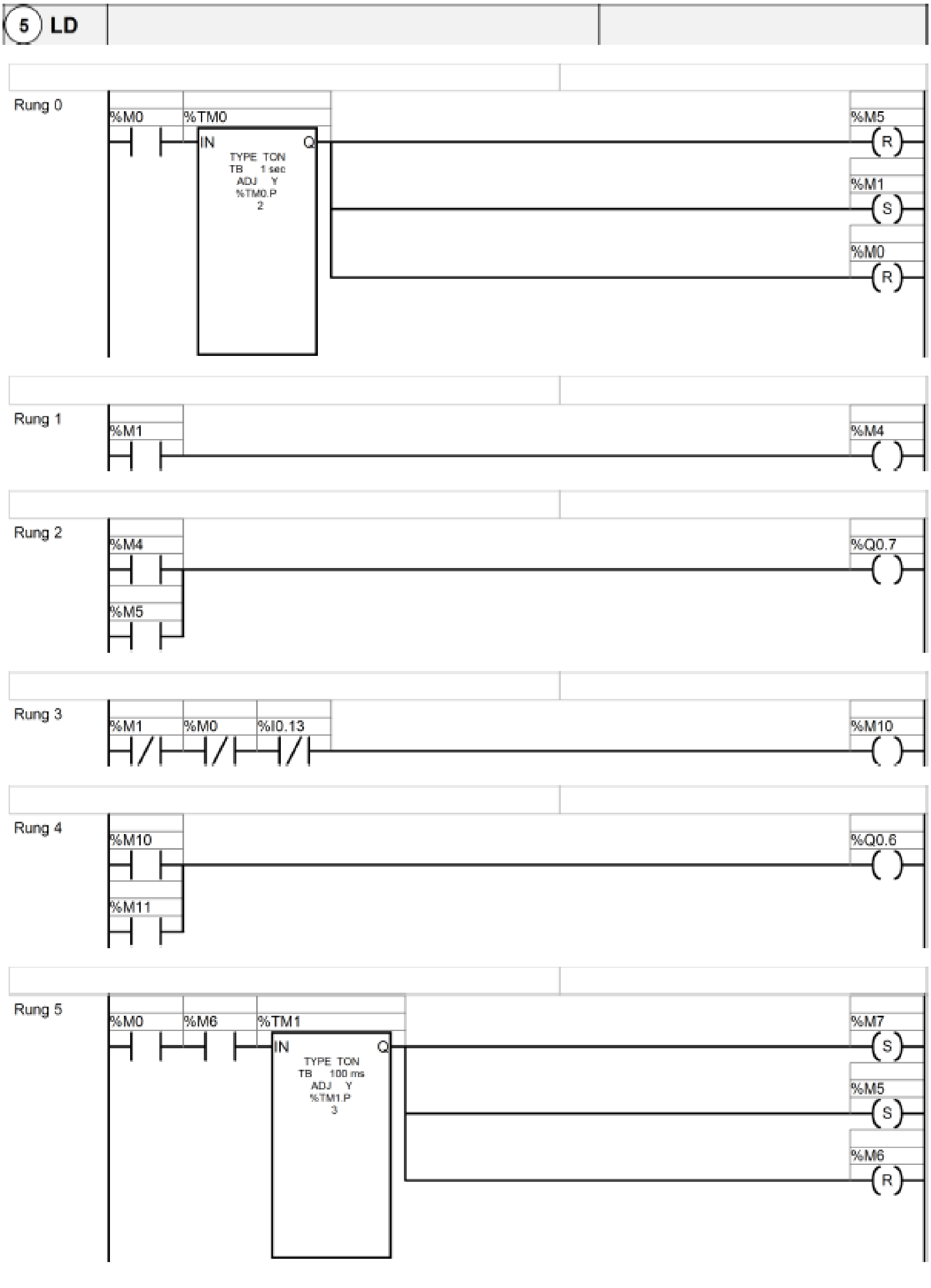

Rung 10
%I0.2
%I0.3
%I0.4
%I0.5
%I0.6
%M9
R

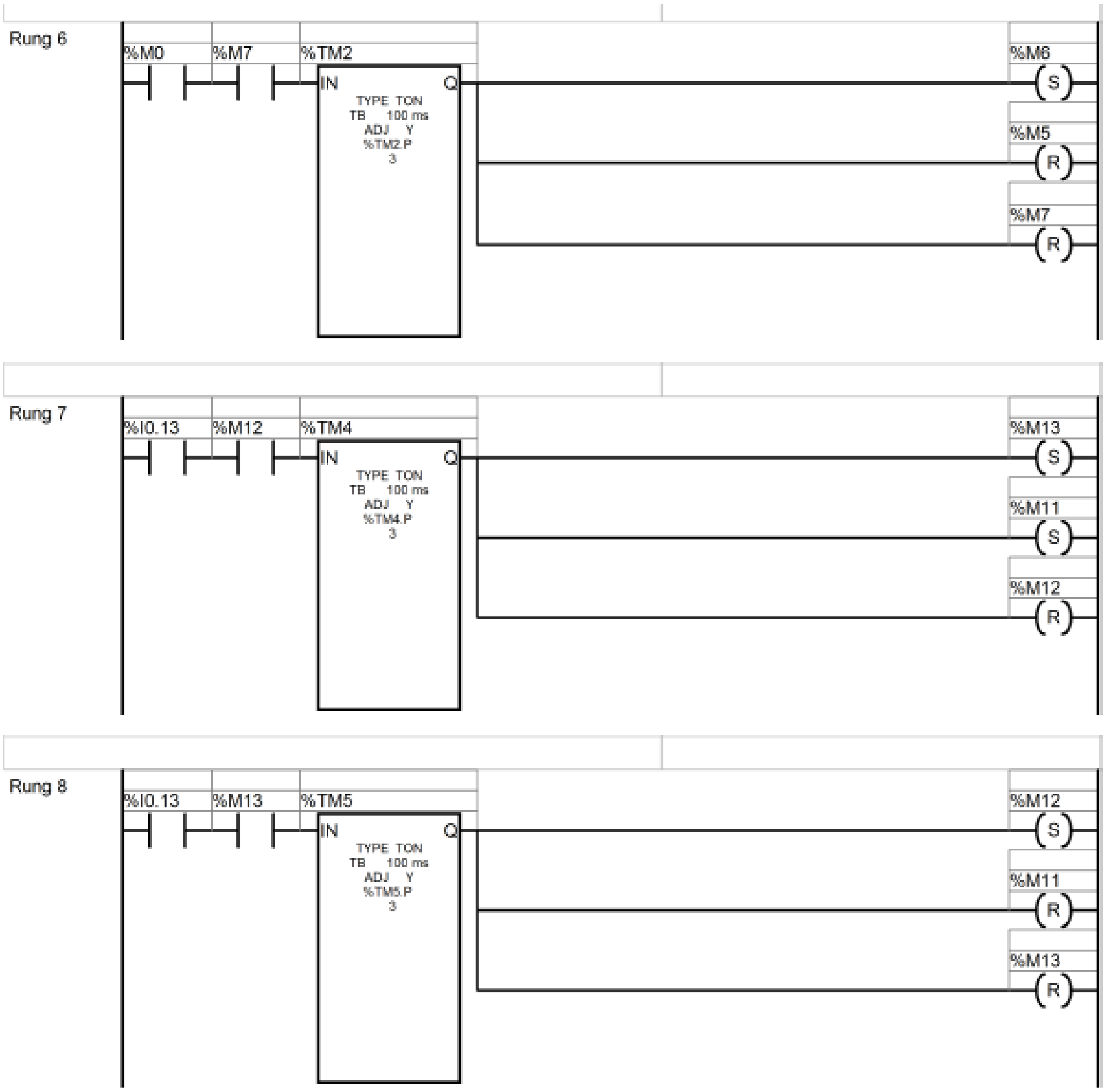
4 LD


Rung 0
%I0.11
P
%M0
%I0.13
%M20
%I0.7
N
%M0
S
%M6
S
%M7
R
%M9
R

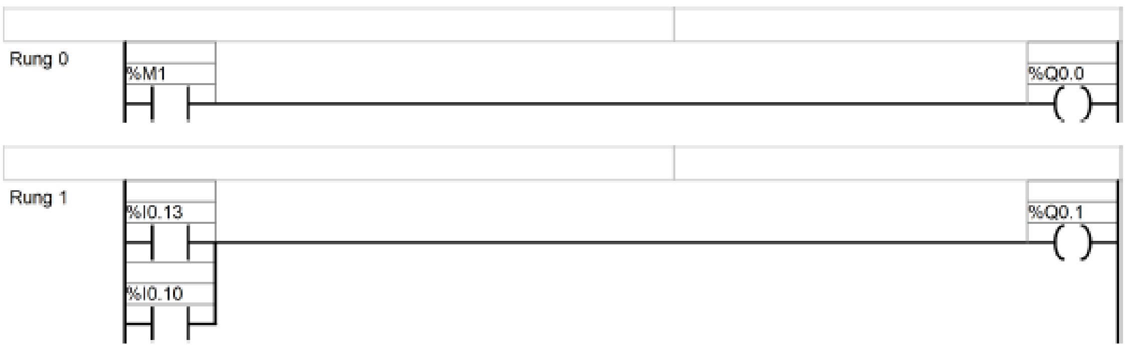

Rung 1
%I0.12
%I0.13
%M0
%I0.8
P
%M9
%M21
P
%M1
R
%M21
R


Rung 2
%I0.12
%I0.8
P
%I0.13
%I0.7
%M9
P
%M0
R
%M5
R
Rung 3
%I0.12
%M9
P
%M9
P
%M20
R
Rung 4
%I0.13
P
%M12
S
%M13
R
%M20
R
Rung 5
%I0.13
N
%M11
R
%M12
R
%M13
R
Rung 6
%M1
%I0.7
P
%M20
S
%M21
S


5 LD
Rung 0
%M0
%TM0
IN
Q
TYPE TON
TB 1 sec
ADJ Y
%TM0.P
2
%M5
R
%M1
S
%M0
R
Rung 1
%M1
%M4
Rung 2
%M4
%M5
%Q0.7
Rung 3
%M1
%M0
%I0.13
%M10
Rung 4
%M10
%M11
%Q0.6
Rung 5
%M0
%M6
%TM1
IN
Q
TYPE TON
TB 100 ms
ADJ Y
%TM1.P
3
%M7
S
%M5
S
%M6
R


Rung 6
%M0
%M7
%TM2
IN
Q
TYPE TON
TB 100 ms
ADJ Y
%TM2.P
3
%M6
S
%M5
R
%M7
R
Rung 7
%I0.13
%M12
%TM4
IN
Q
TYPE TON
TB 100 ms
ADJ Y
%TM4.P
3
%M13
S
%M11
S
%M12
R
Rung 8
%I0.13
%M13
%TM5
IN
Q
TYPE TON
TB 100 ms
ADJ Y
%TM5.P
3
%M12
S
%M11
R
%M13
R

6 LD


Rung 0
%M1
%Q0.0
Rung 1
%I0.13
%I0.10
%Q0.1

List of preferences to print

Directory:

Parameters

Path:	C:\Program Files (x86)\Schneider Electric\TwidoSuite\My projects

Image:

Parameters

Image:	Default image
Path:	

Functional levels:

Parameters

Type:	Automatic
Level:	The very highest

Connections management:

Connection

Name	COM1
Connection type	COM
IP / Phone	COM1
Punit / Address	Punit
Baud rate	
Parity	None
Stop bits	
Timeout	5000
Break timeout	5

Connection

Name	COM6
Connection type	COM
IP / Phone	COM6
Punit / Address	Punit
Baud rate	
Parity	None
Stop bits	
Timeout	5000
Break timeout	5

About

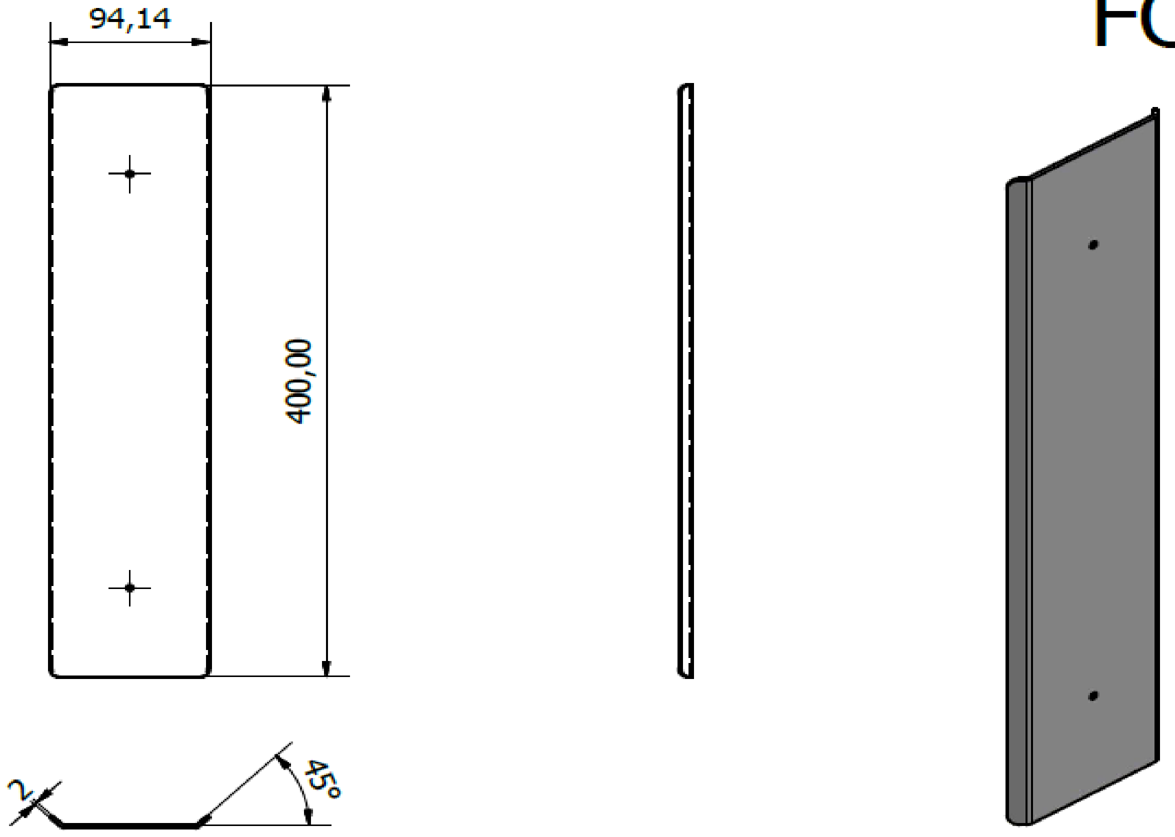
License:

```
Company: Nelson Mandela Metropoli
User First Name -
User Last Name -
State: Test version
Number of test days: 30
```

ANNEXURE B

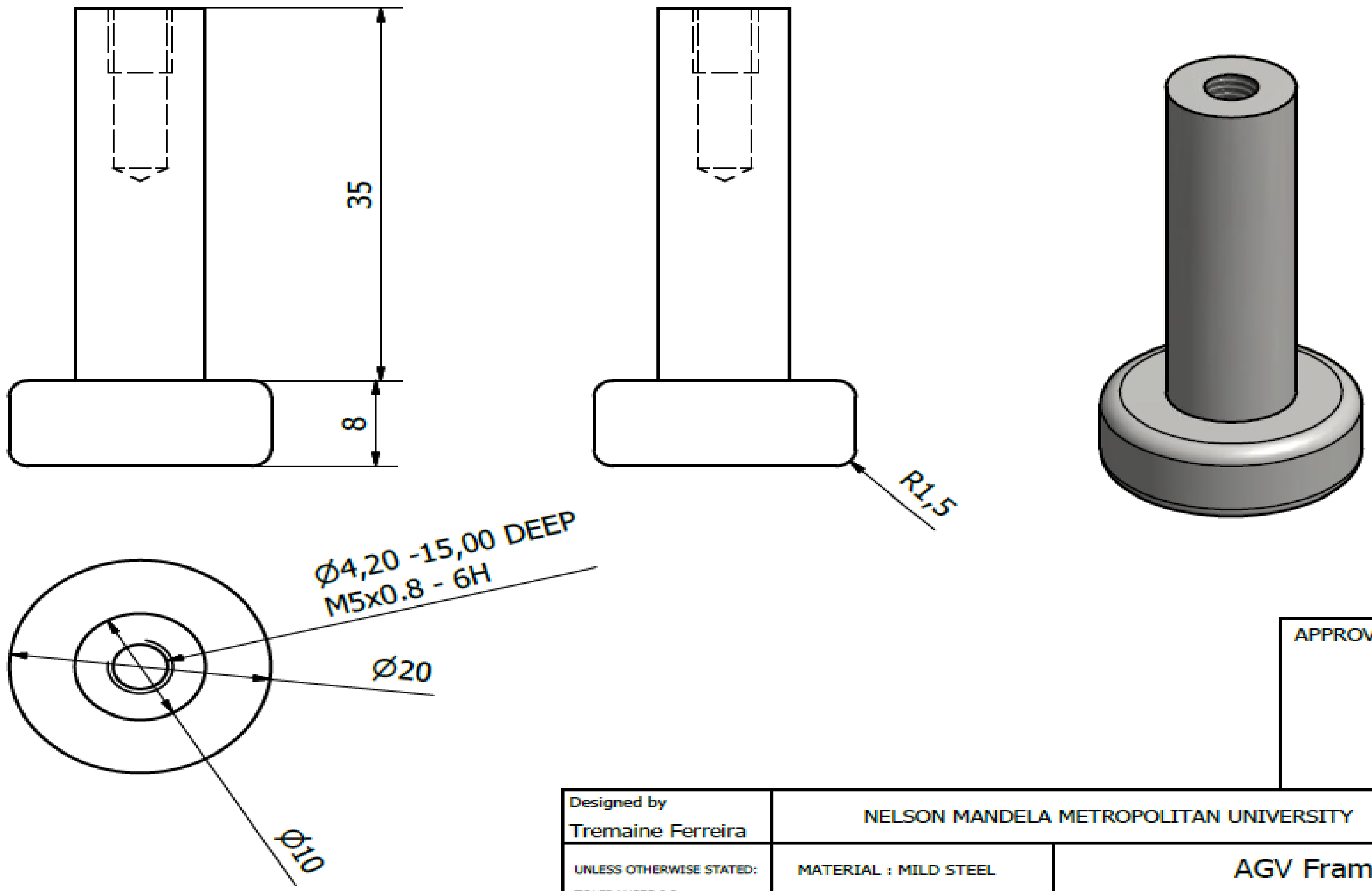
MECHANICAL DRAWINGS

FOLDED VIEW

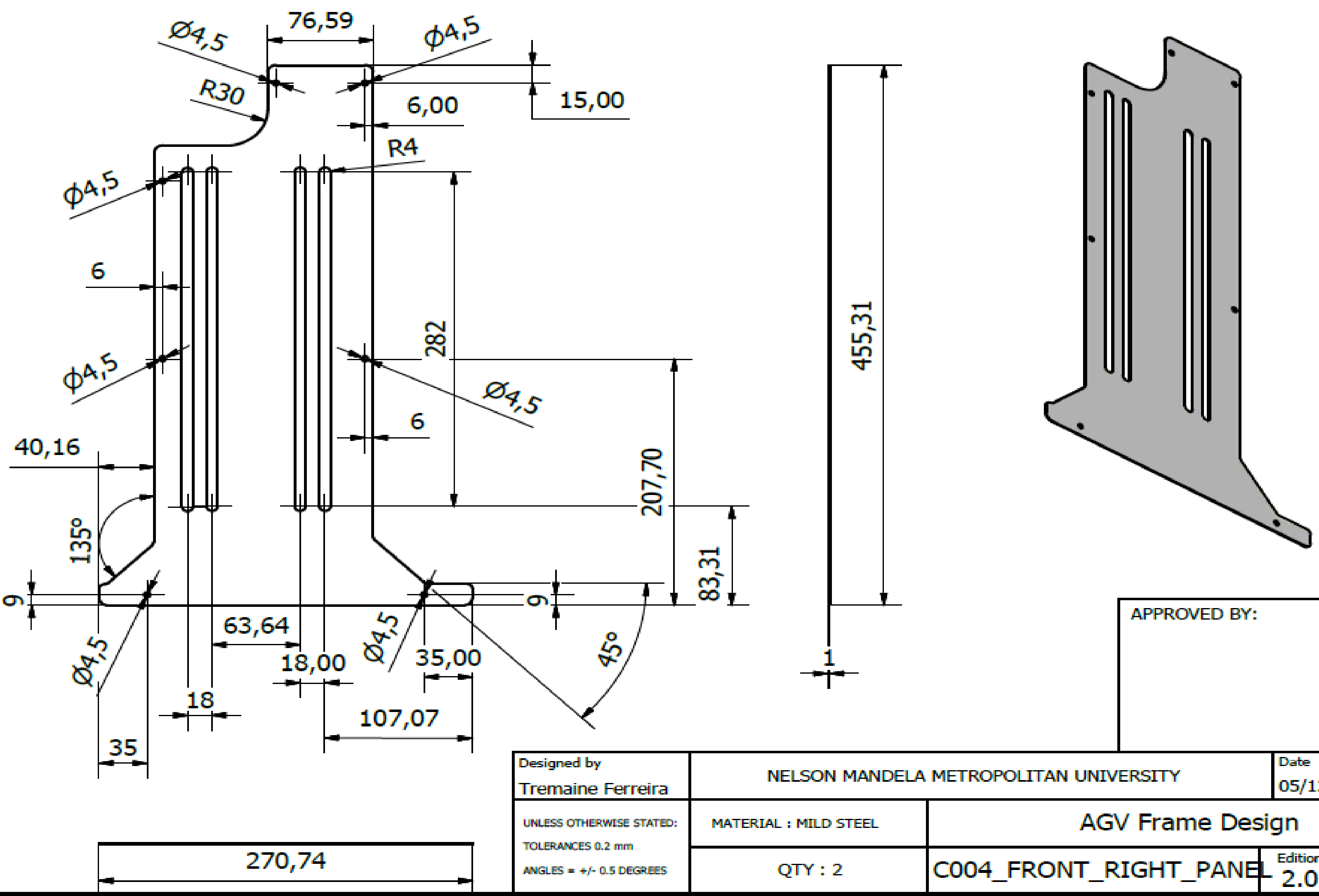


APPROVED BY:

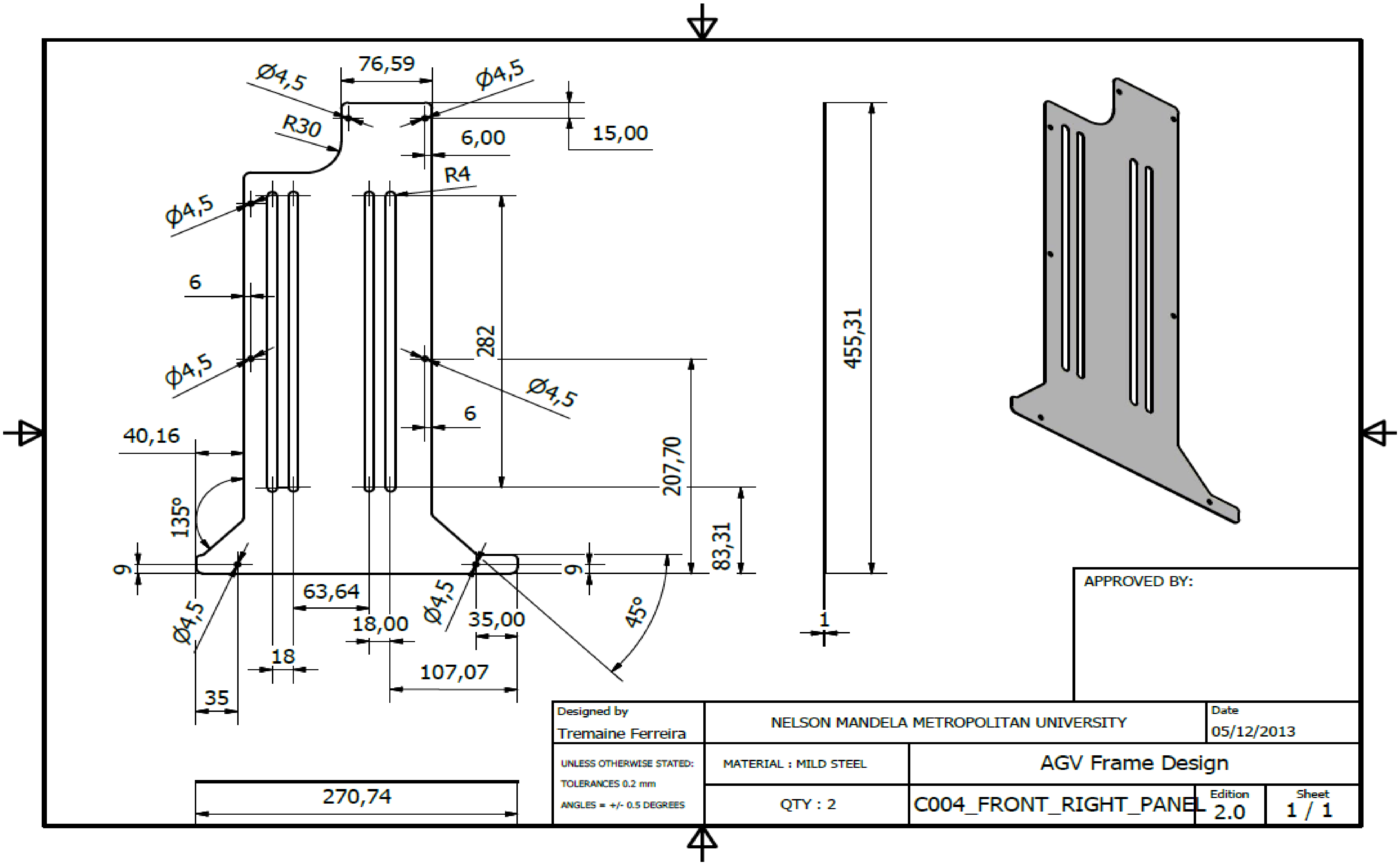
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY			Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C001_BUMPER	Edition 2.0	Sheet 1 / 2



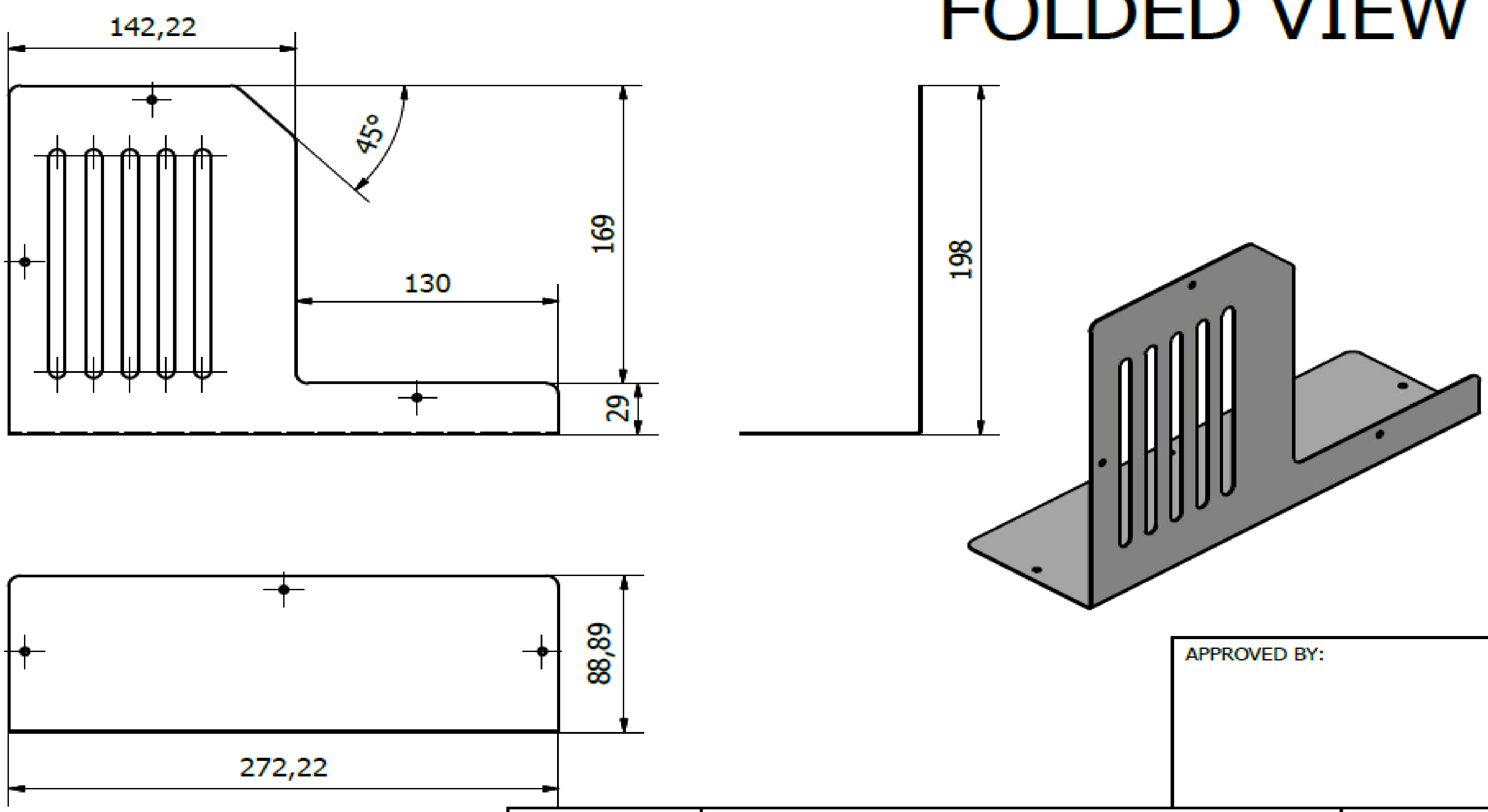
			APPROVED BY:	
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013	
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 4	C002_BUMPER_PINS	Edition 2.0	Sheet 1 / 1



			APPROVED BY:	
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013	
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C004_FRONT_RIGHT_PANEL	Edition 2.0	Sheet 1 / 1

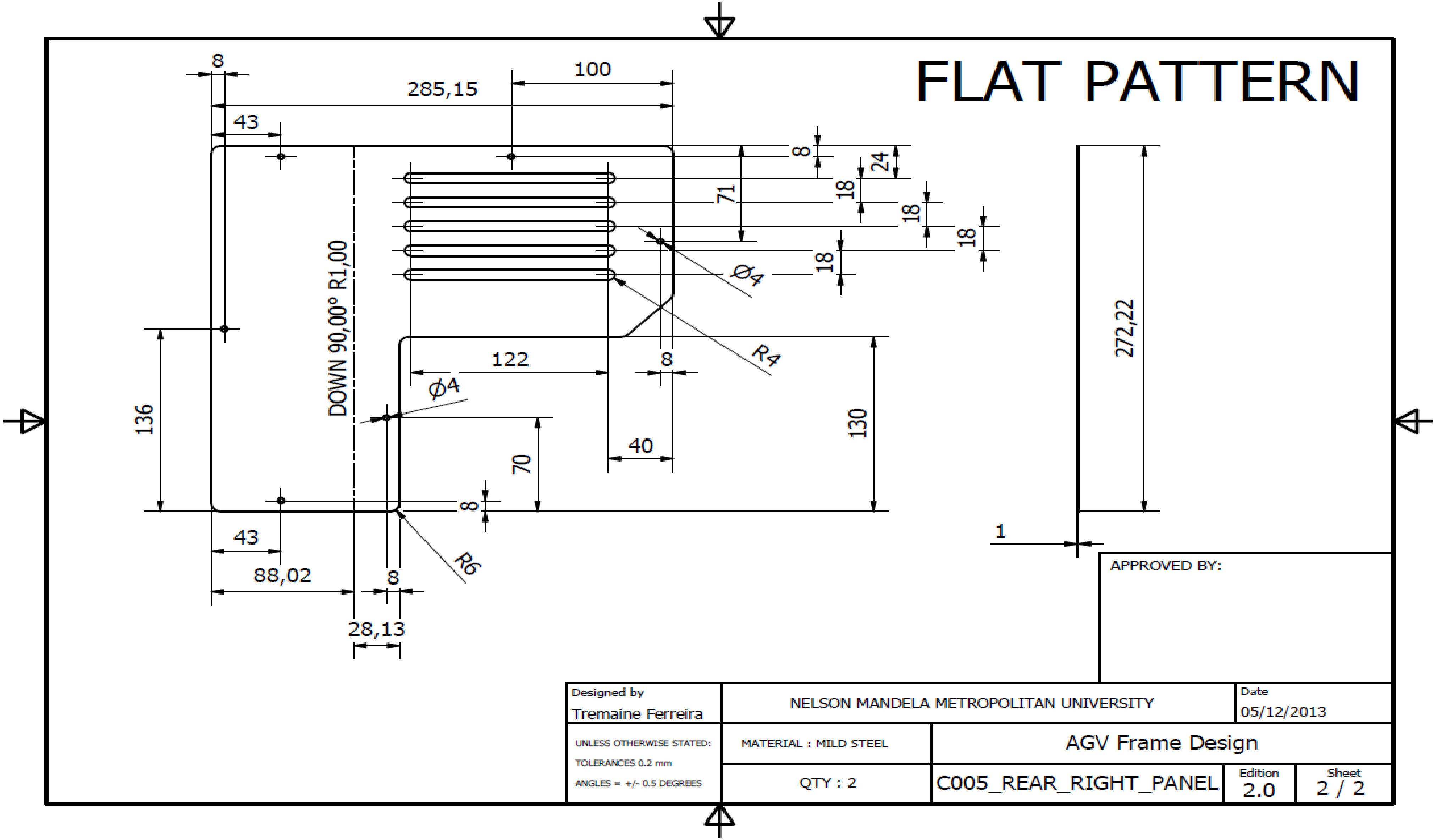

Ø4,5
76,59
Ø4,5
R30
15,00
6,00
R4
Ø4,5
6
282
Ø4,5
Ø4,5
6
40,16
207,70
135°
83,31
9
9
Ø4,5
63,64
Ø4,5
18,00
35,00
45°
18
107,07
35
270,74
455,31
1
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C004_FRONT_RIGHT_PANEL
Edition
2.0
Sheet
1 / 1

FOLDED VIEW

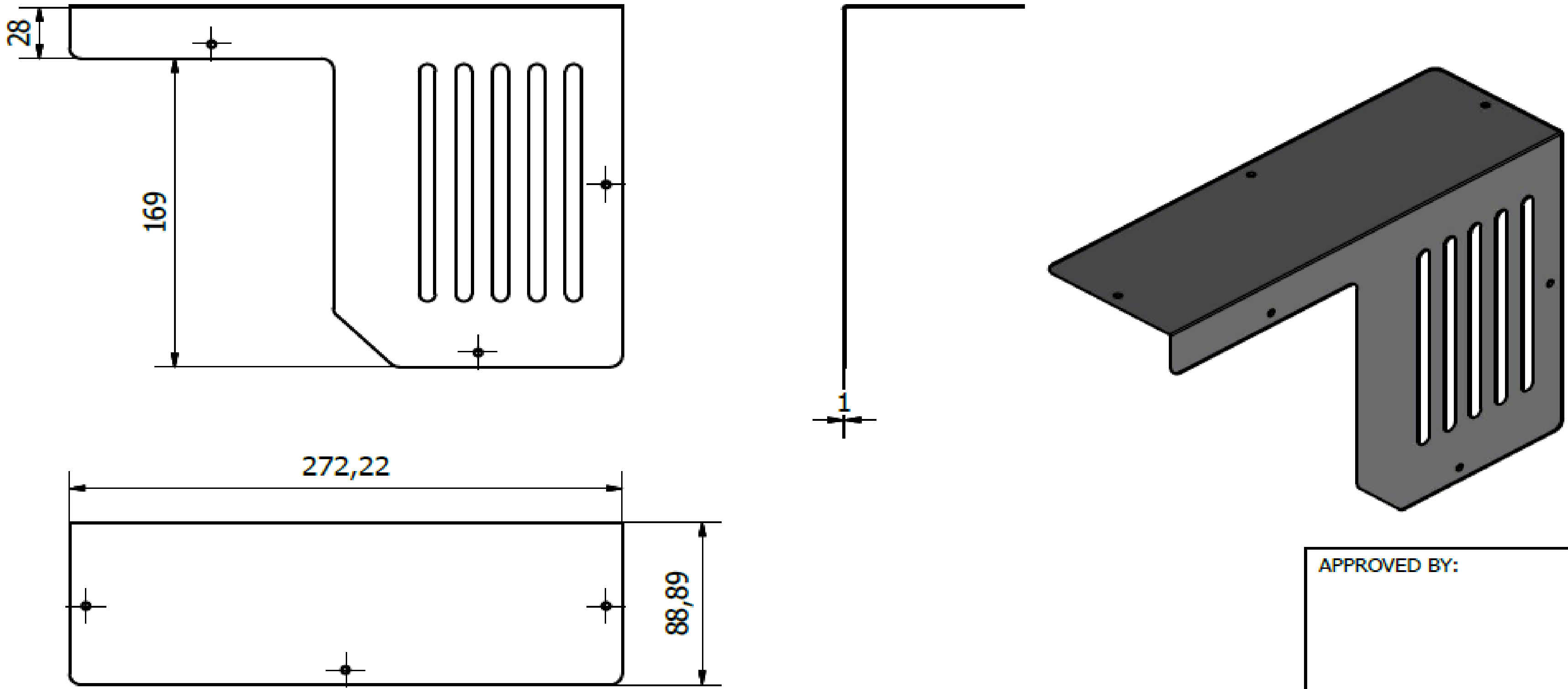


Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY			Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C005_REAR_RIGHT_PANEL	Edition 2.0	Sheet 1 / 2

APPROVED BY:

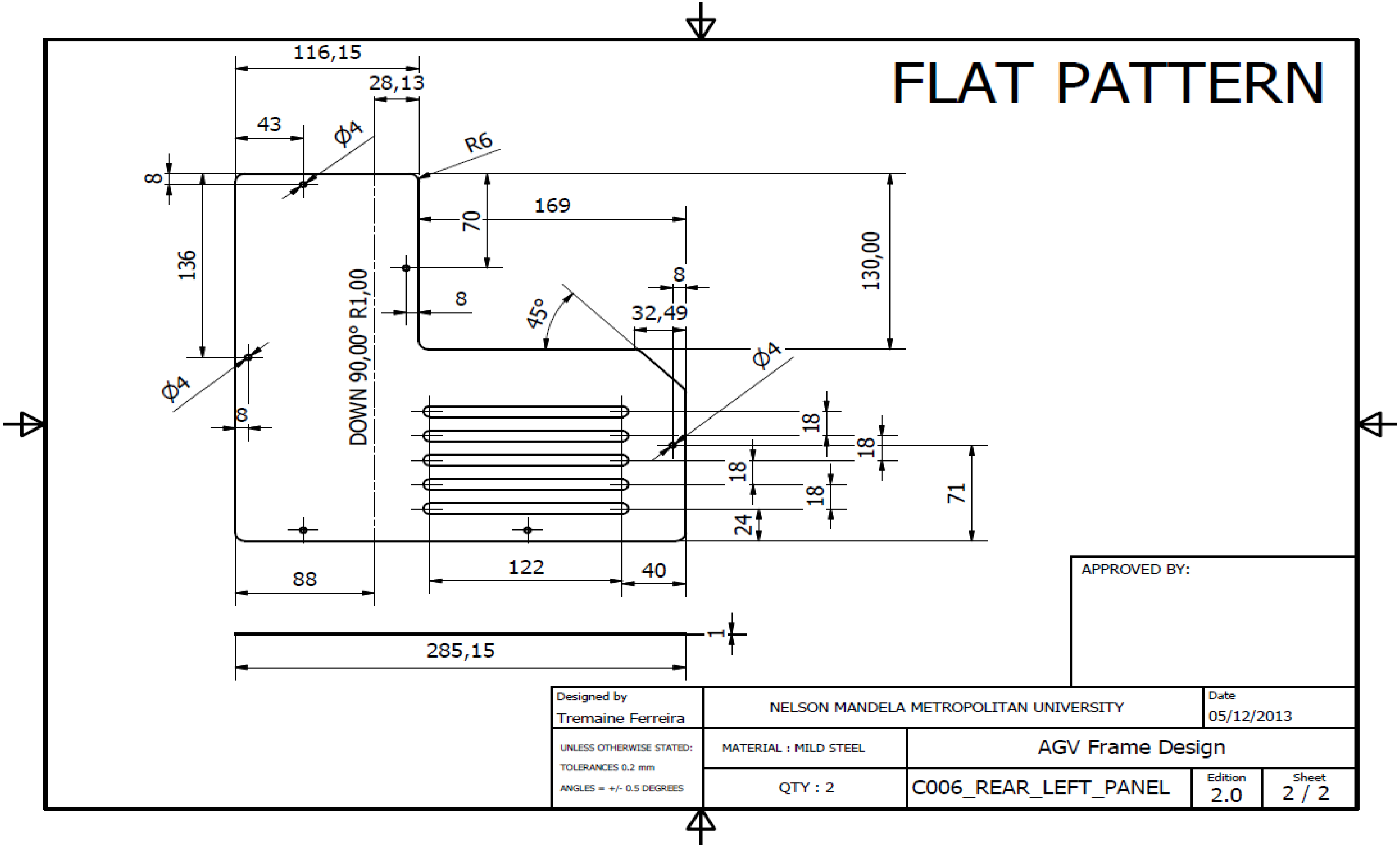

FLAT PATTERN
8
285,15
100
43
8
24
18
71
18
18
18
Ø4
DOWN 90,00° R1,00
R4
136
122
8
Ø4
130
272,22
70
40
8
43
R6
88,02
8
28,13
1
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C005_REAR_RIGHT_PANEL
Edition
2.0
Sheet
2 / 2

FOLDED VIEW

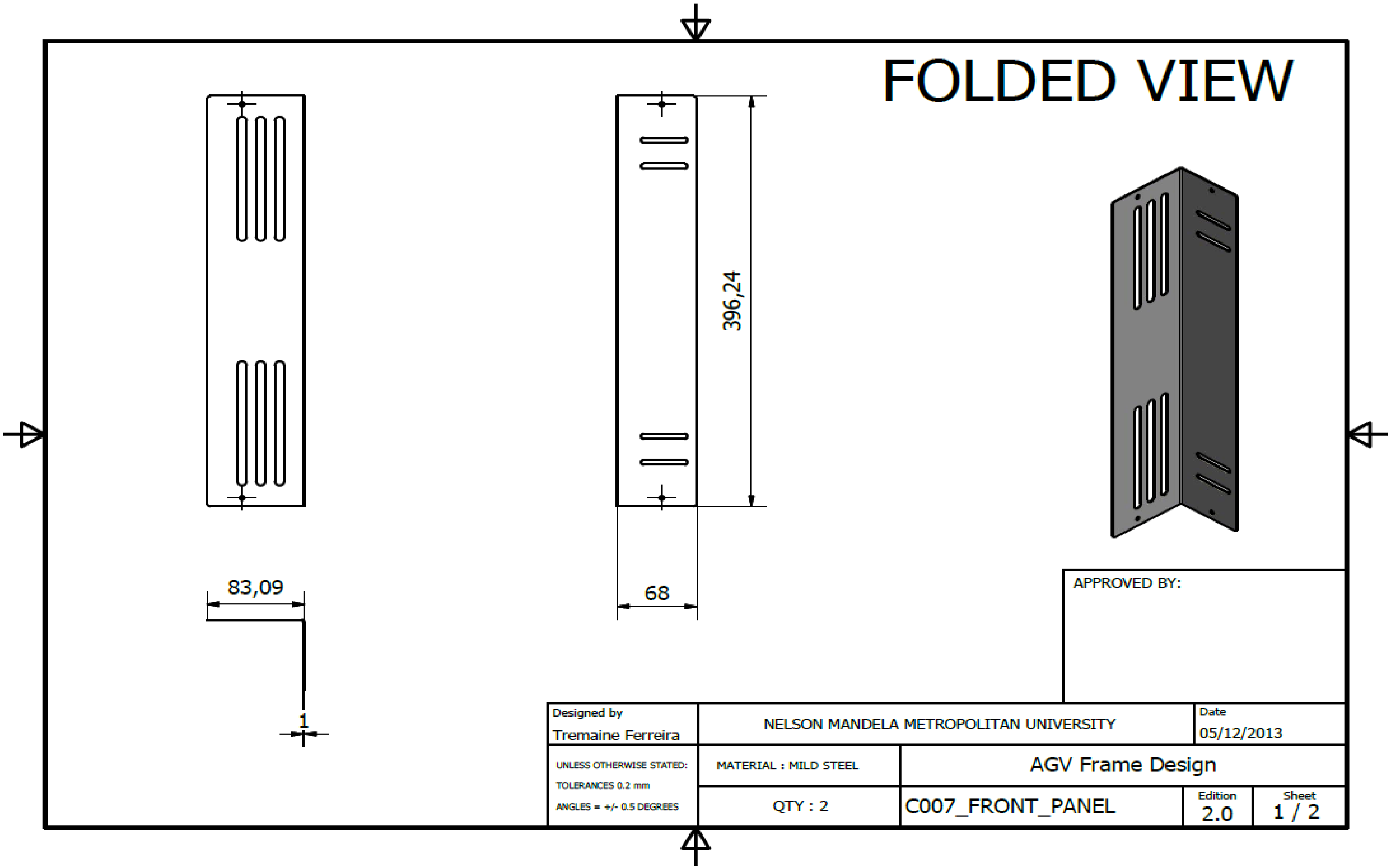


APPROVED BY:

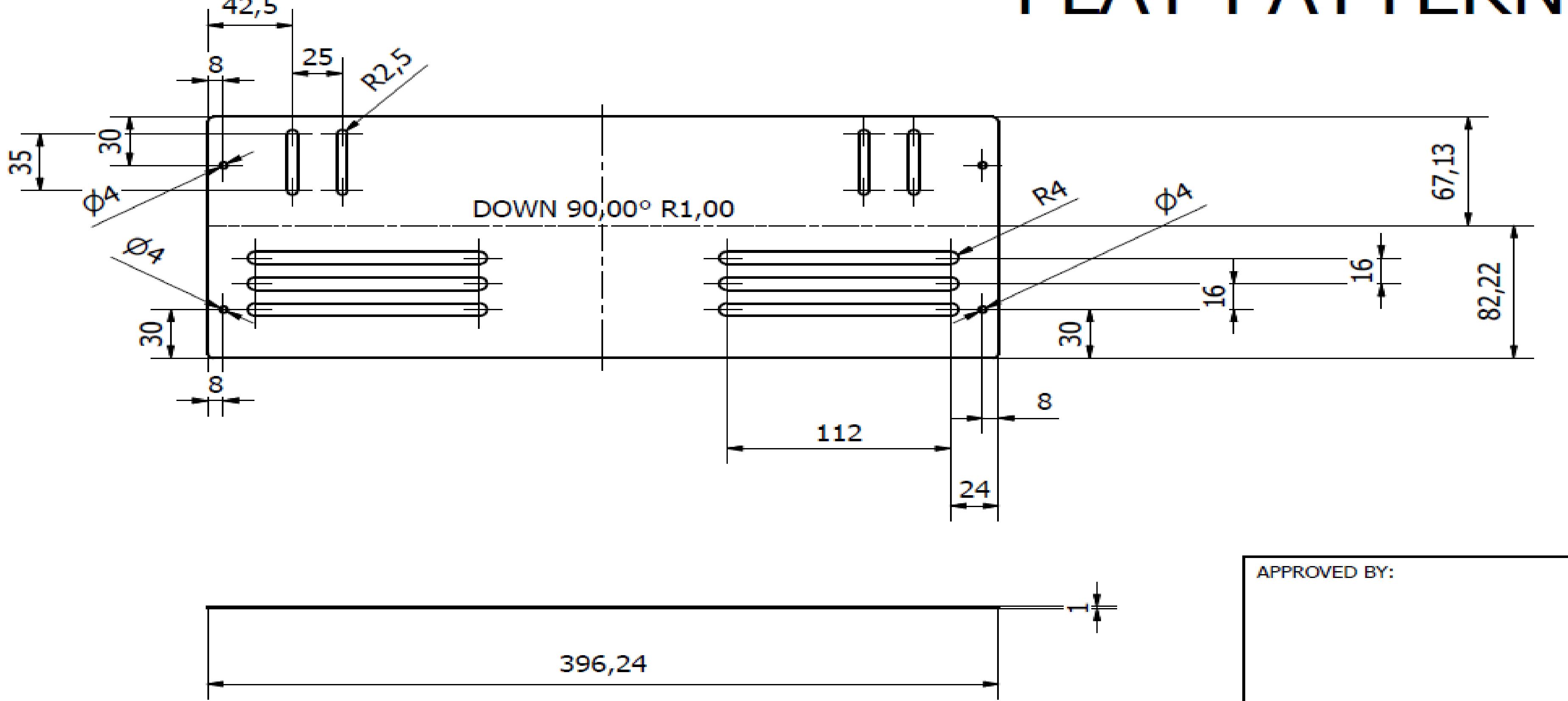
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY			Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C006_REAR_LEFT_PANEL	Edition 2.0	Sheet 1 / 2



FLAT PATTERN
116,15
28,13
43
Ø4
R6
8
136
70
169
DOWN 90,00° R1,00
8
45°
8
32,49
130,00
Ø4
Ø4
8
18
18
18
18
71
24
88
122
40
1
285,15
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C006_REAR_LEFT_PANEL
Edition
2.0
Sheet
2 / 2

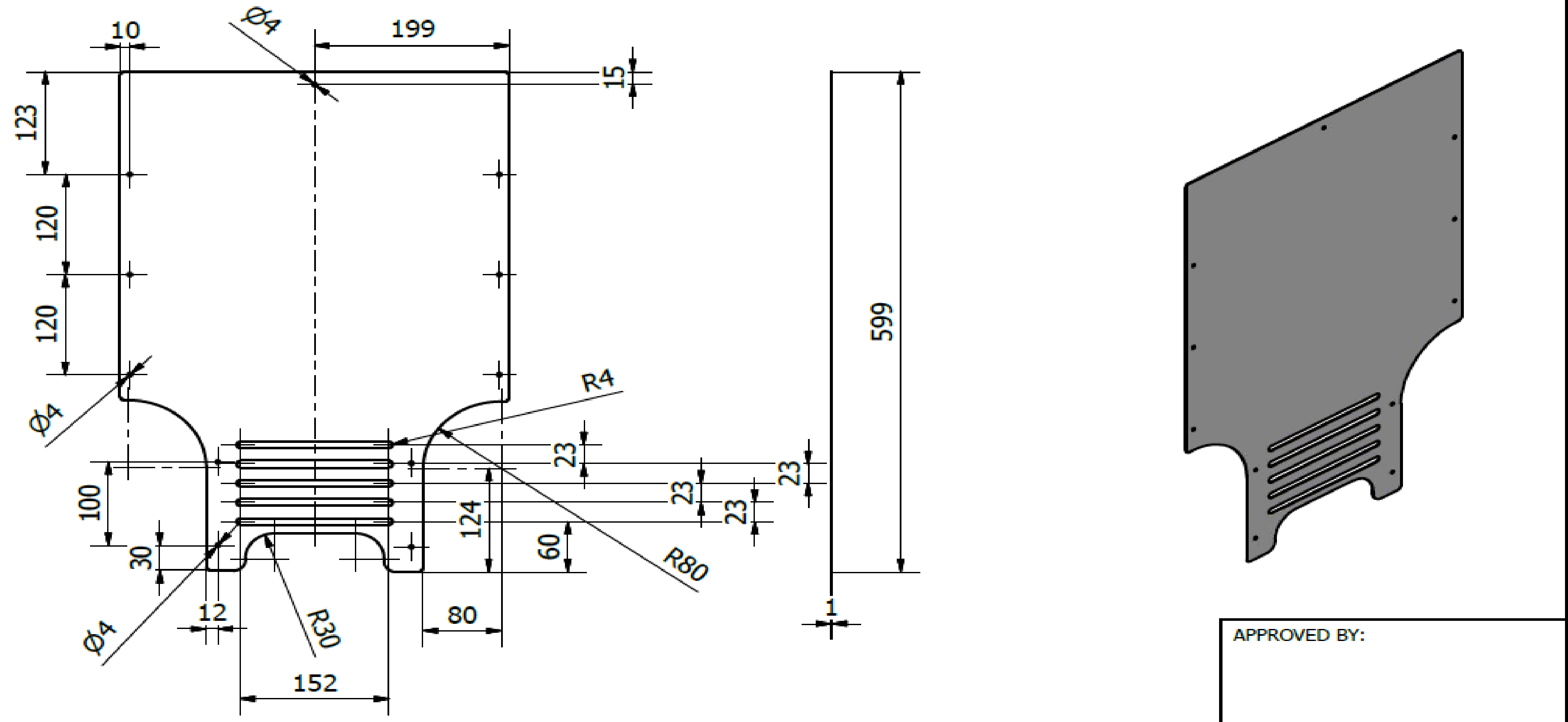

FOLDED VIEW
396,24
83,09
68
1
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C007_FRONT_PANEL
Edition
2.0
Sheet
1 / 2

FLAT PATTERN

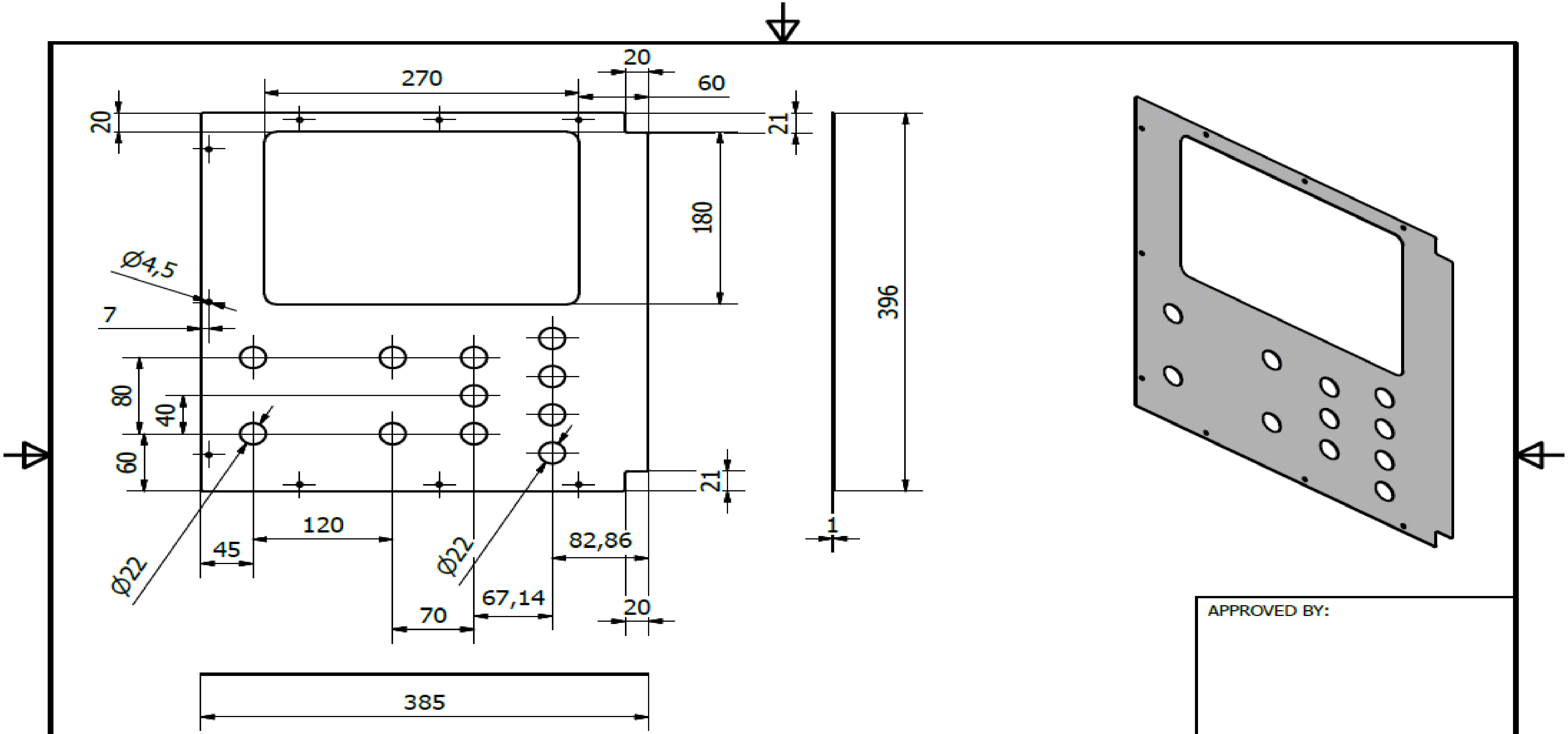


APPROVED BY:

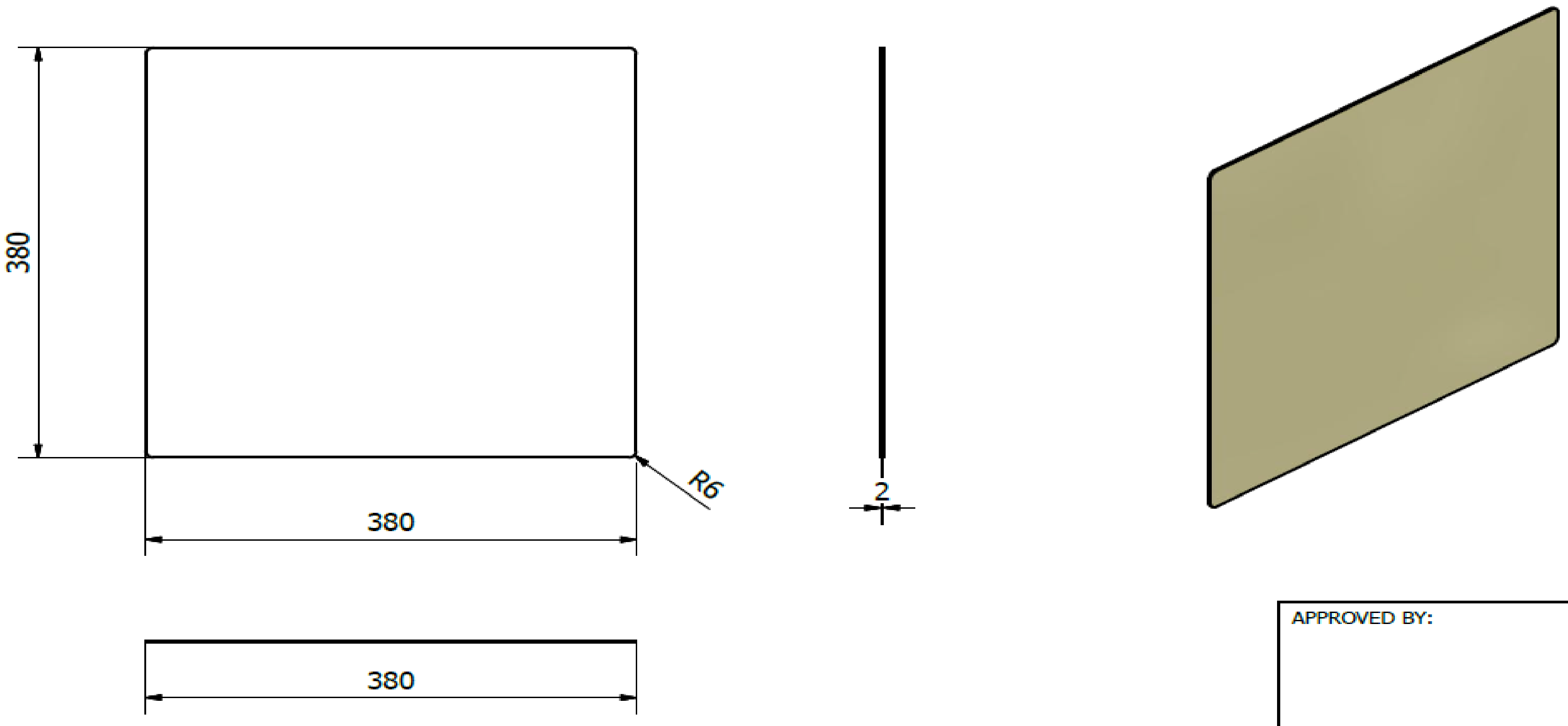
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design	
	QTY : 2	C007_FRONT_PANEL	Edition 2.0 / Sheet 2 / 2



Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013	
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C008_TOP_PANEL	Edition 2.0	Sheet 1 / 1

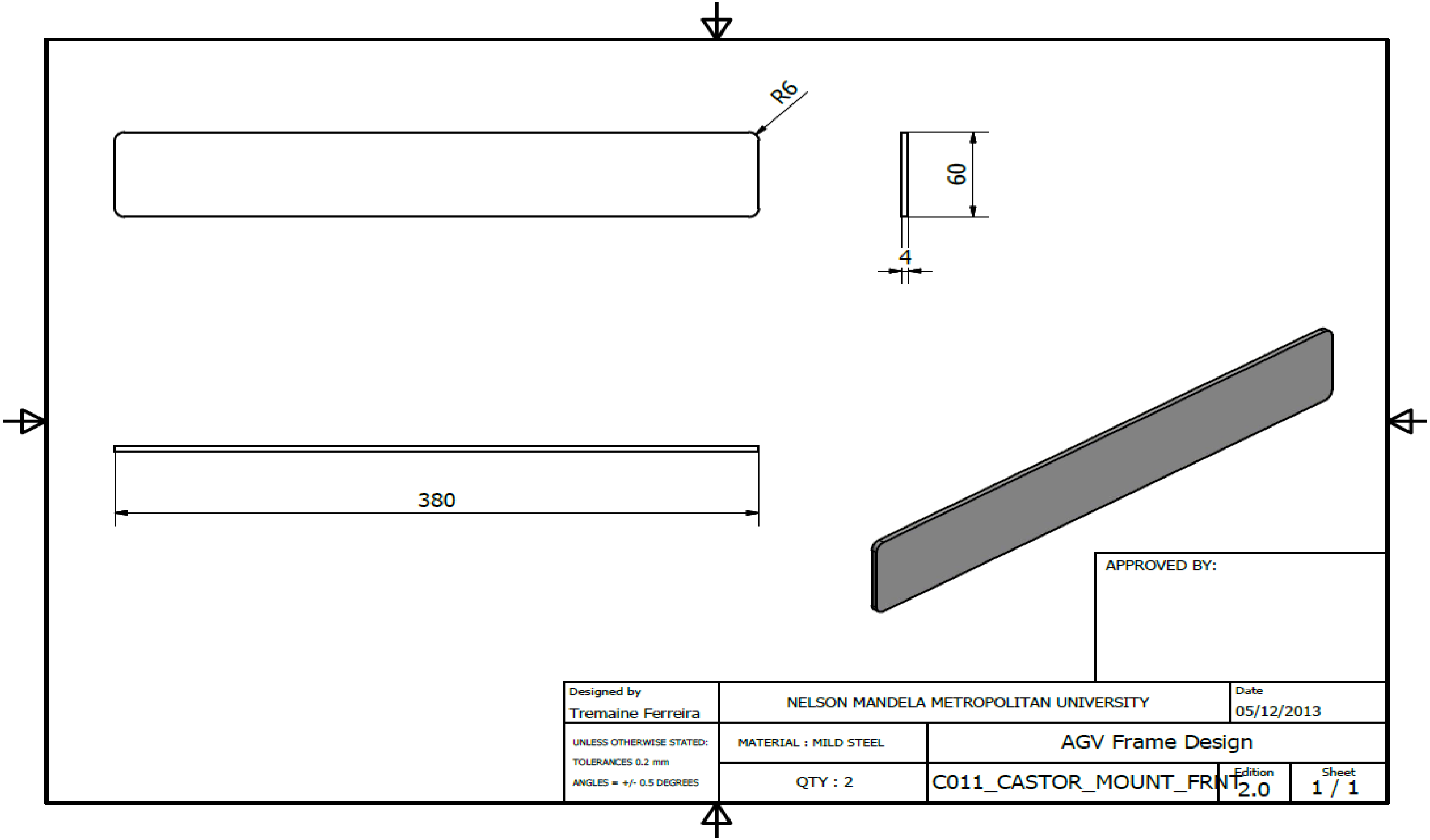


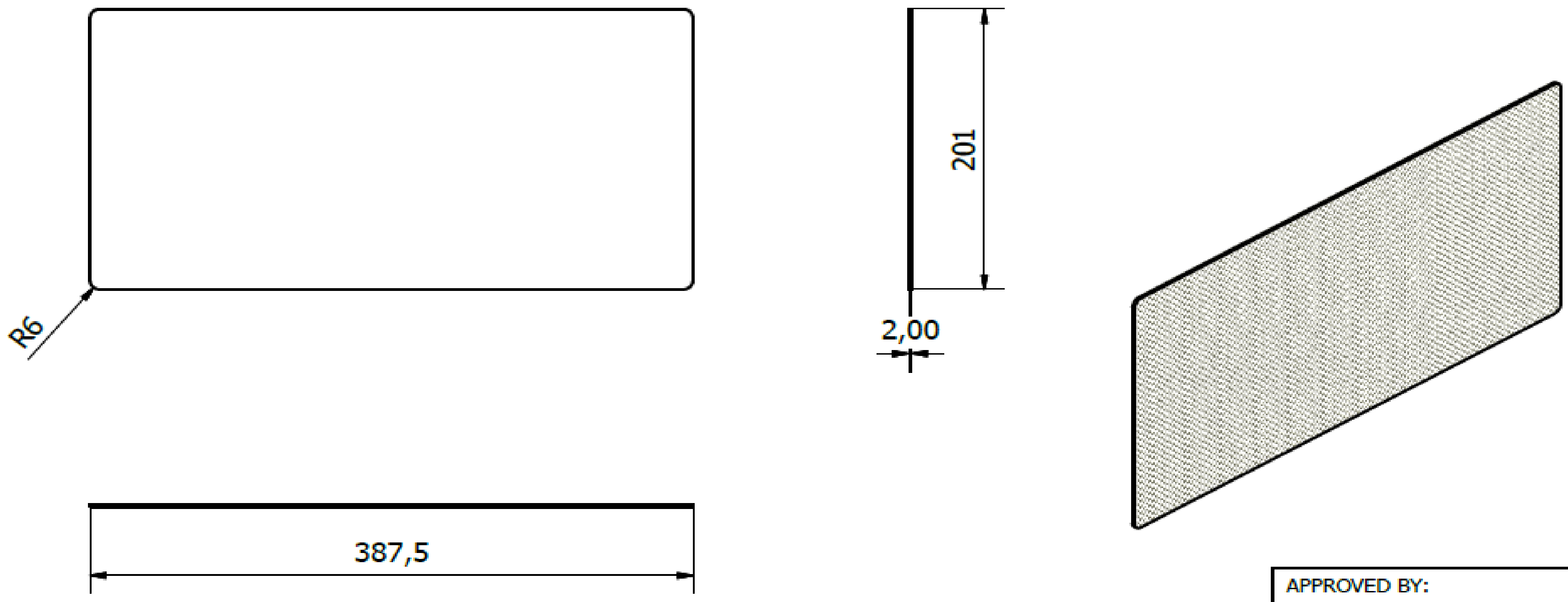
APPROVED BY:				
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013	
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C009_CONTROL_PANEL	Edition 2.0	Sheet 1 / 1



APPROVED BY:

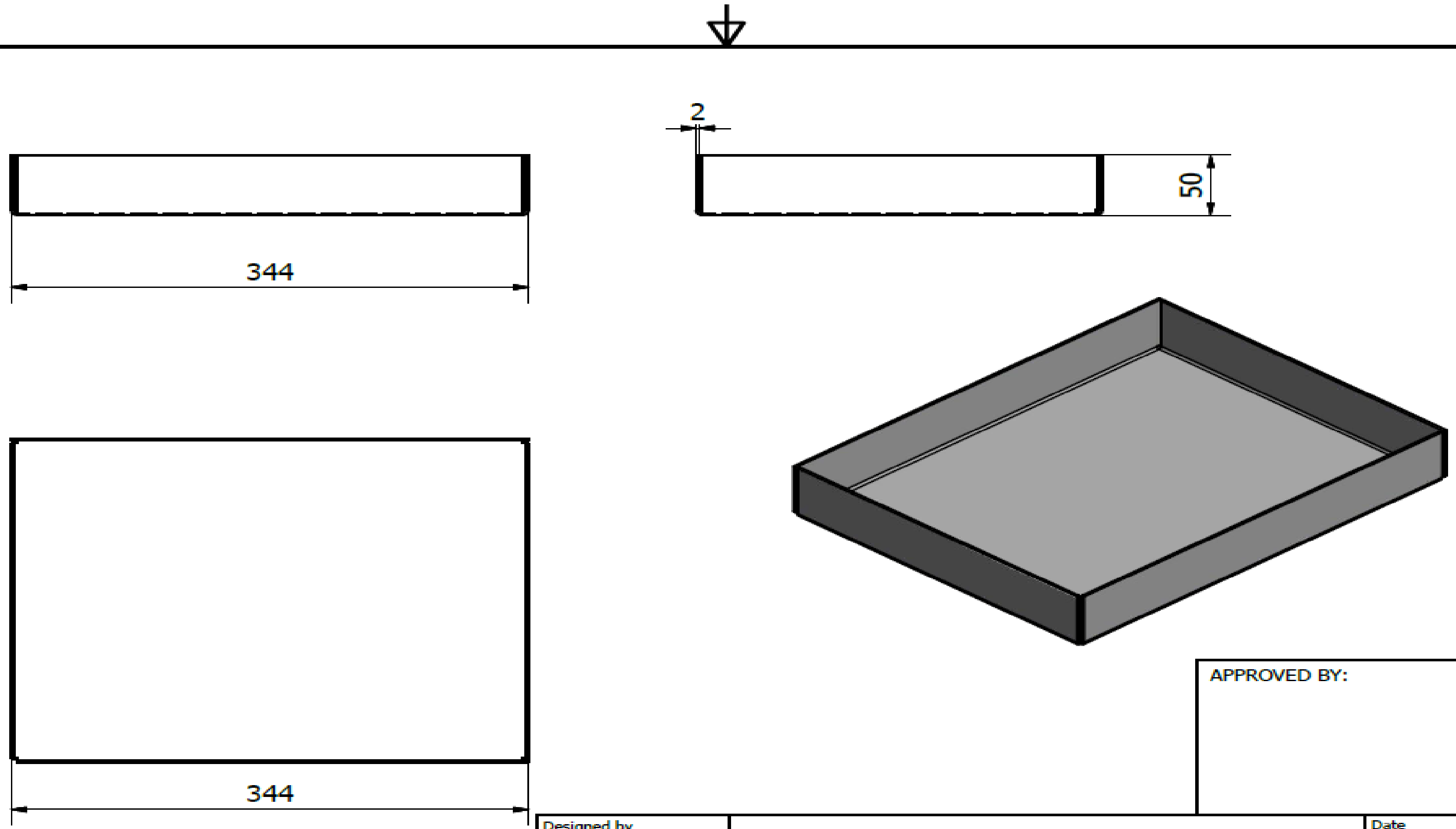
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY			Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C010_BACKING_PLATE	Edition 2.0	Sheet 1 / 1


R6
60
4
380
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C011_CASTOR_MOUNT_FRNT
Edition
2.0
Sheet
1 / 1



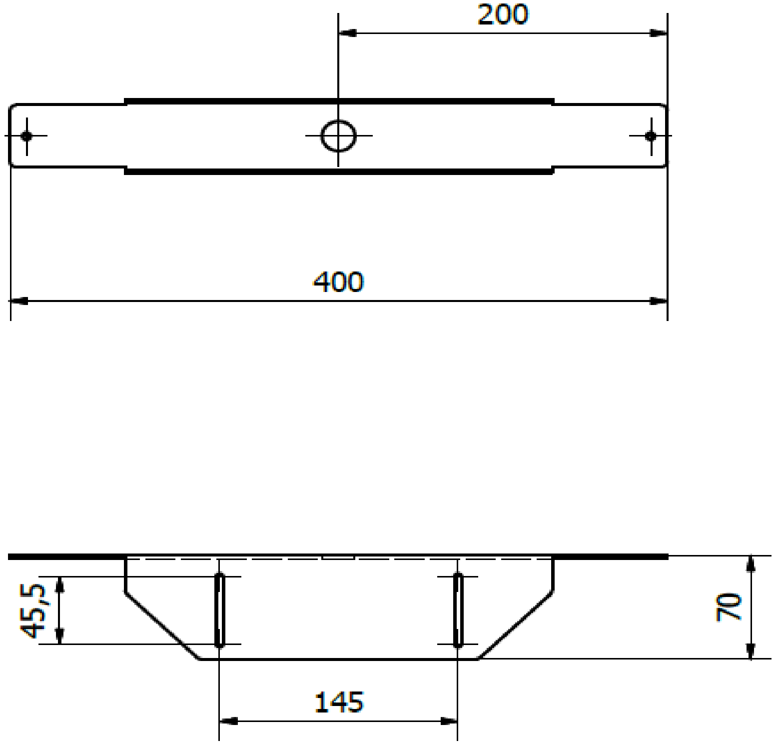
APPROVED BY:

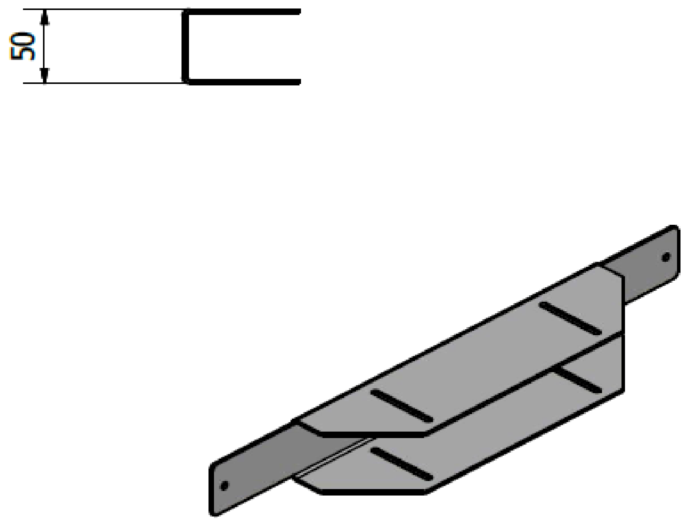
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013	
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C012_EXP_METAL_COVER	Edition 2.0	Sheet 1 / 1



		APPROVED BY:		
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013	
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C013_BATTERY_PACK	Edition 2.0	Sheet 1 / 1

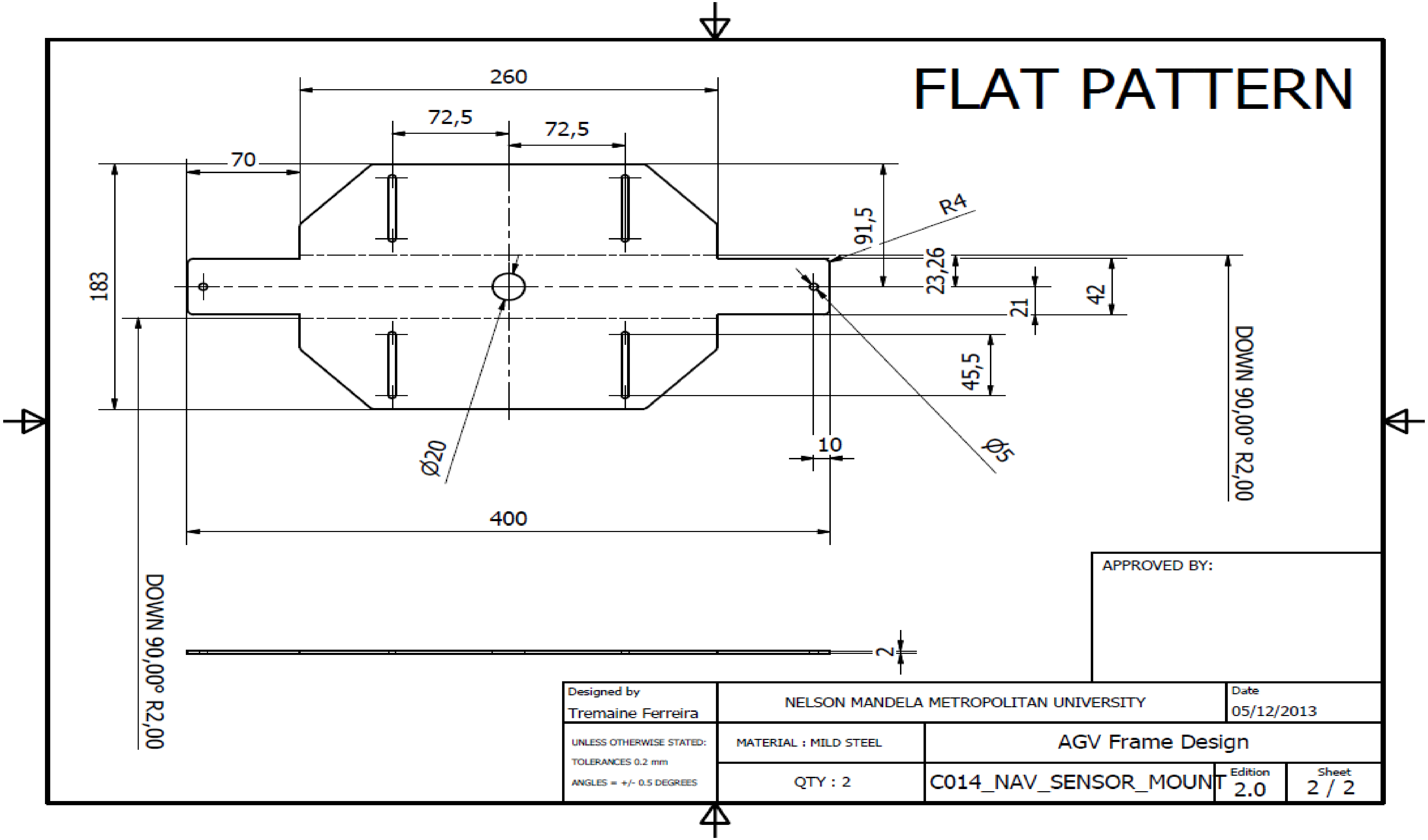
FOLDED VIEW

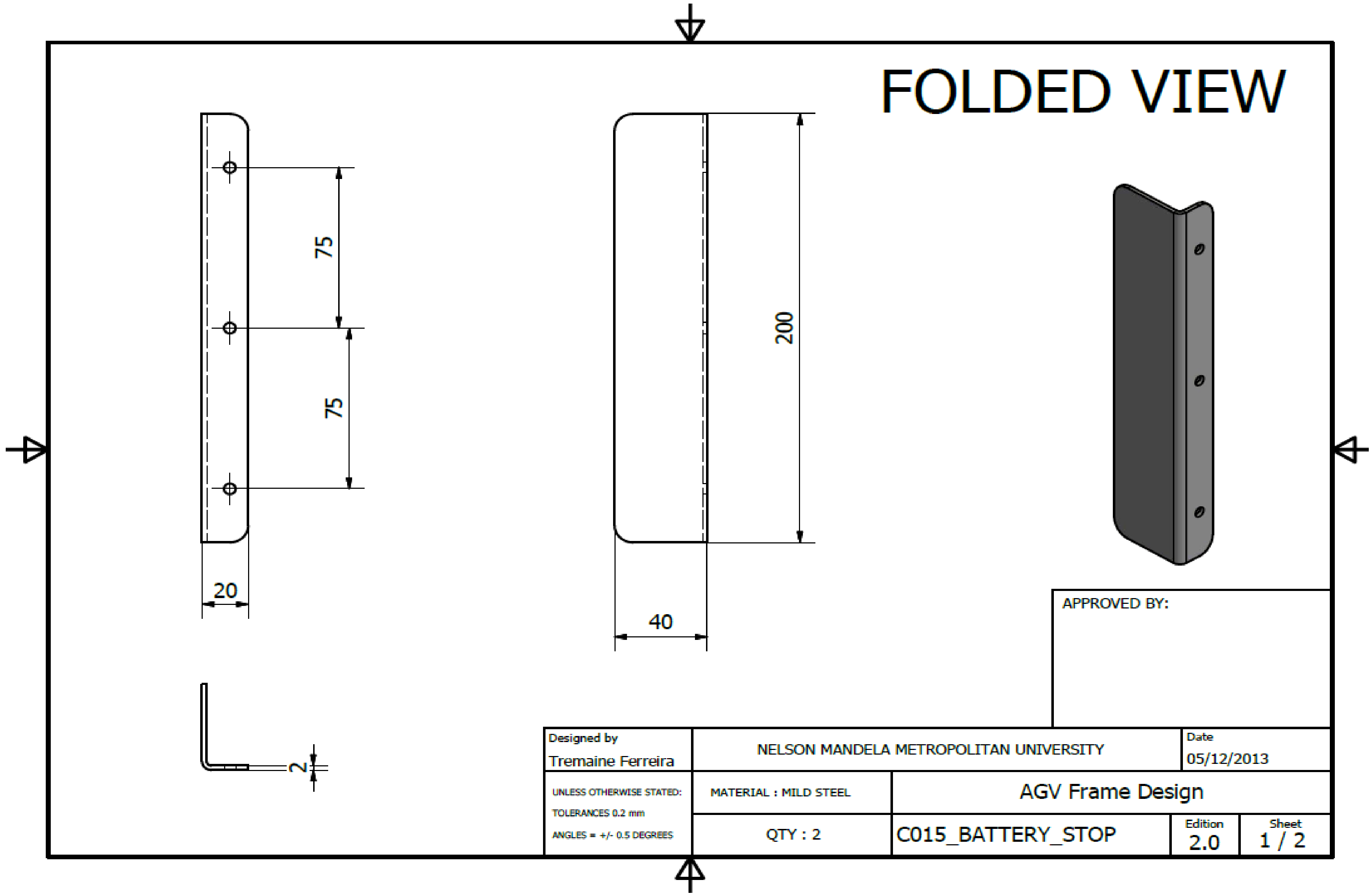




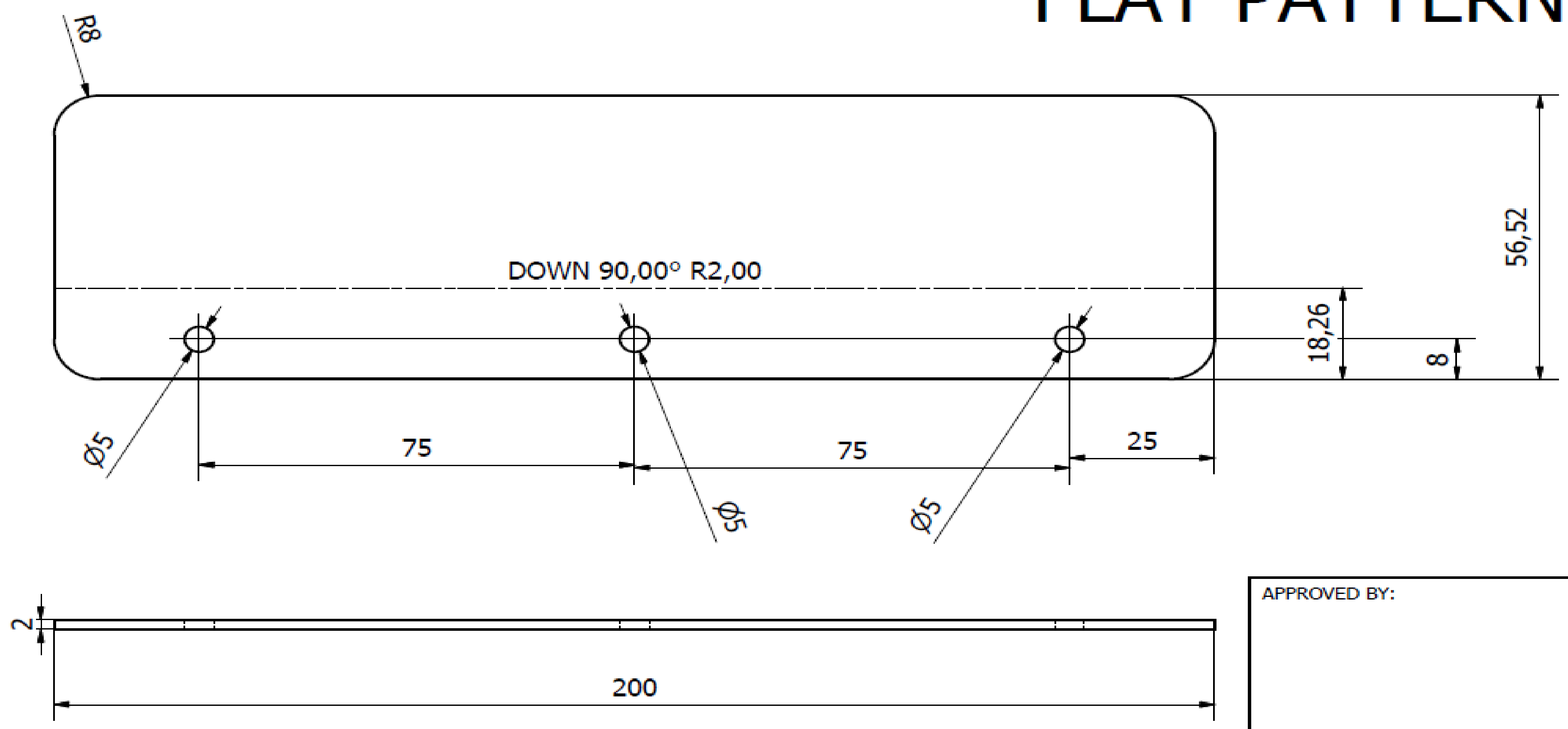
APPROVED BY:

Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013	
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C014_NAV_SENSOR_MOUNT	Edition 2.0	Sheet 1 / 2

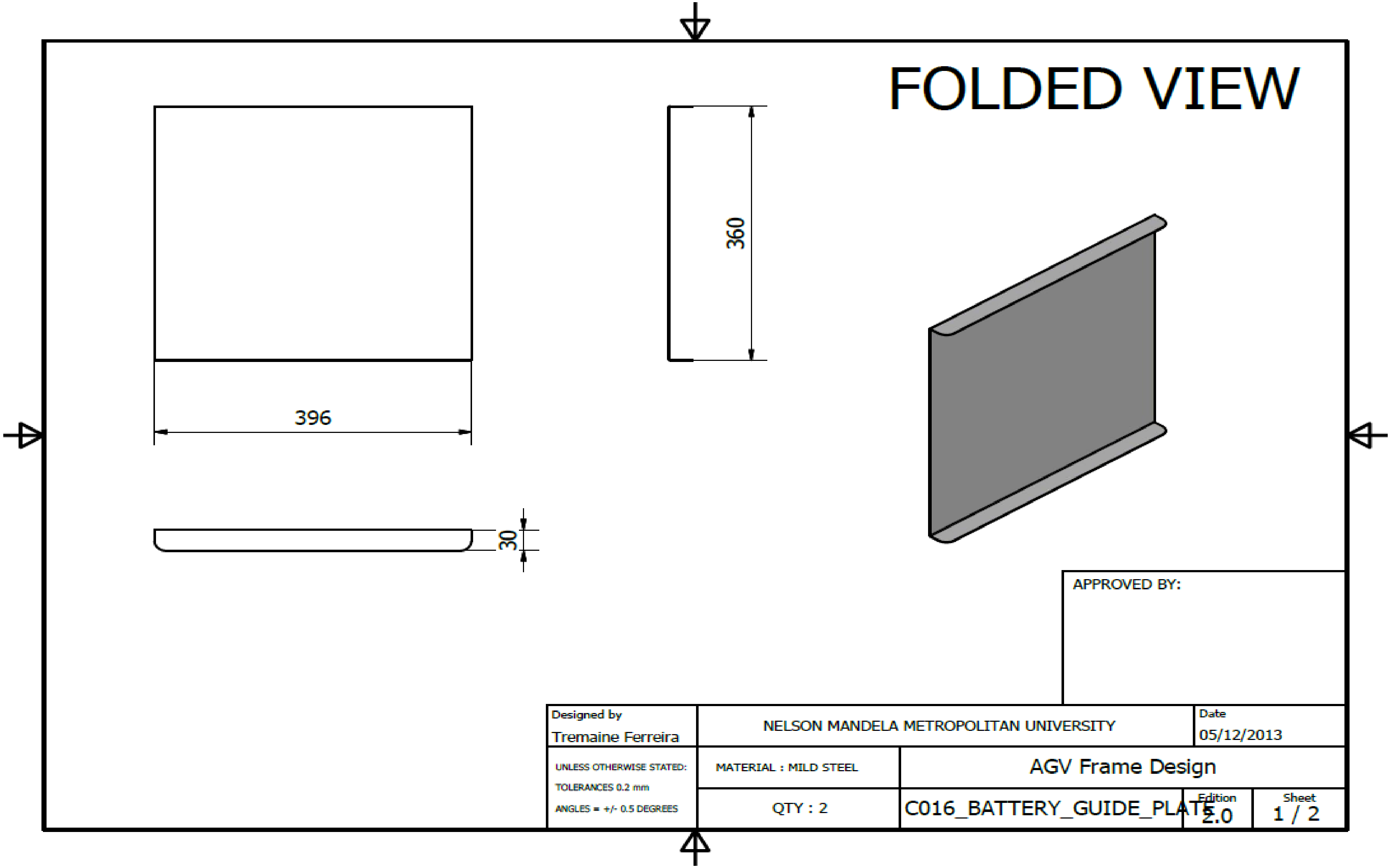

FLAT PATTERN
260
72,5
72,5
70
183
91,5
R4
23,26
21
42
45,5
Ø20
10
Ø5
400
DOWN 90,00° R2,00
DOWN 90,00° R2,00
2
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C014_NAV_SENSOR_MOUNT
Edition
2.0
Sheet
2 / 2


FOLDED VIEW
75
75
20
200
40
2
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C015_BATTERY_STOP
Edition
2.0
Sheet
1 / 2

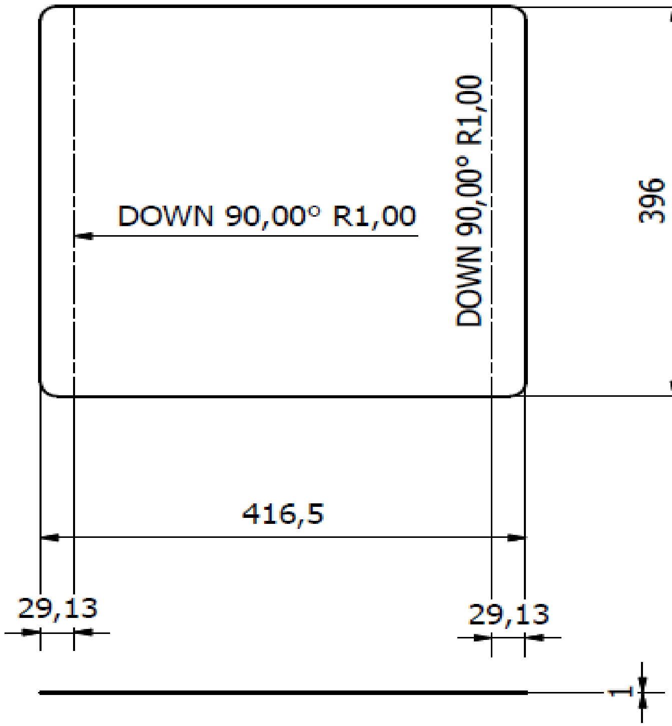
FLAT PATTERN



		APPROVED BY:	
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design	
	QTY : 2	C015_BATTERY_STOP	Edition 2.0 / Sheet 2 / 2

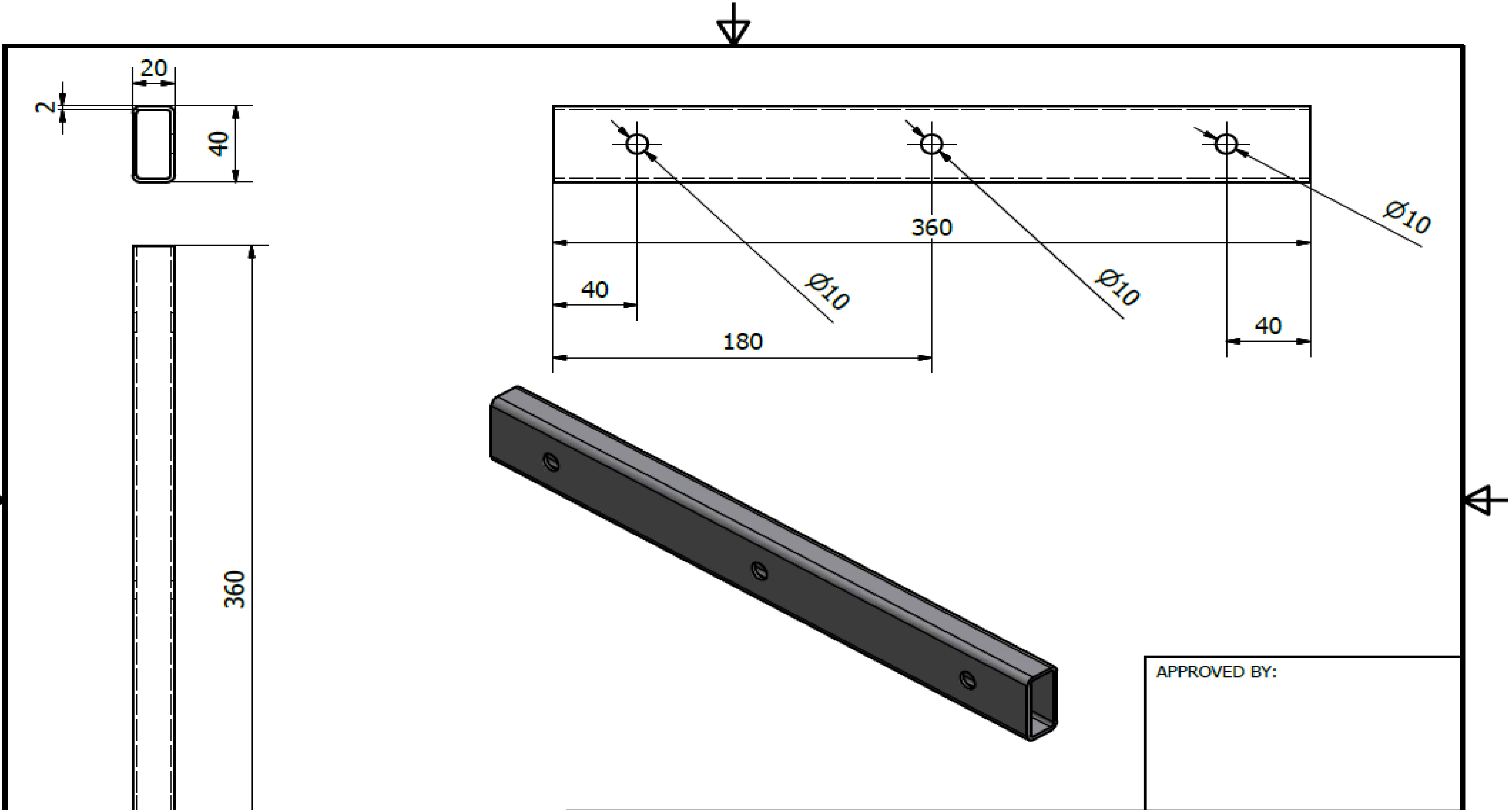

FOLDED VIEW
396
360
30
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C016_BATTERY_GUIDE_PLATE
Edition
2.0
Sheet
1 / 2

FLAT PATTERN



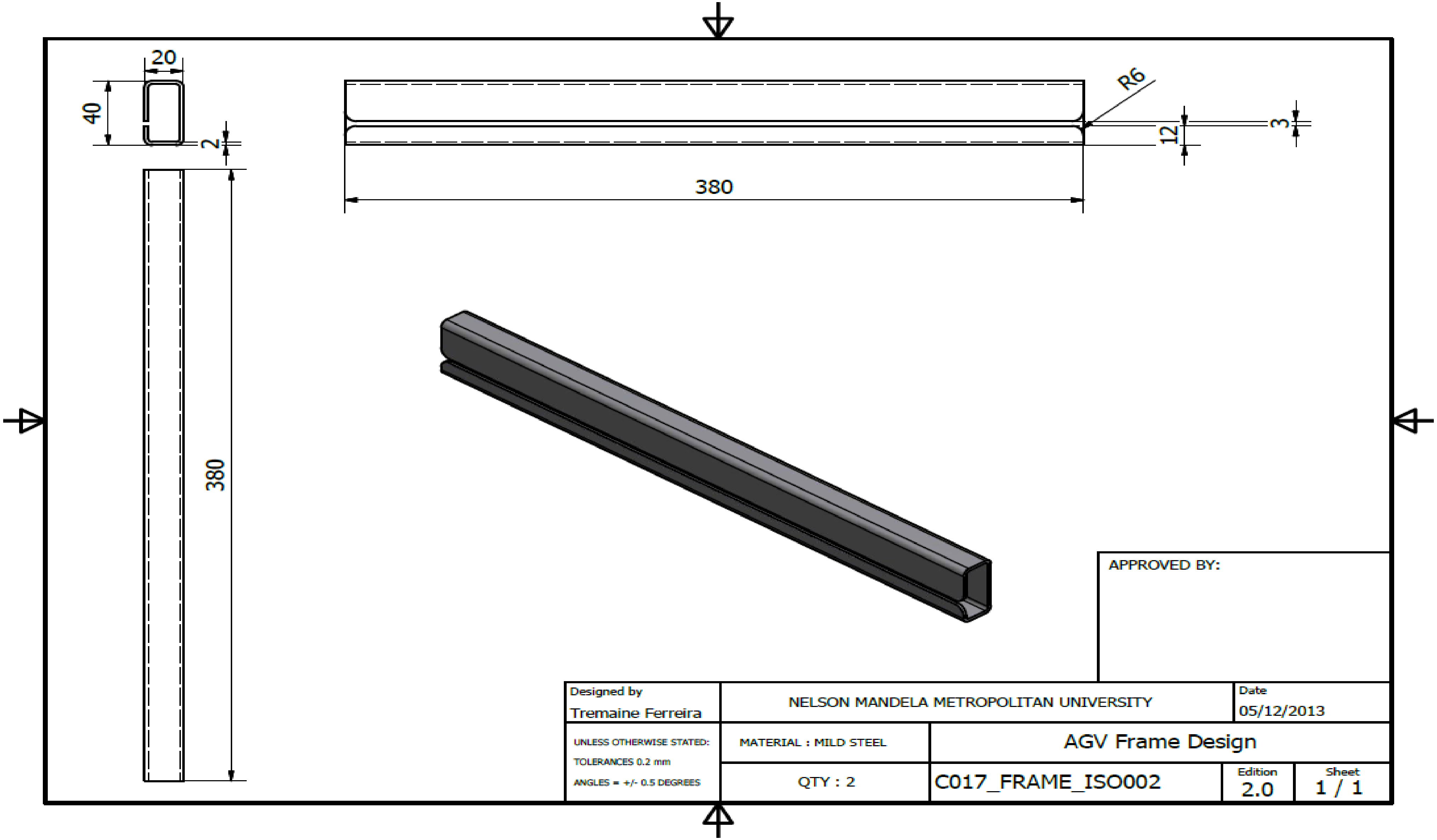
APPROVED BY:

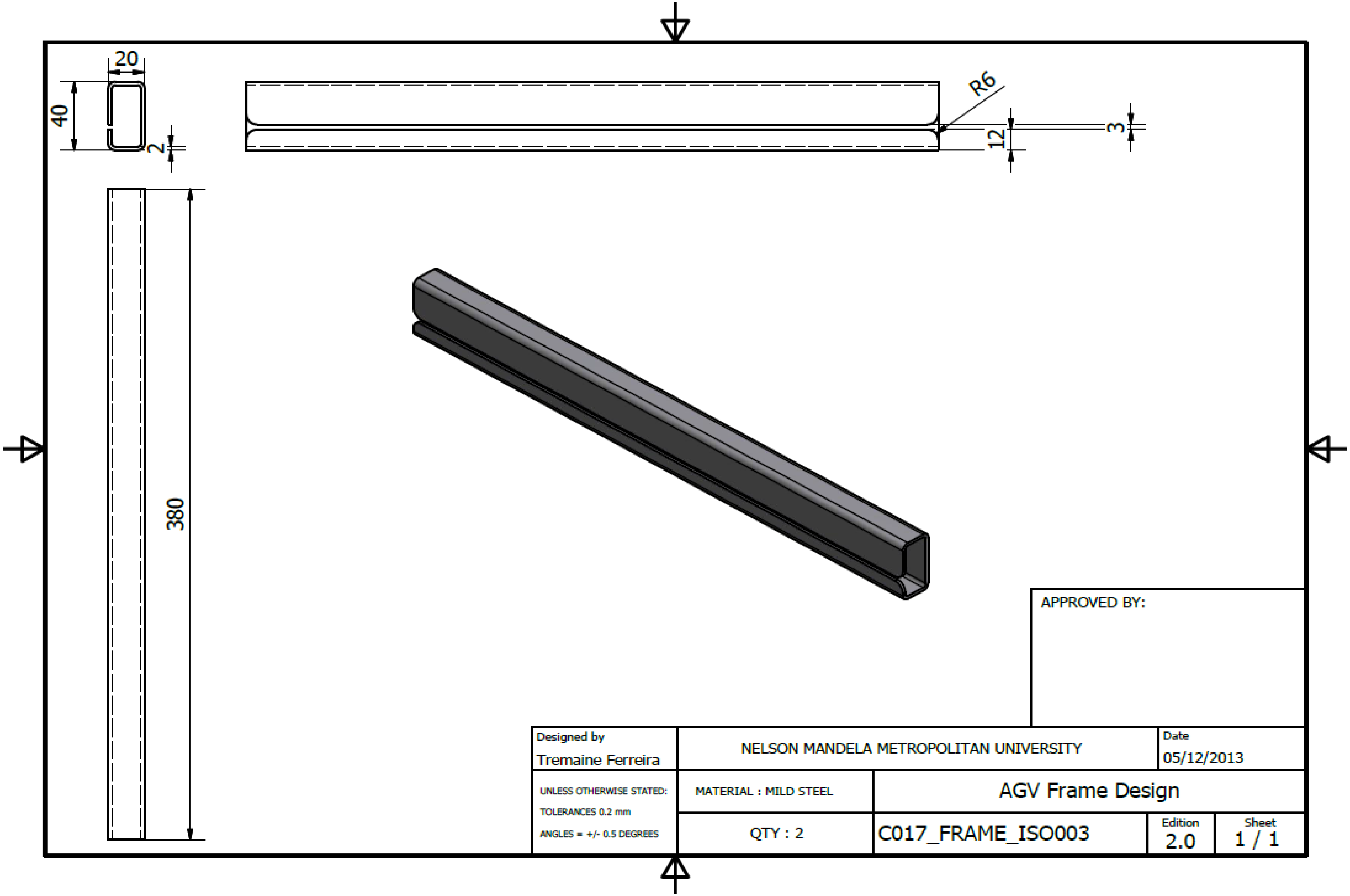
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design	
	QTY : 2	C016_BATTERY_GUIDE_PLATE	Edition 2.0 · Sheet 2 / 2



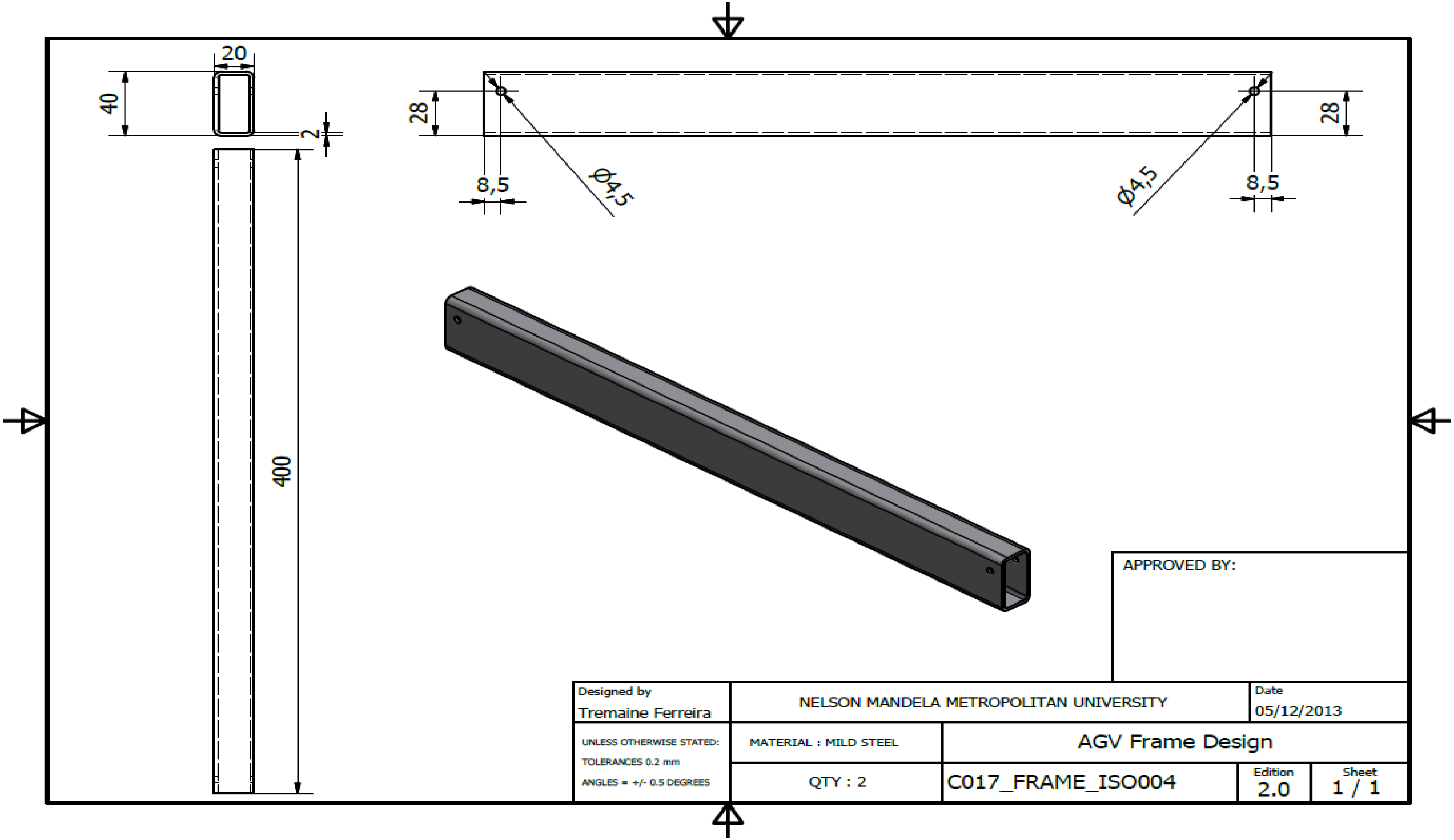
APPROVED BY:

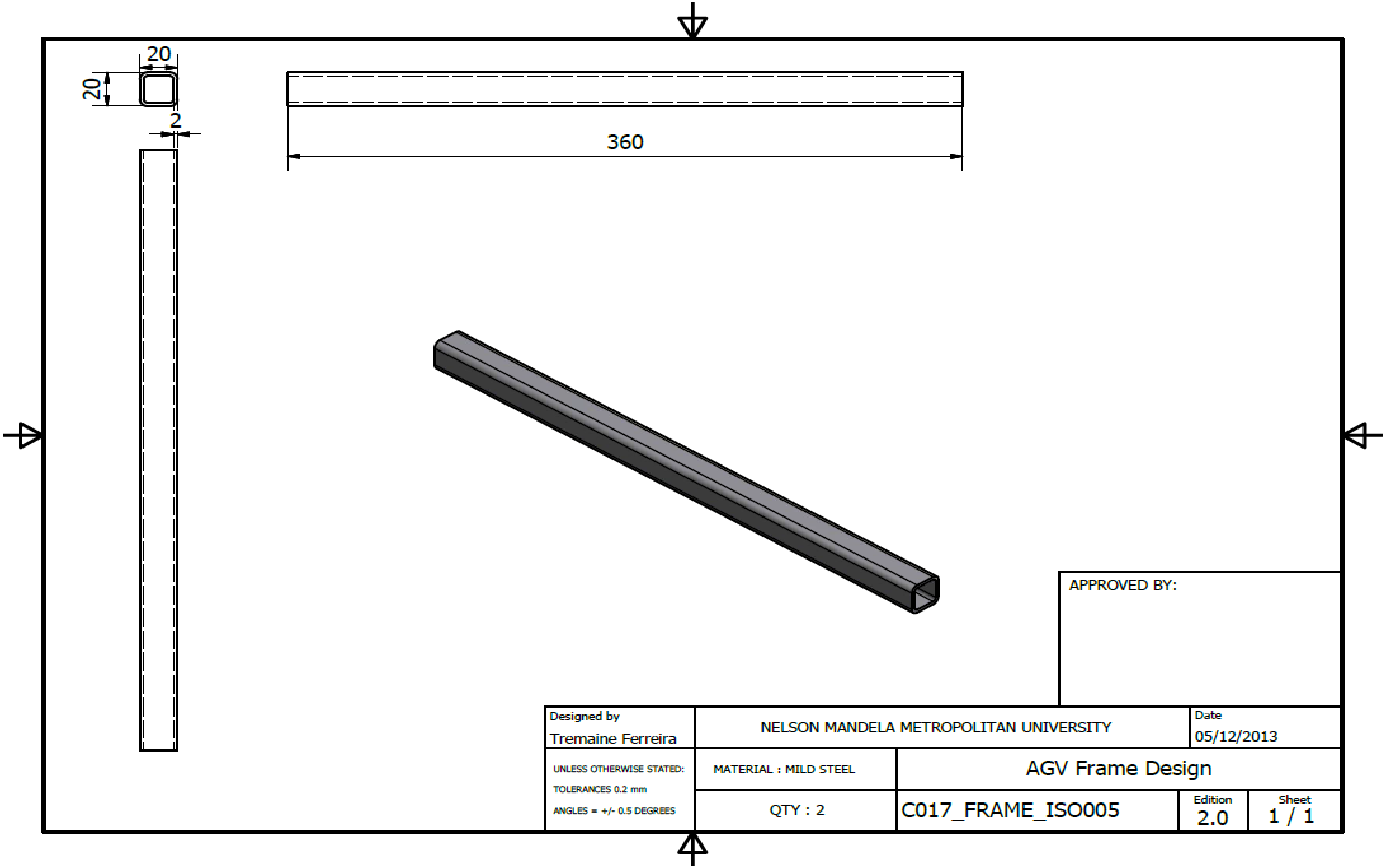
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013	
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C017_FRAME_ISO001	Edition 2.0	Sheet 1 / 1

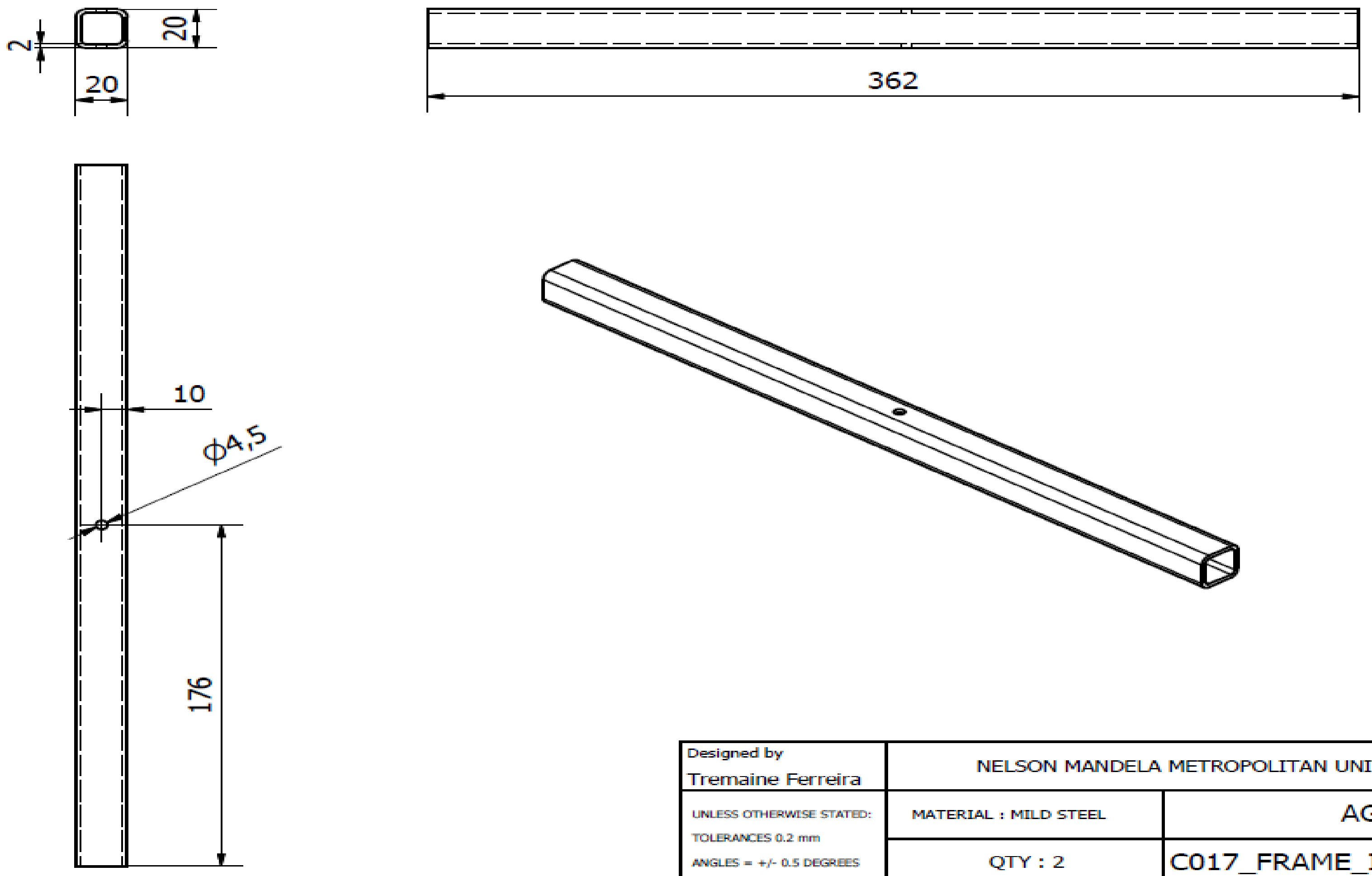

20
40
2
R6
12
3
380
380
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C017_FRAME_ISO002
Edition
2.0
Sheet
1 / 1



Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY			Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C017_FRAME_ISO003	Edition 2.0	Sheet 1 / 1

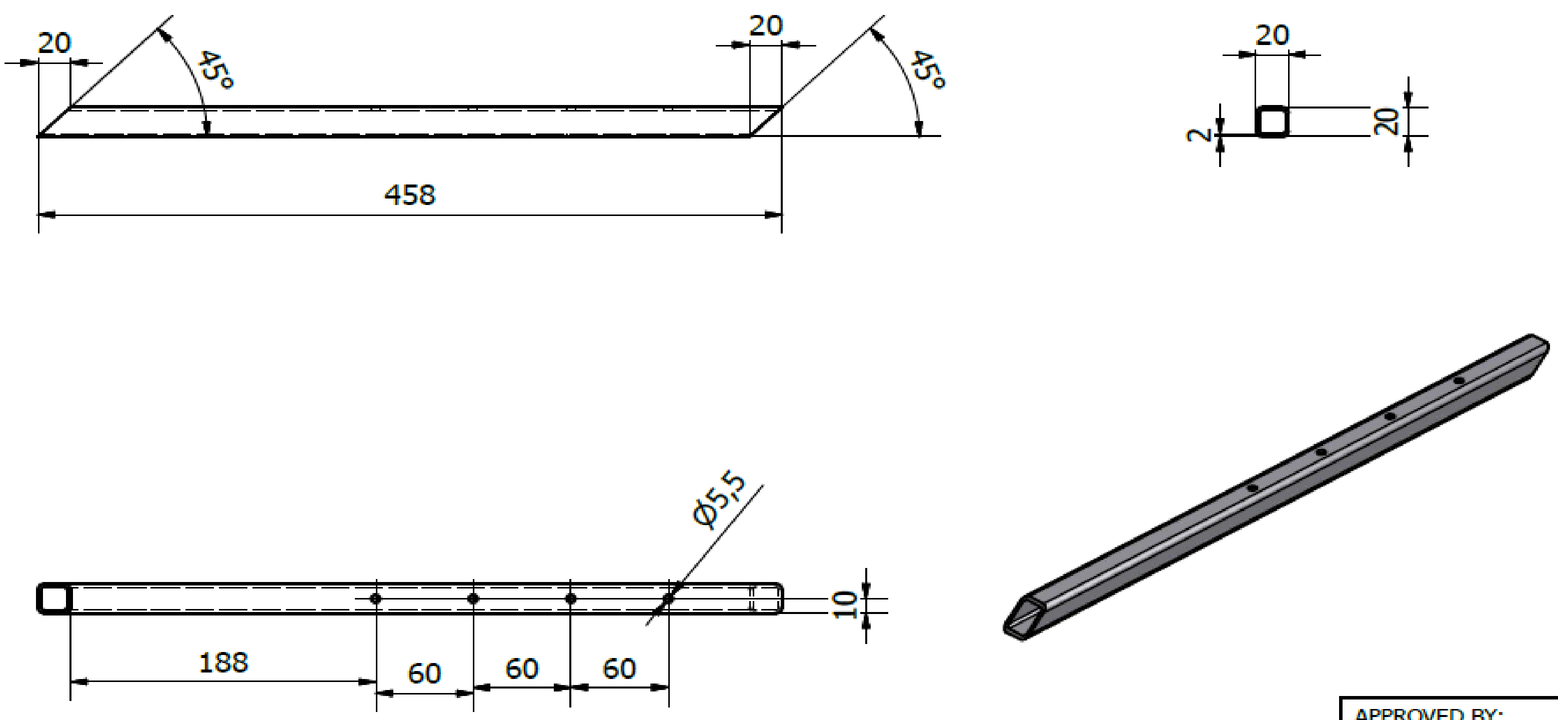

20
40
2
400
28
8,5
Ø4,5
Ø4,5
8,5
28
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C017_FRAME_ISO004
Edition
2.0
Sheet
1 / 1


20
20
2
360
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C017_FRAME_ISO005
Edition
2.0
Sheet
1 / 1



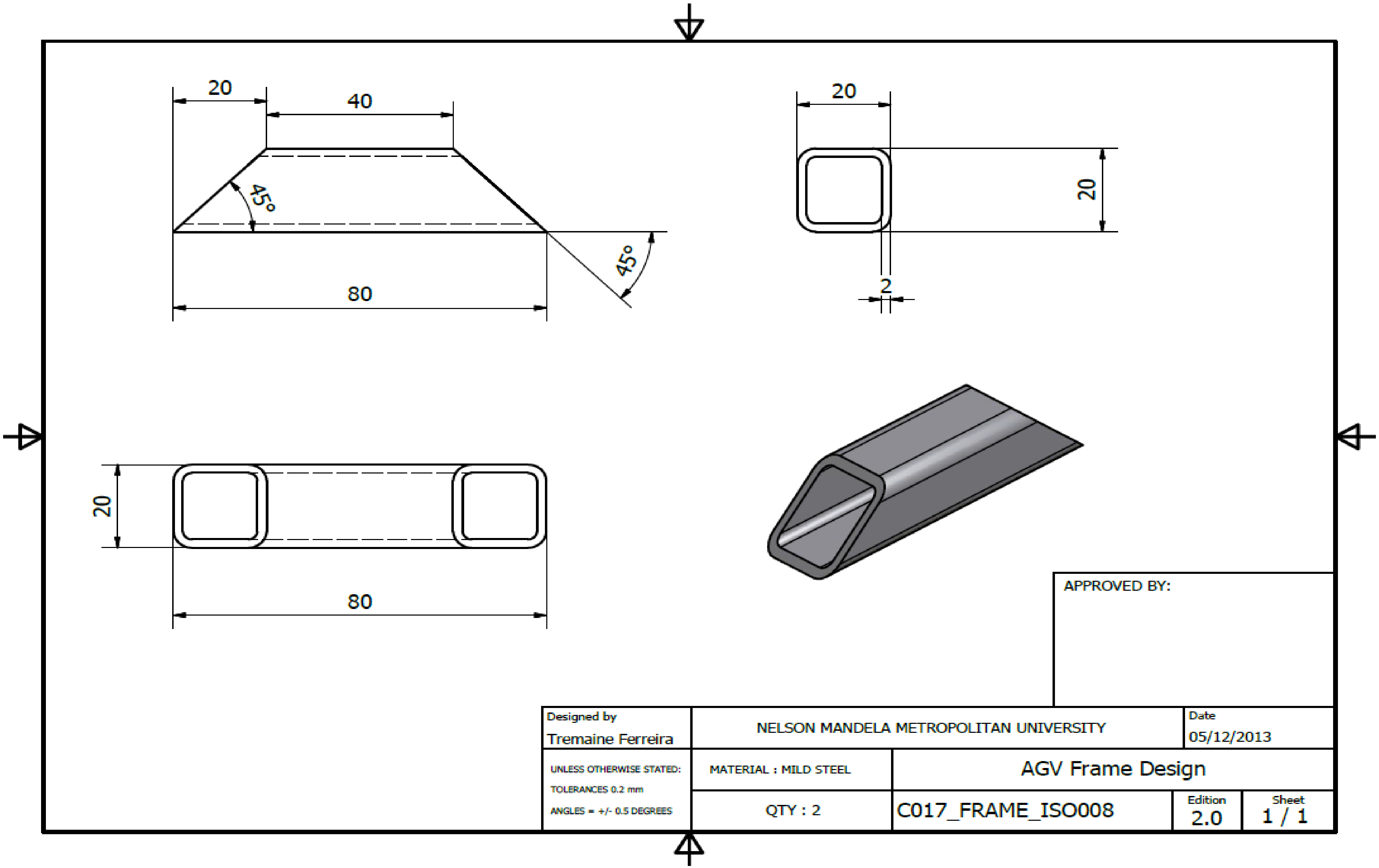
APPROVED BY:

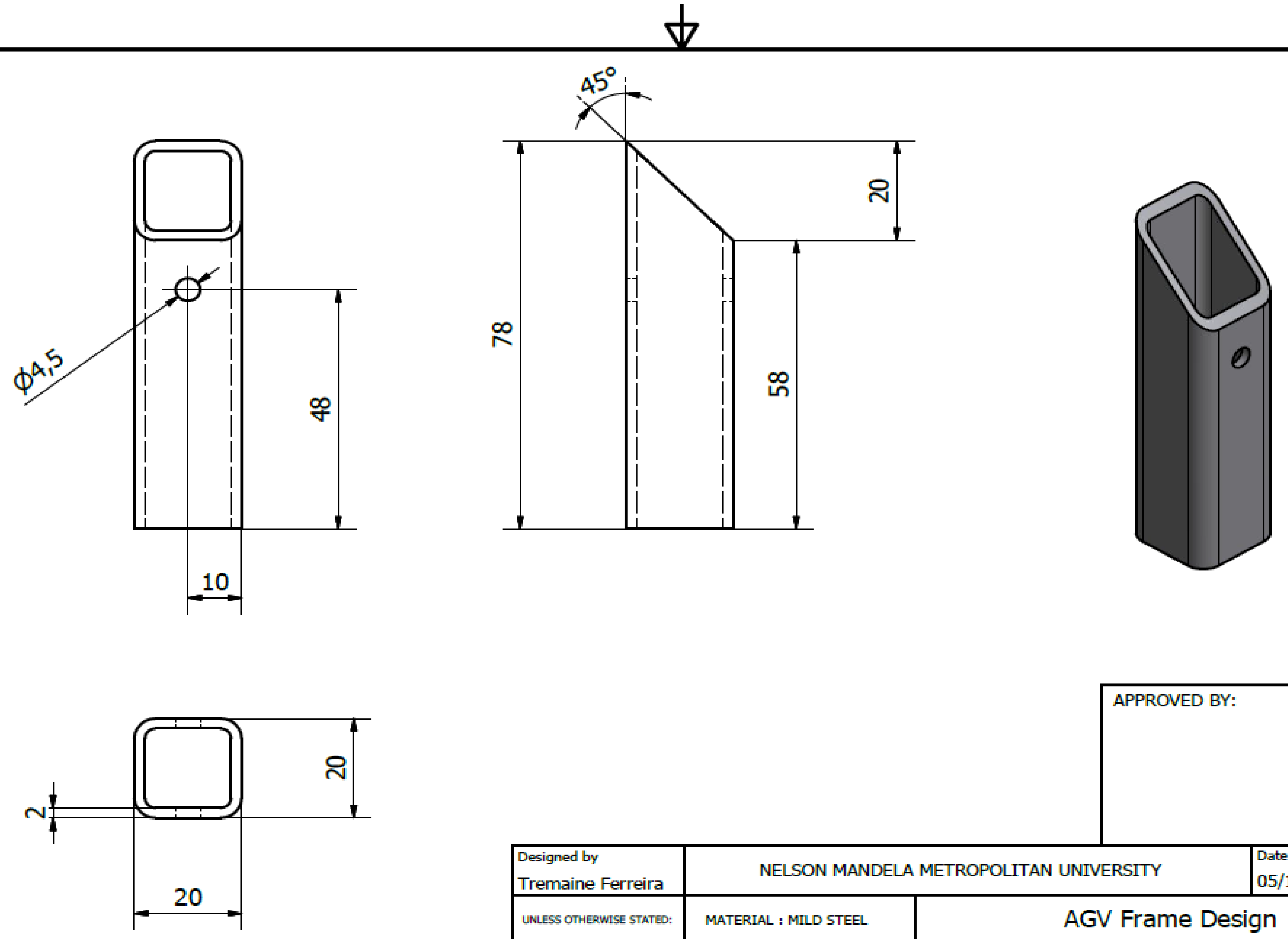
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY			Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C017_FRAME_ISO006	Edition 2.0	Sheet 1 / 1



APPROVED BY:

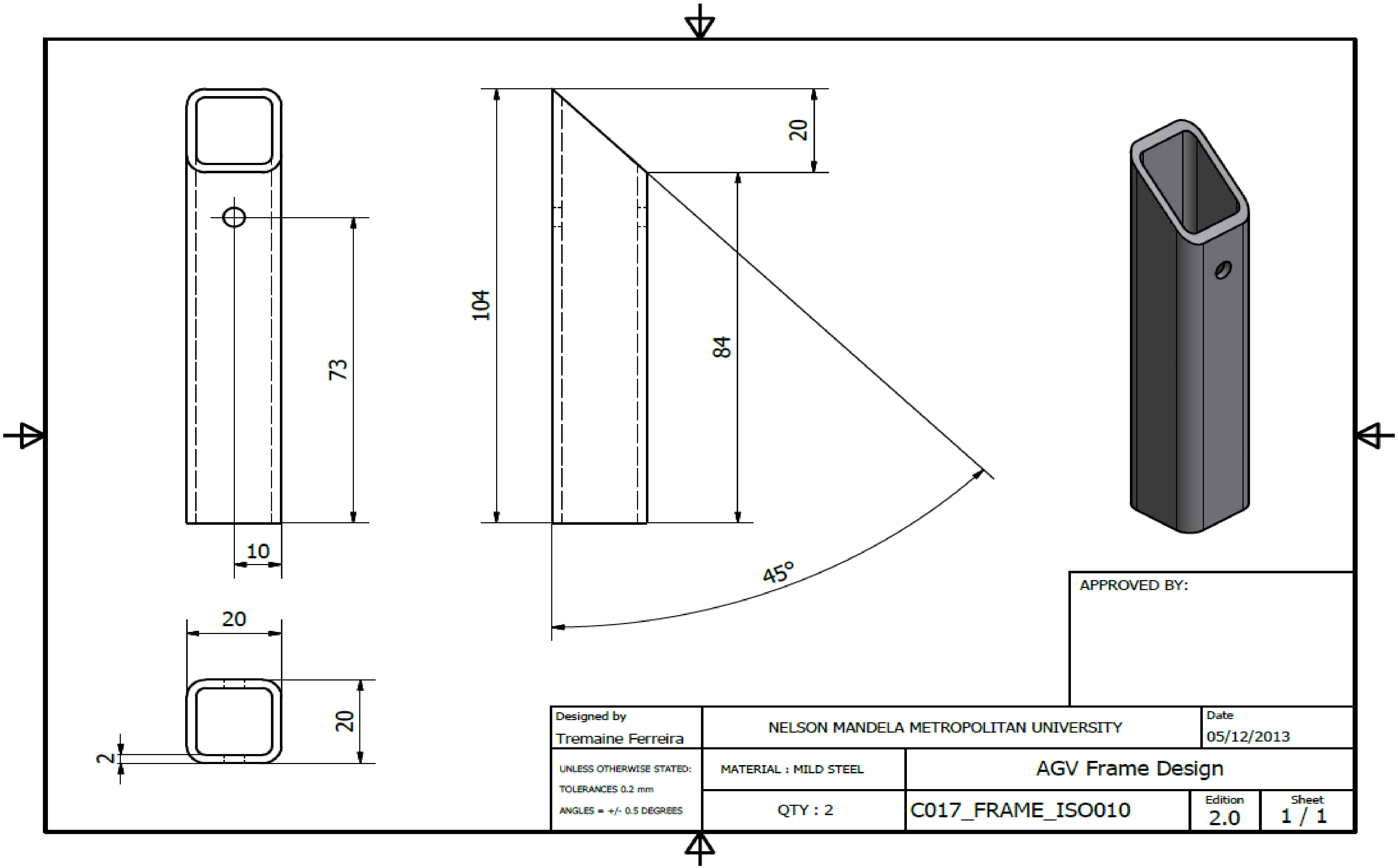
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY	Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design
	QTY : 2	C017_FRAME_ISO007
		Edition 2.0
		Sheet 1 / 1

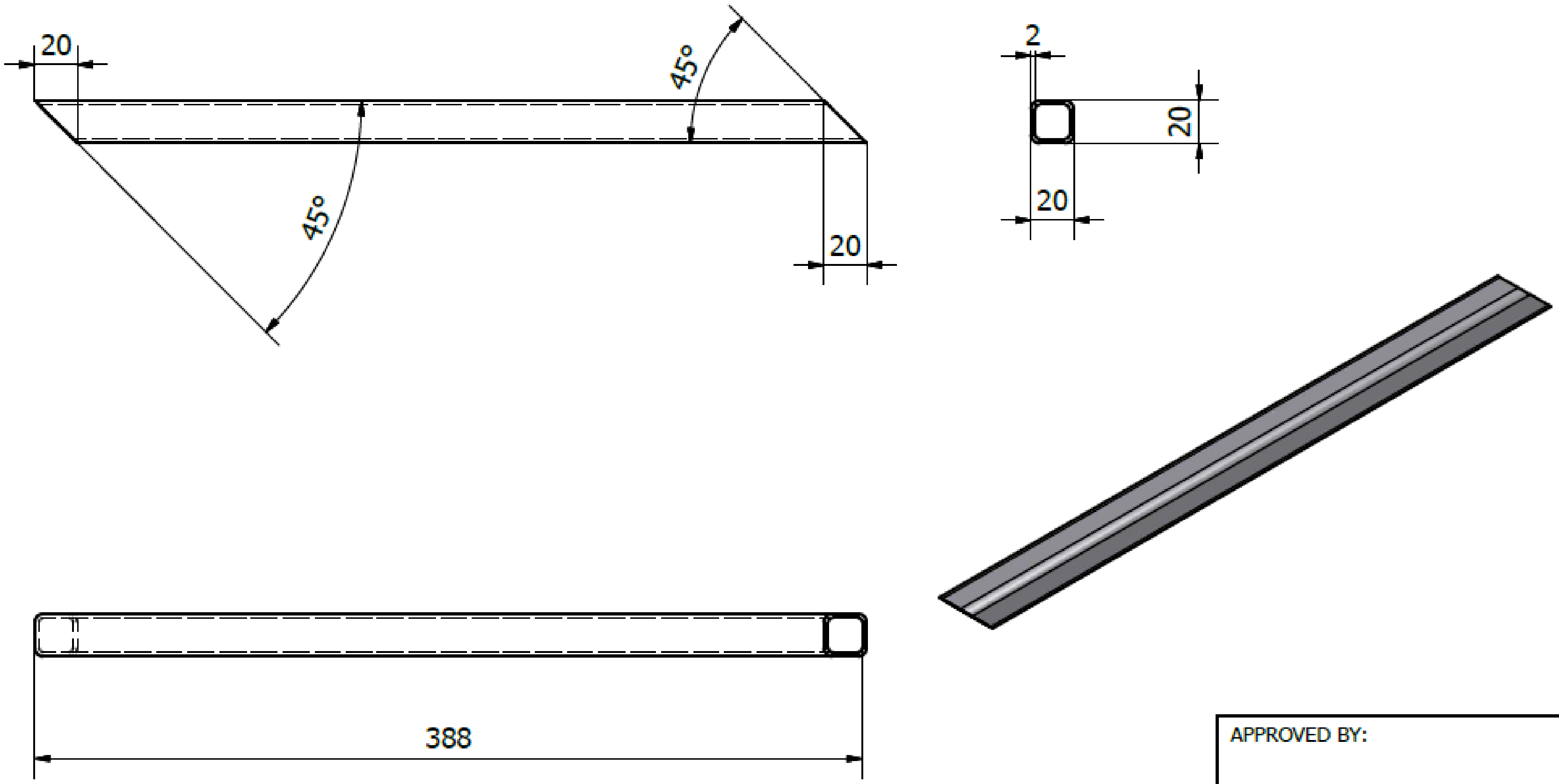

20
40
45°
45°
80
20
20
2
20
80
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C017_FRAME_ISO008
Edition
2.0
Sheet
1 / 1



APPROVED BY:

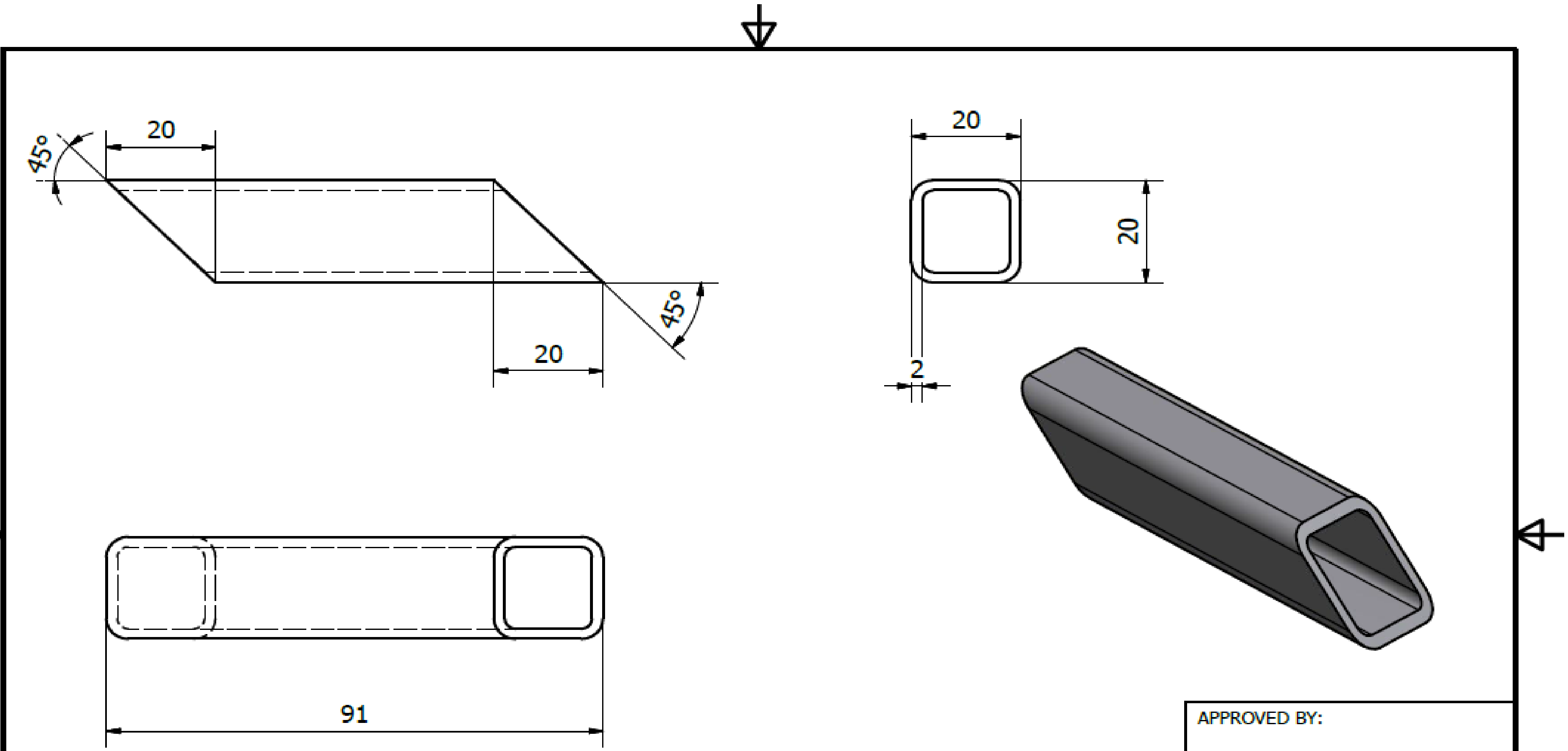
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design	
	QTY : 2	C017_FRAME_ISO009	Edition 2.0 / Sheet 1 / 1


73
10
20
20
2
104
20
84
45°
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C017_FRAME_ISO010
Edition
2.0
Sheet
1 / 1



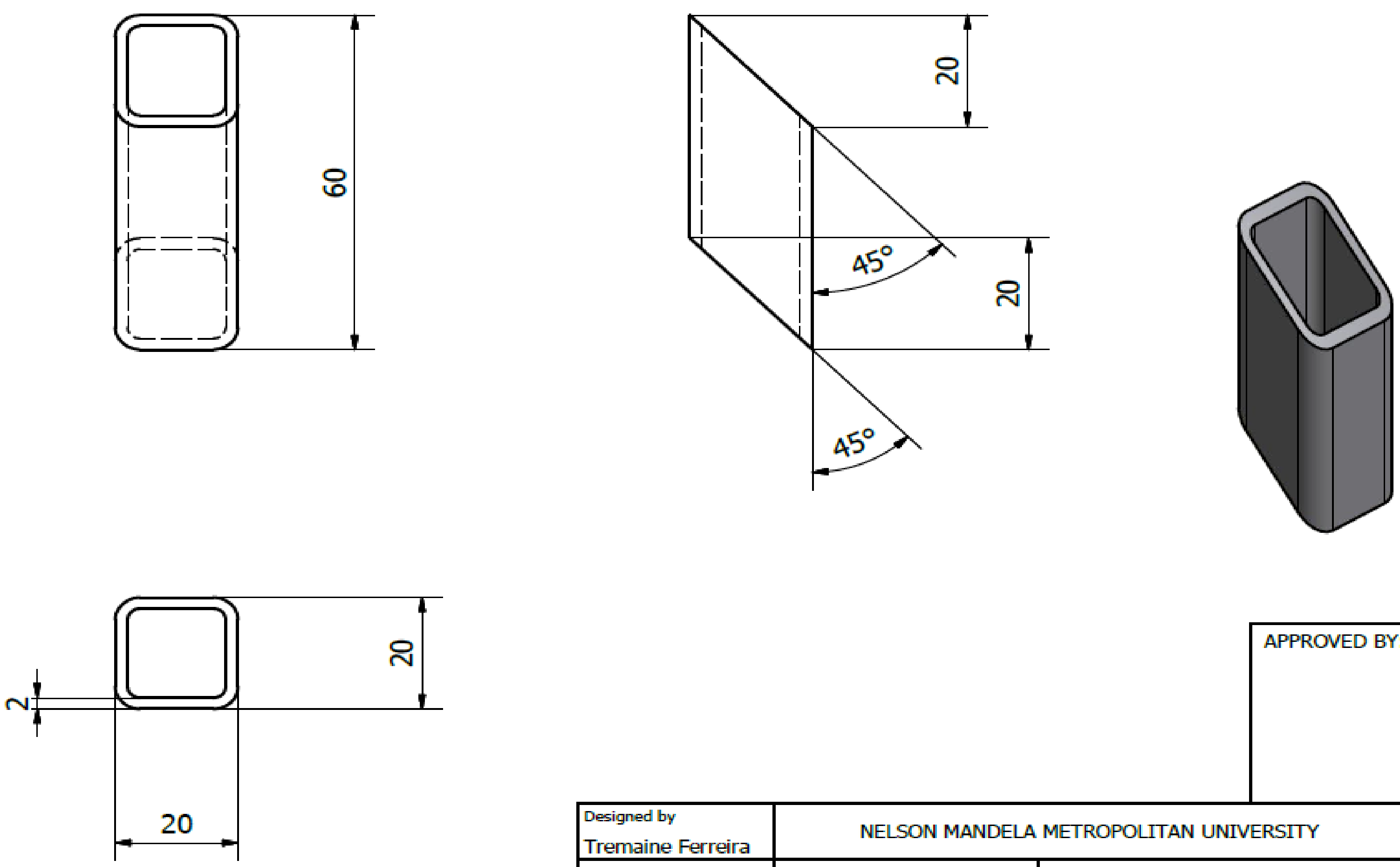
APPROVED BY:

Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY			Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C017_FRAME_ISO011	Edition 2.0	Sheet 1 / 1



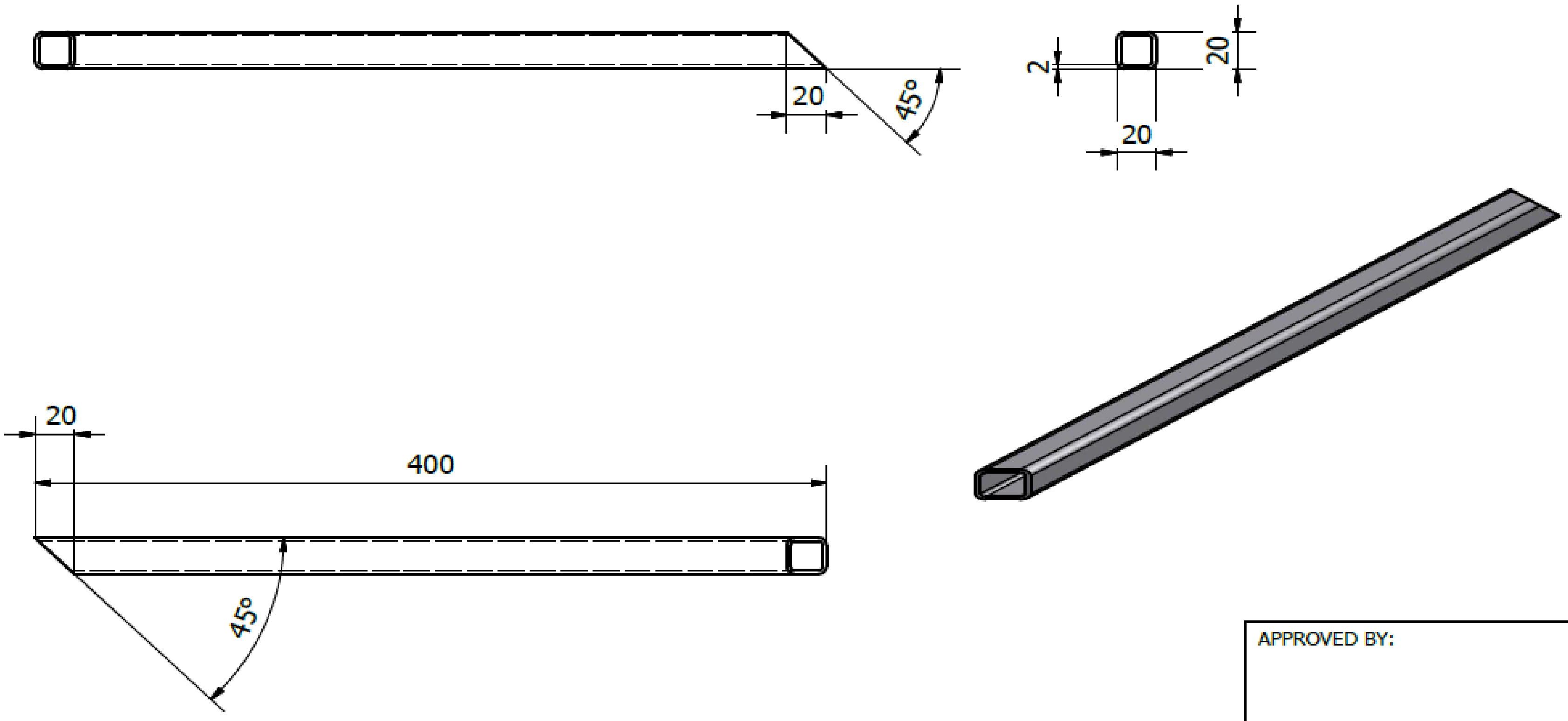
APPROVED BY:

Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design	
	QTY : 2	C017_FRAME_ISO012	Edition 2.0 / Sheet 1 / 1

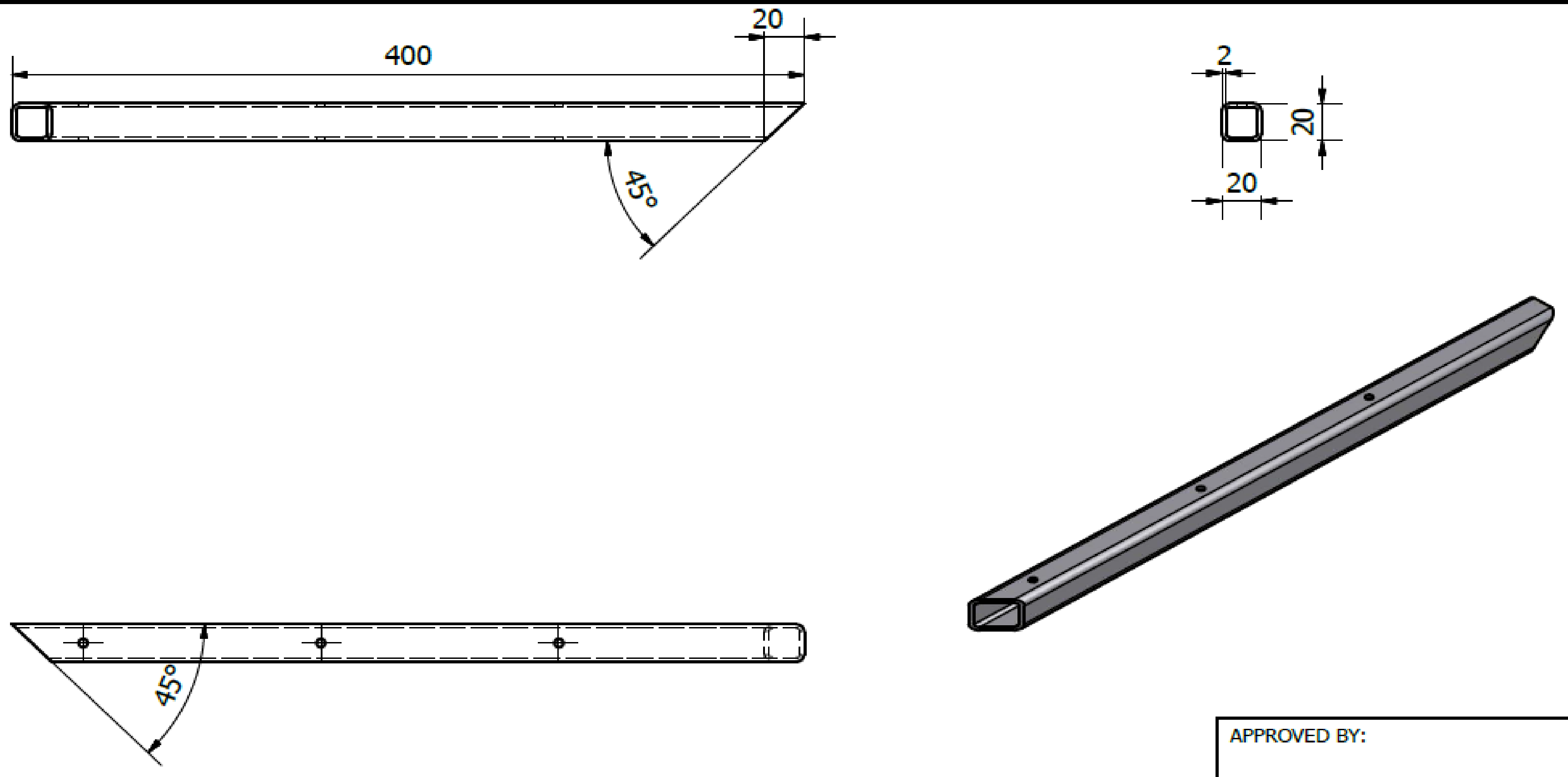


APPROVED BY:		

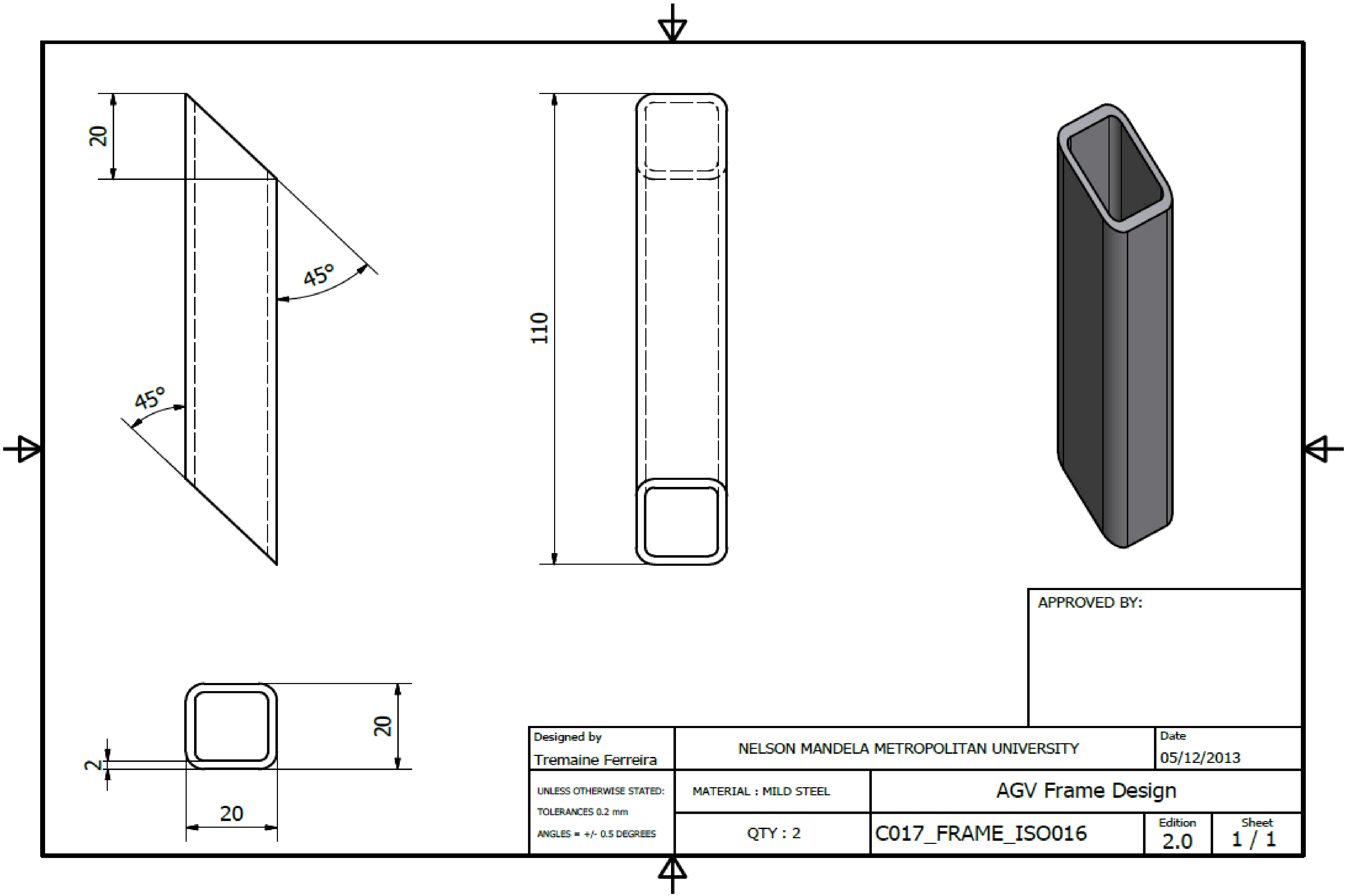
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY			Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C017_FRAME_ISO013	Edition 2.0	Sheet 1 / 1



		APPROVED BY:	
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design	
	QTY : 2	C017_FRAME_ISO014	Edition 2.0 / Sheet 1 / 1



APPROVED BY:			
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design	
	QTY : 2	C017_FRAME_ISO015	Edition 2.0 / Sheet 1 / 1



Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY			Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
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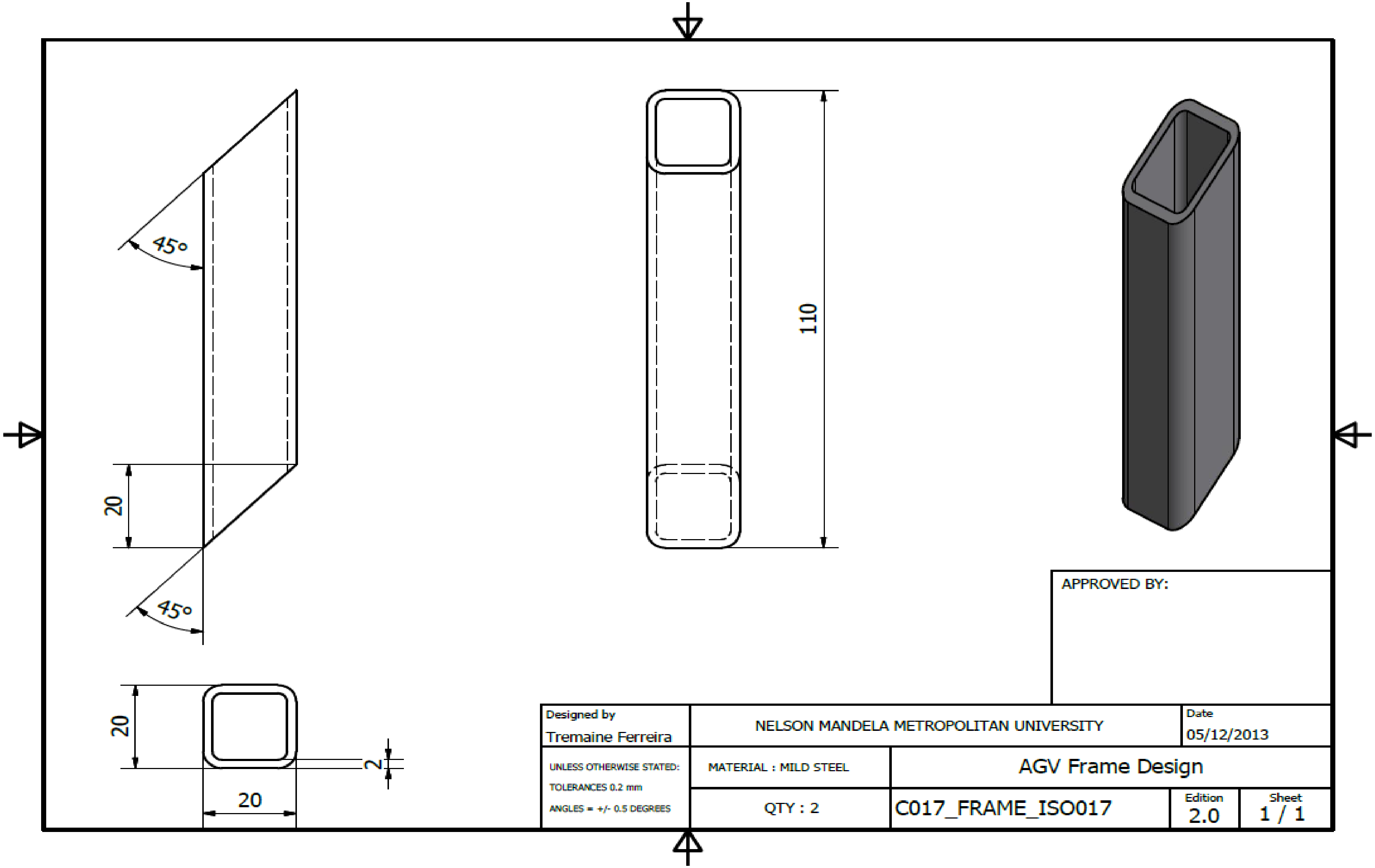
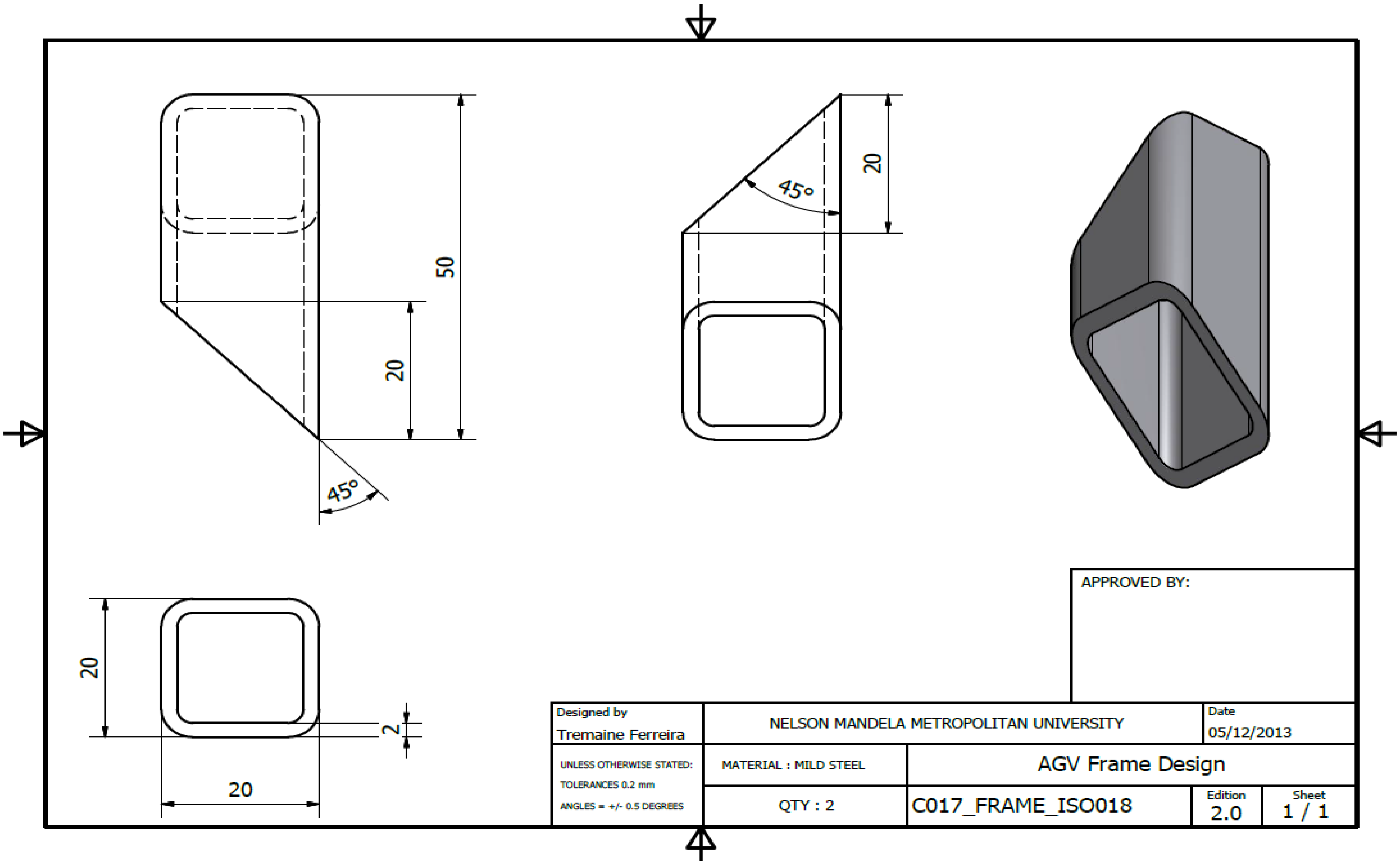
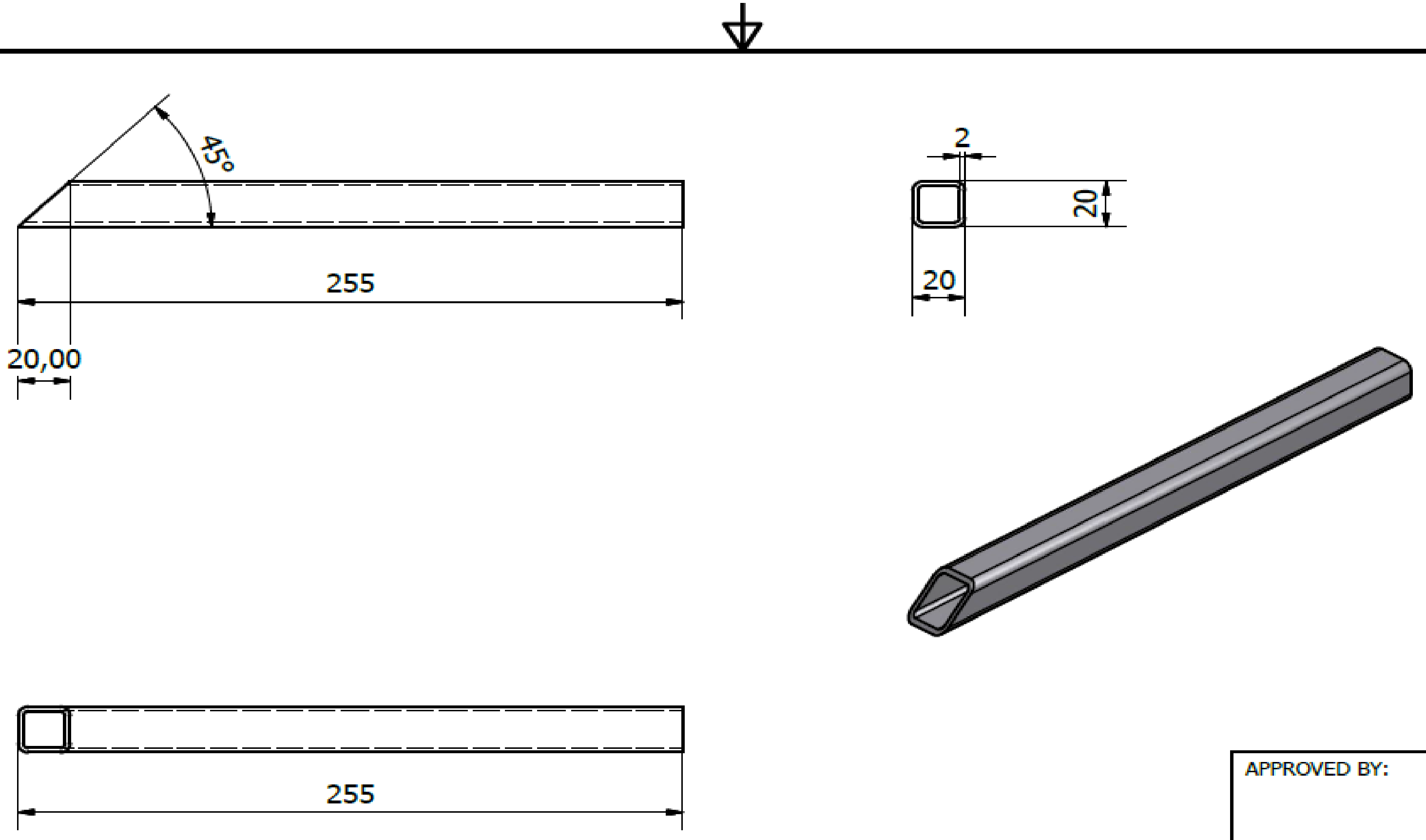
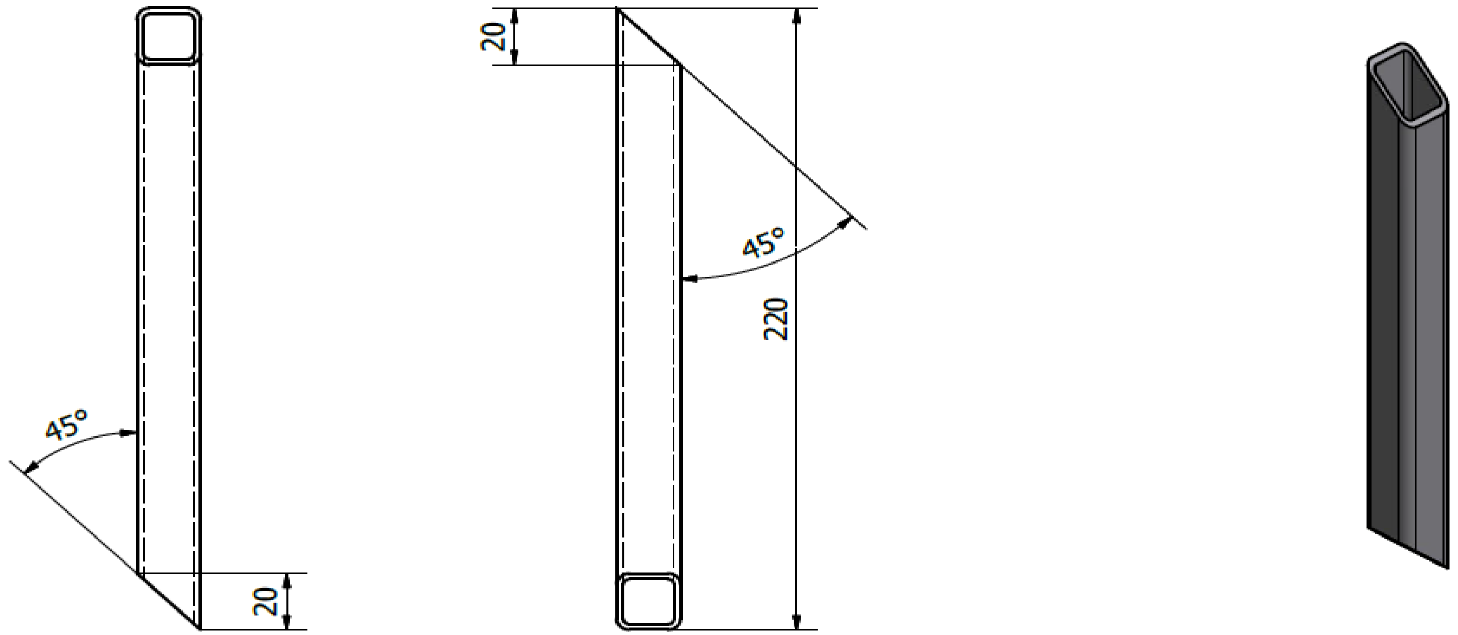

45°
45°
20
110
20
20
2
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C017_FRAME_ISO017
Edition
2.0
Sheet
1 / 1

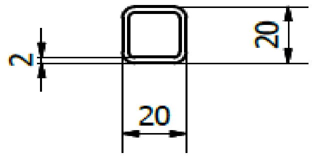

50
20
45°
20
45°
20
2
20
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C017_FRAME_ISO018
Edition
2.0
Sheet
1 / 1



APPROVED BY:

Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY			Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C017_FRAME_ISO019	Edition 2.0	Sheet 1 / 1





APPROVED BY:

Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY			Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
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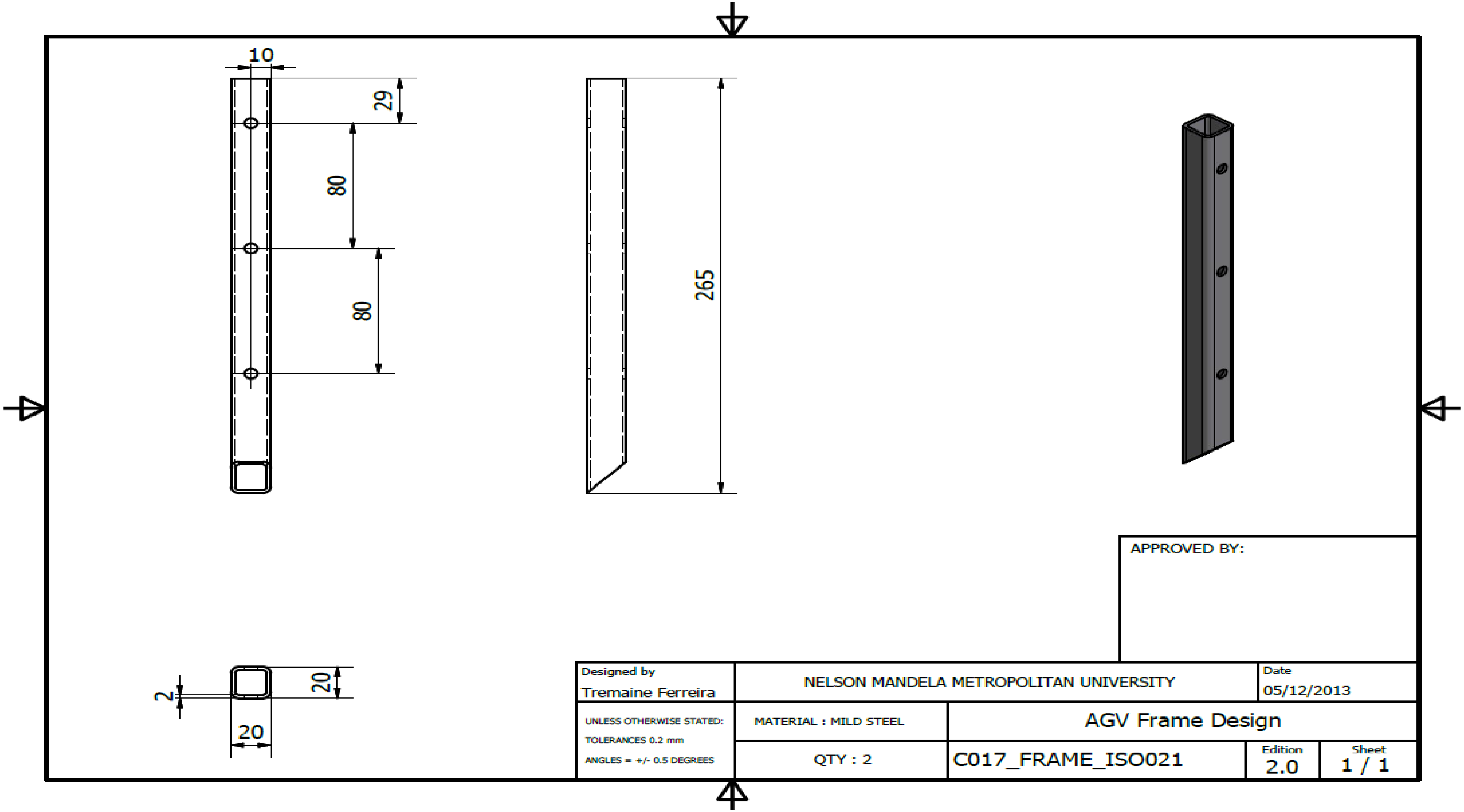
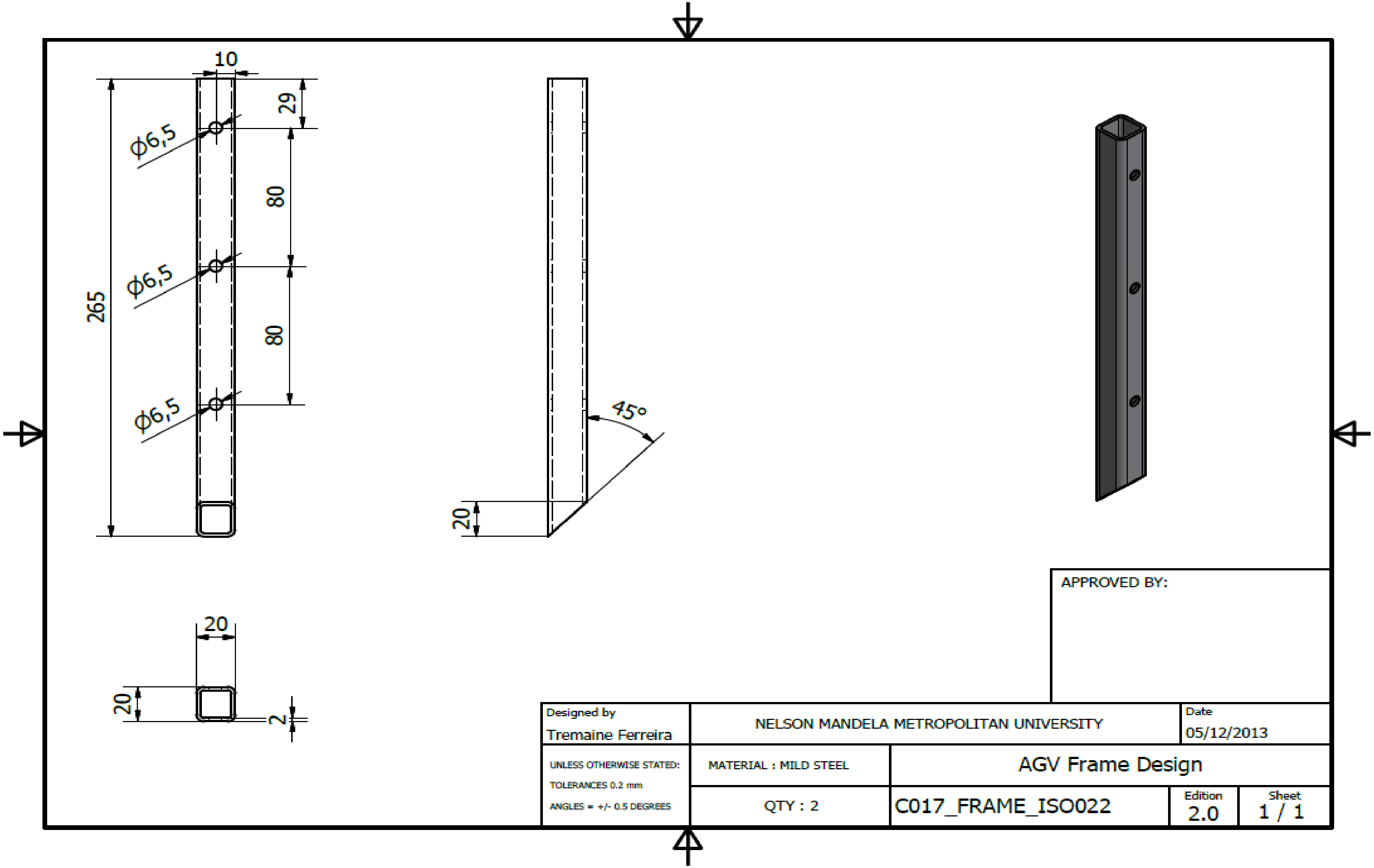
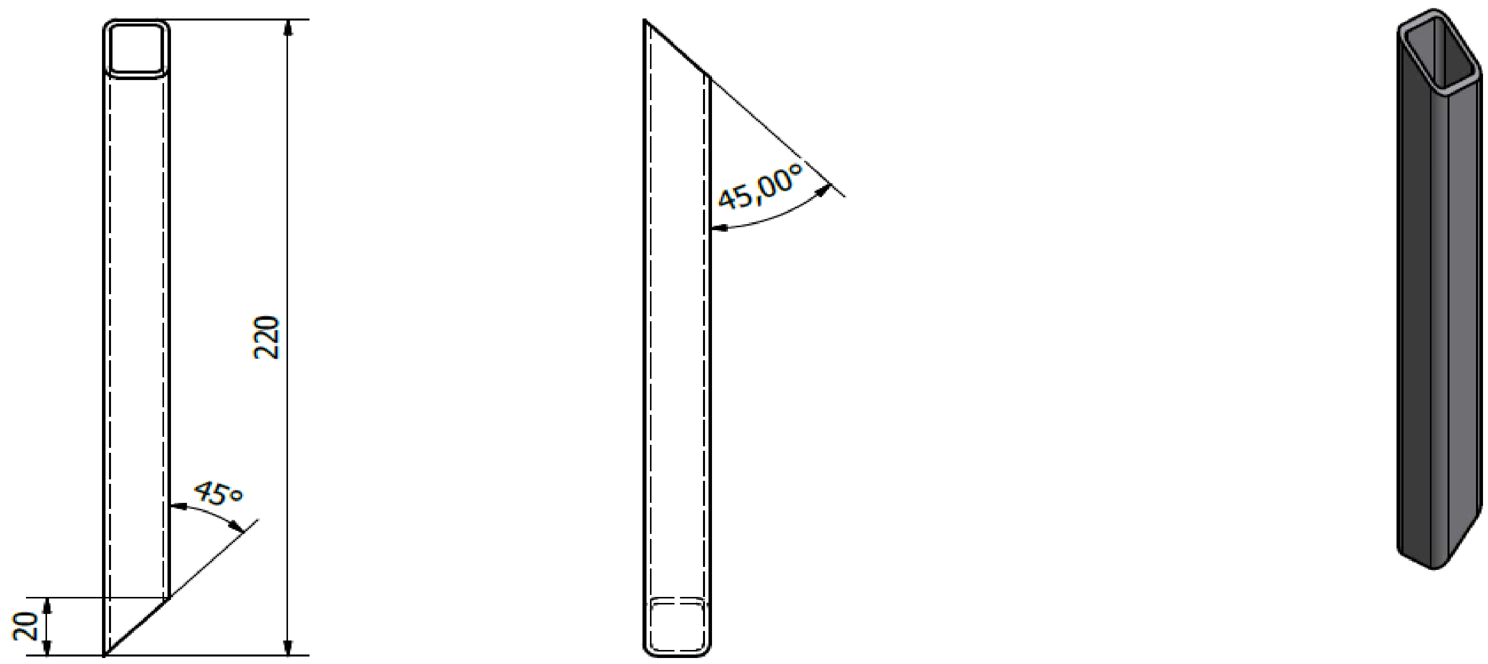
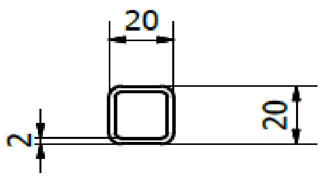

10
29
80
80
265
2
20
20
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C017_FRAME_ISO021
Edition
2.0
Sheet
1 / 1

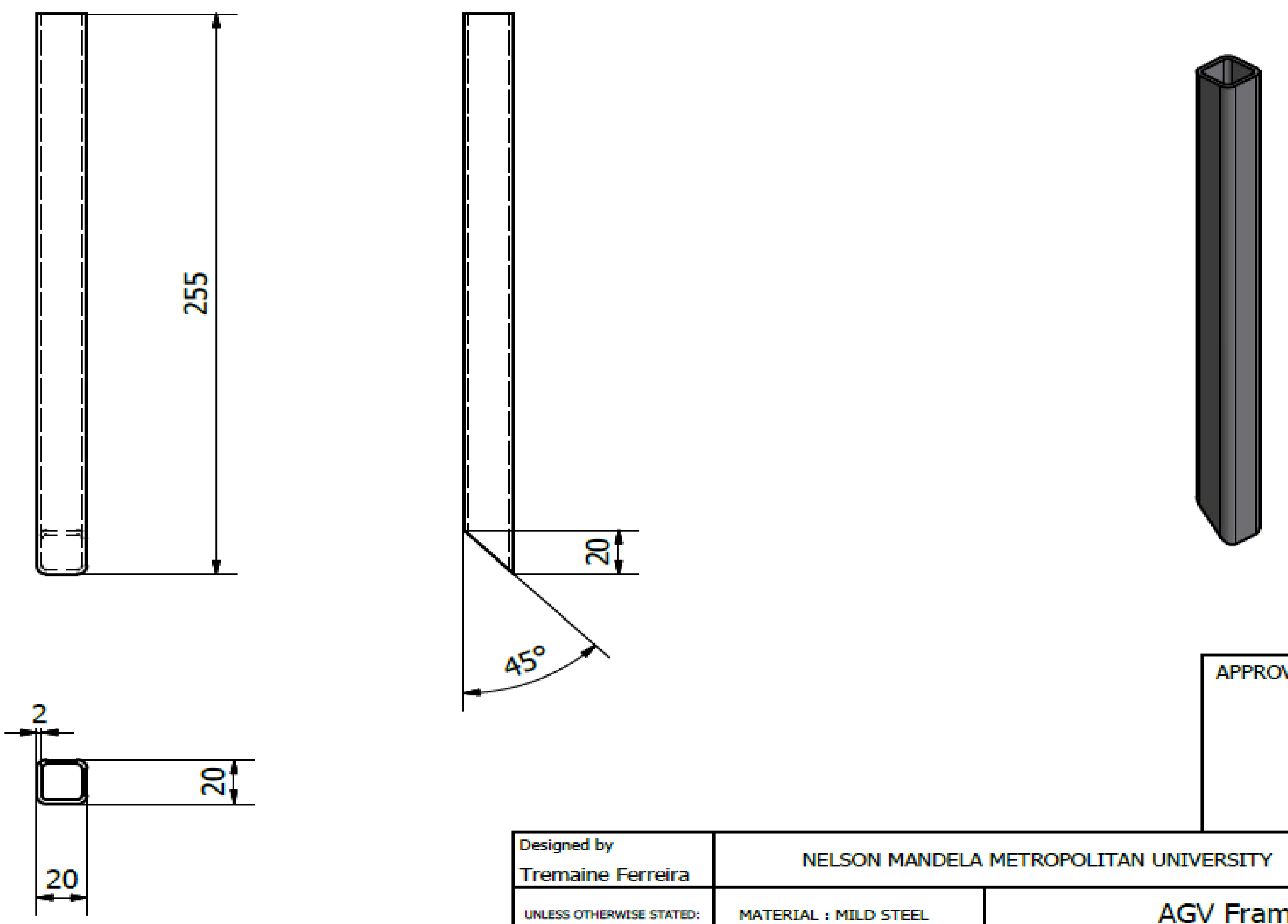

10
29
80
80
265
ϕ6,5
ϕ6,5
ϕ6,5
45°
20
20
20
2
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C017_FRAME_ISO022
Edition
2.0
Sheet
1 / 1





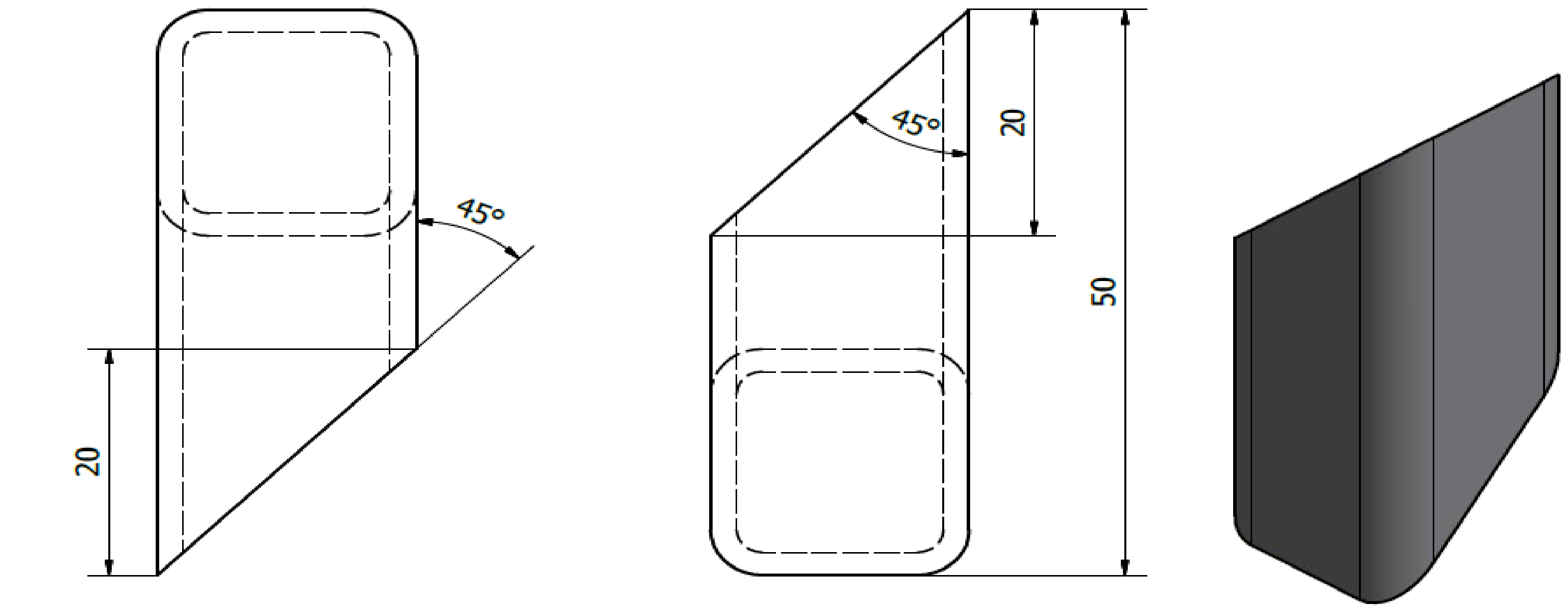
APPROVED BY:

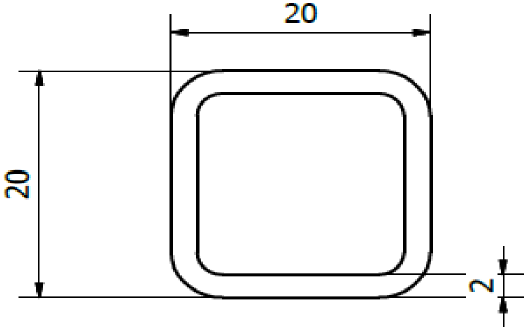
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY	Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL QTY : 2	AGV Frame Design C017_FRAME_ISO023 Edition 2.0 Sheet 1 / 1



APPROVED BY:

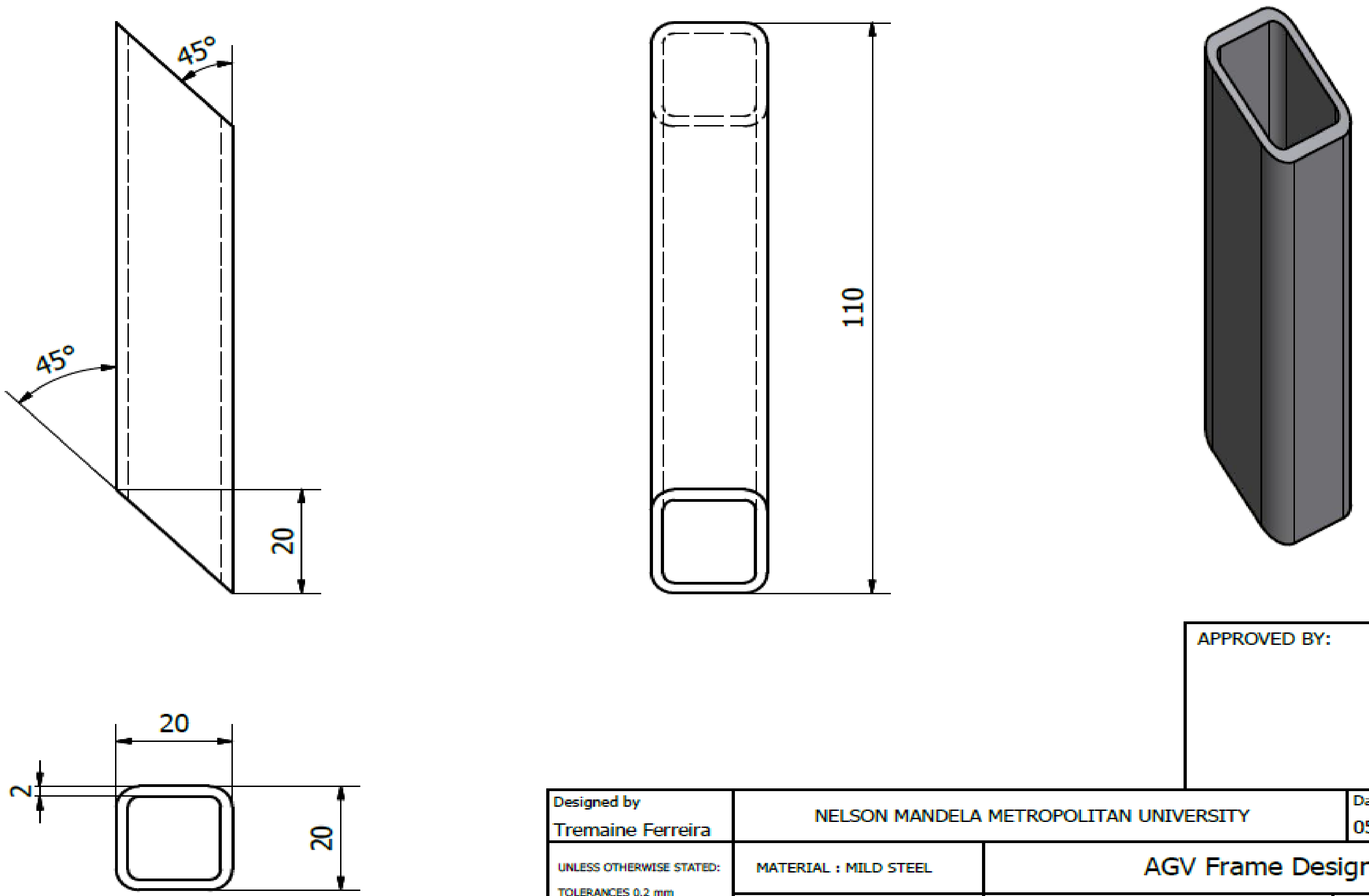
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013	
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C017_FRAME_ISO024	Edition 2.0	Sheet 1 / 1





APPROVED BY:

Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013	
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C017_FRAME_ISO025	Edition 2.0	Sheet 1 / 1



APPROVED BY:

Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY			Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
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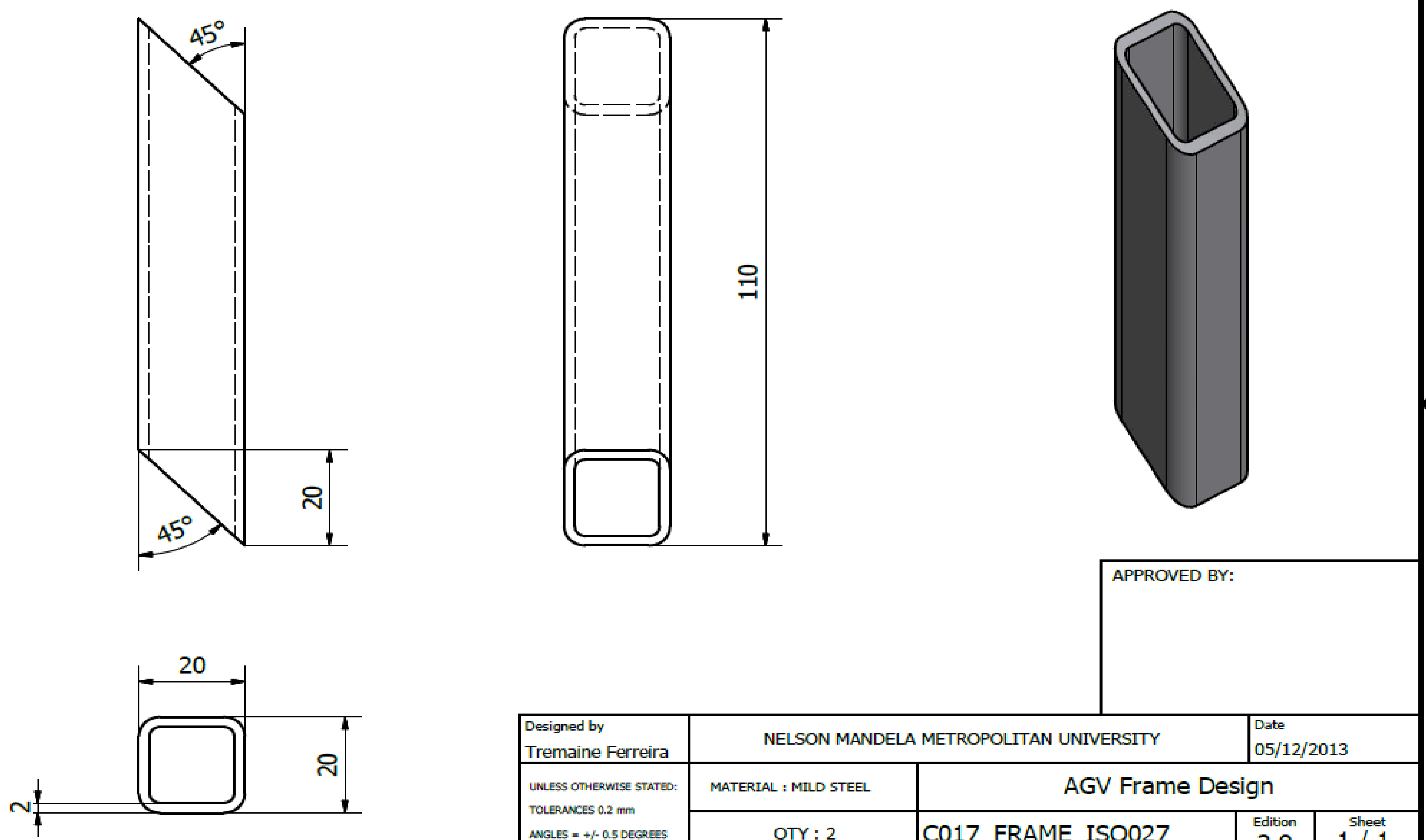
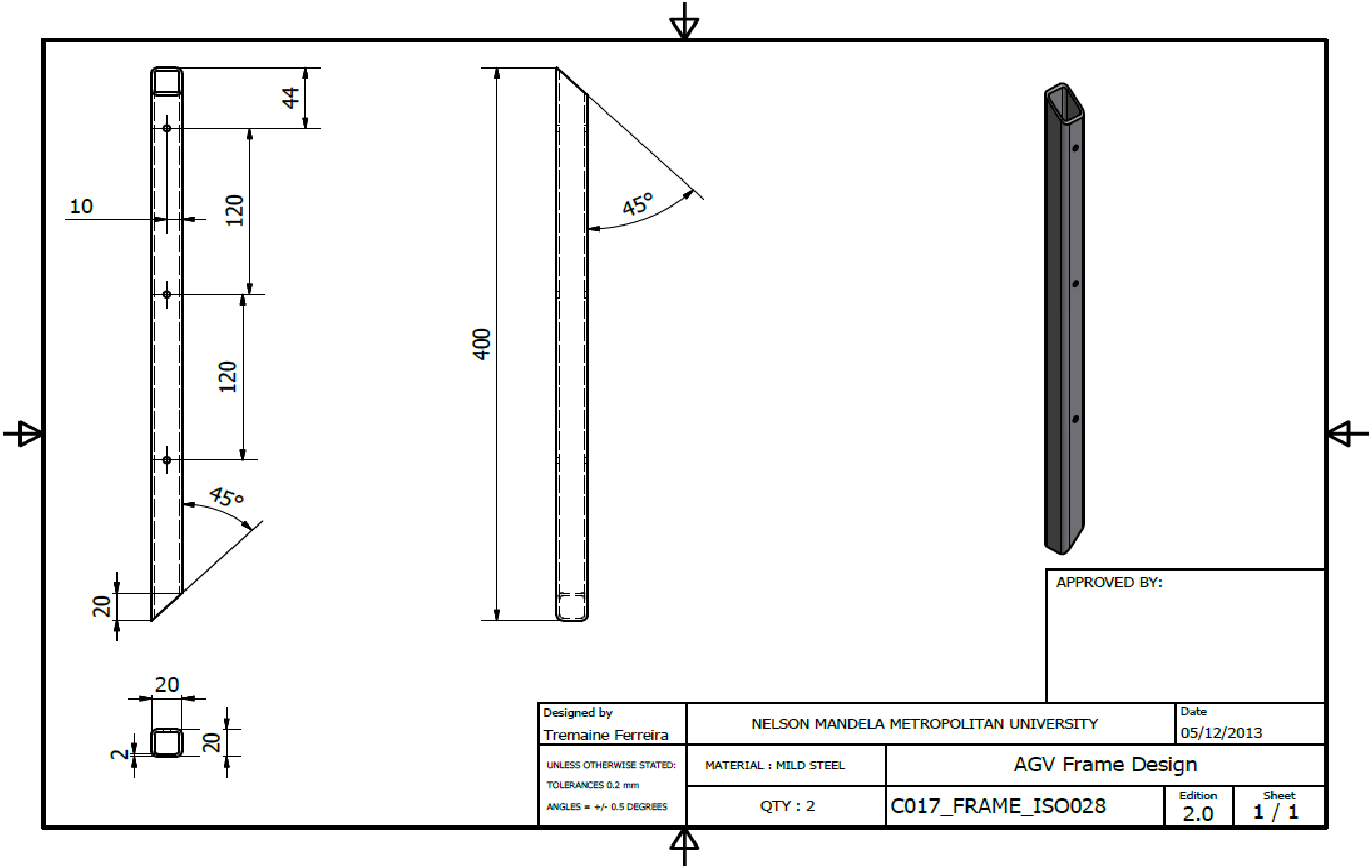
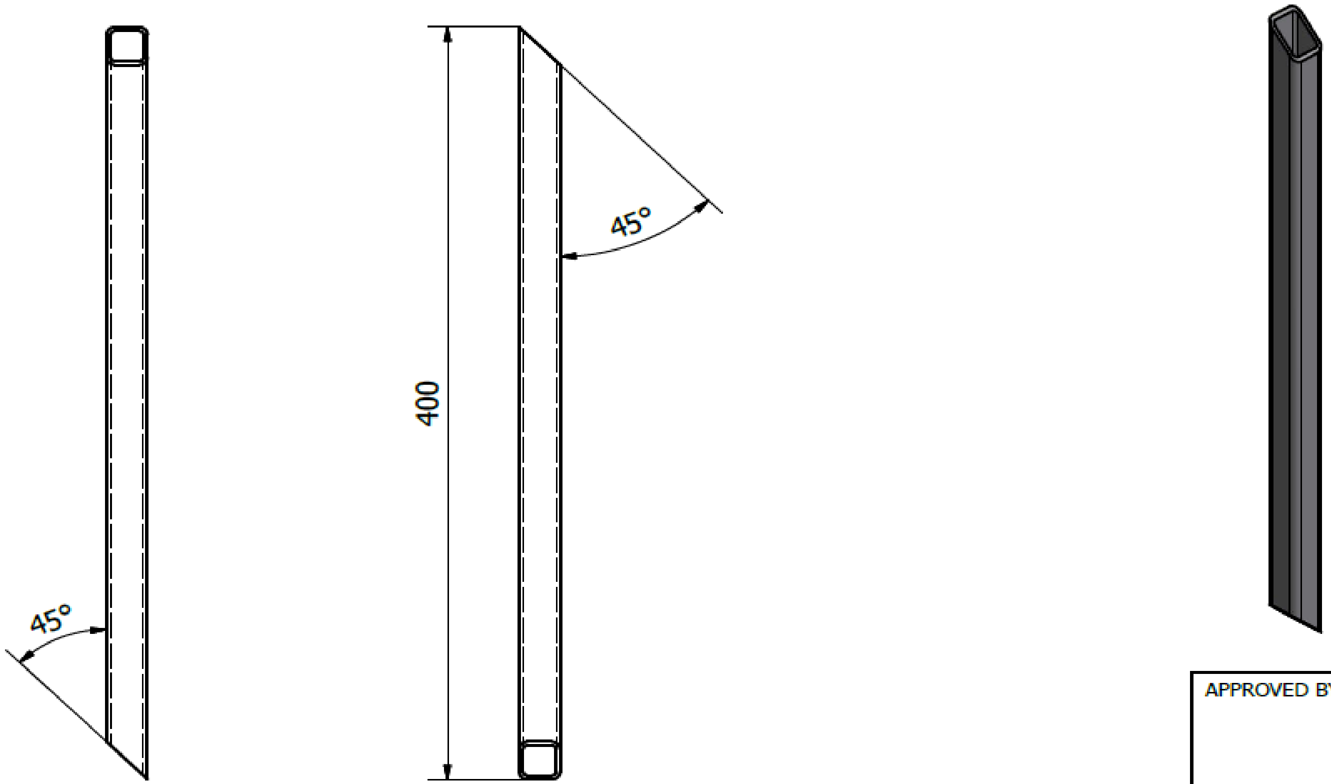
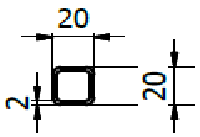


Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013	
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C017_FRAME_ISO027	Edition 2.0	Sheet 1 / 1

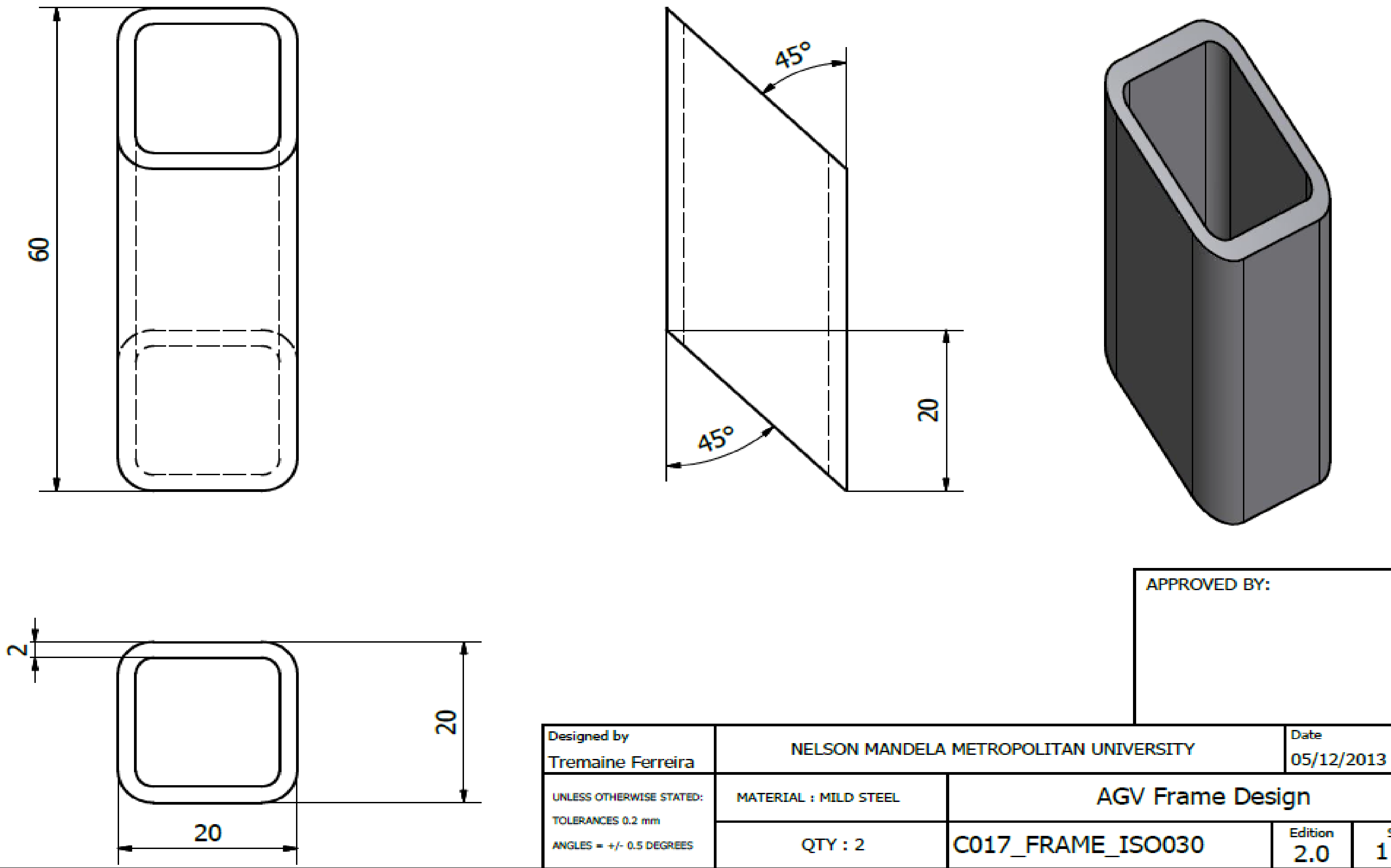

44
10
120
120
45°
20
400
45°
20
2
20
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C017_FRAME_ISO028
Edition
2.0
Sheet
1 / 1





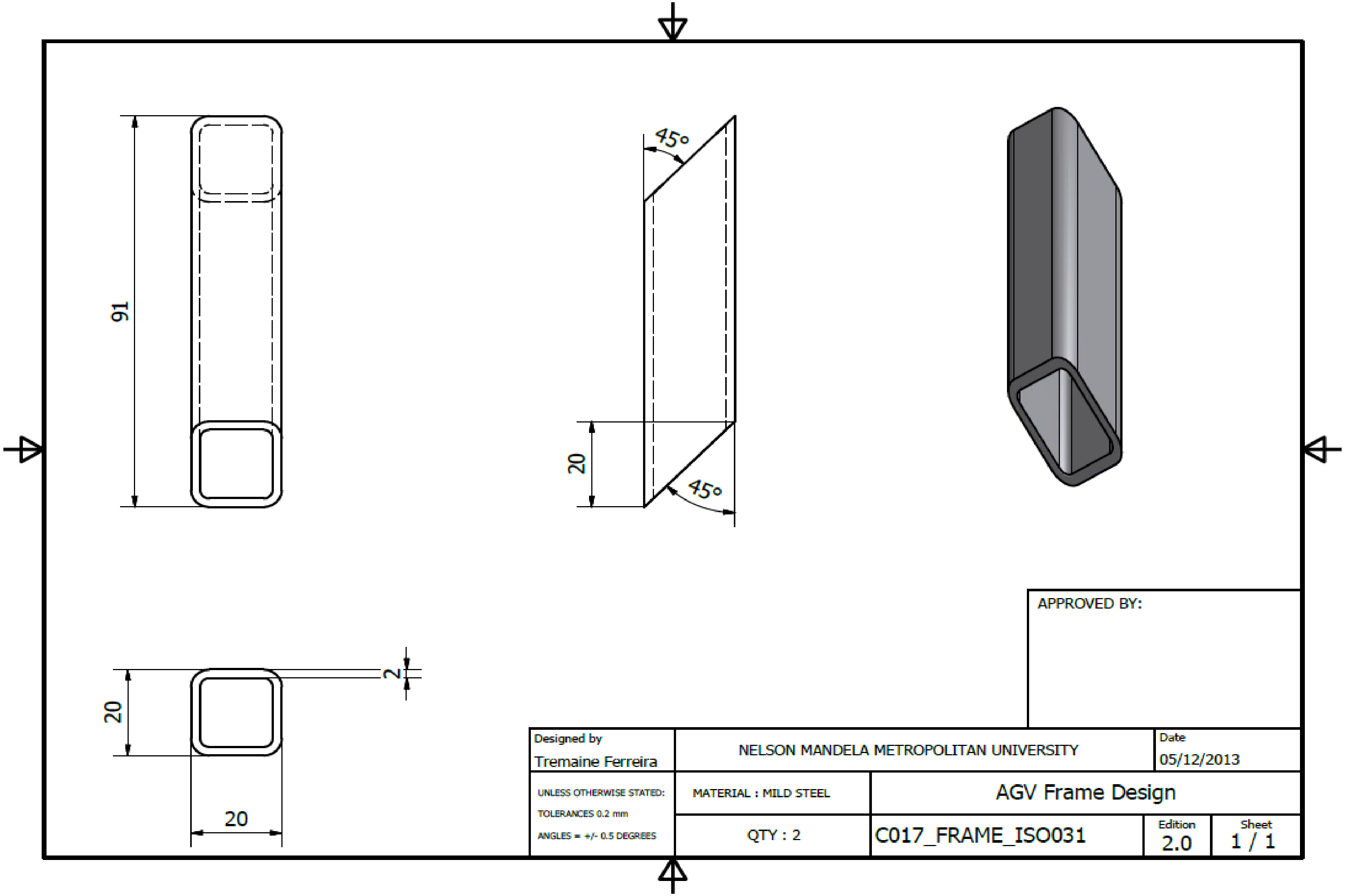
APPROVED BY:

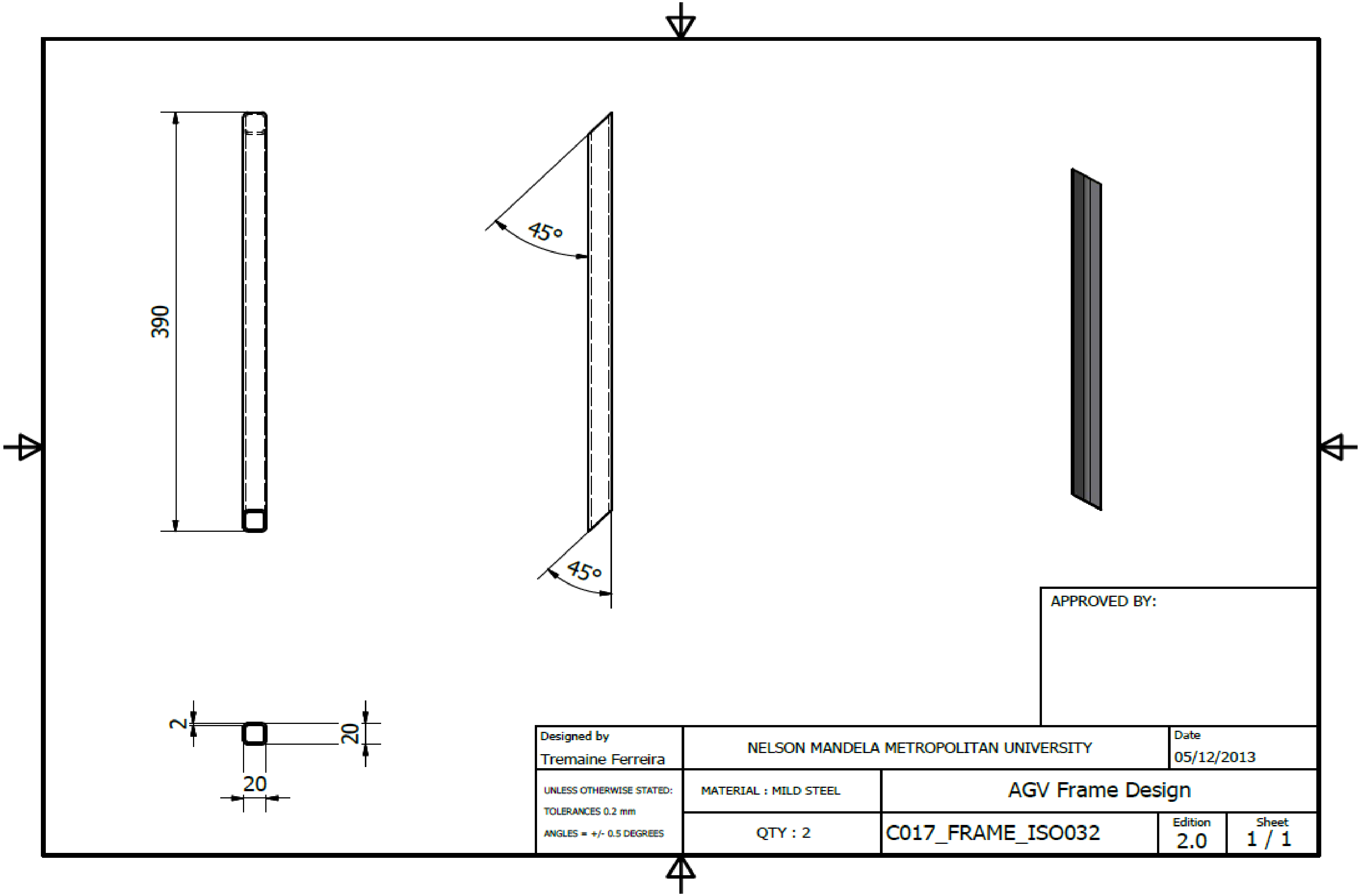
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design	
	QTY : 2	C017_FRAME_ISO029	Edition 2.0 / Sheet 1 / 1



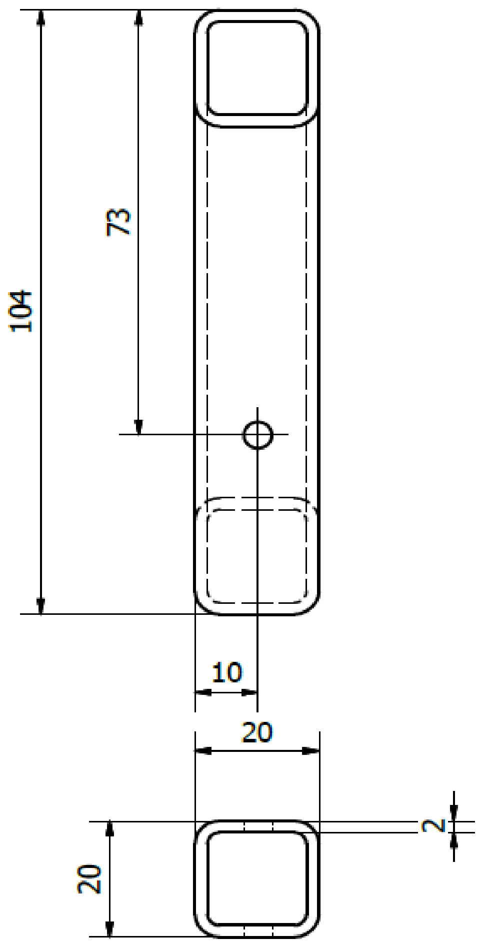
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY			Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C017_FRAME_ISO030	Edition 2.0	Sheet 1 / 1

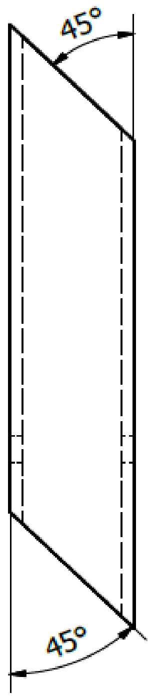
APPROVED BY:

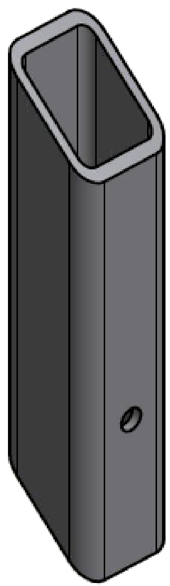

91
45°
20
45°
20
2
20
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C017_FRAME_ISO031
Edition
2.0
Sheet
1 / 1



390
45°
45°
2
20
20
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C017_FRAME_ISO032
Edition
2.0
Sheet
1 / 1

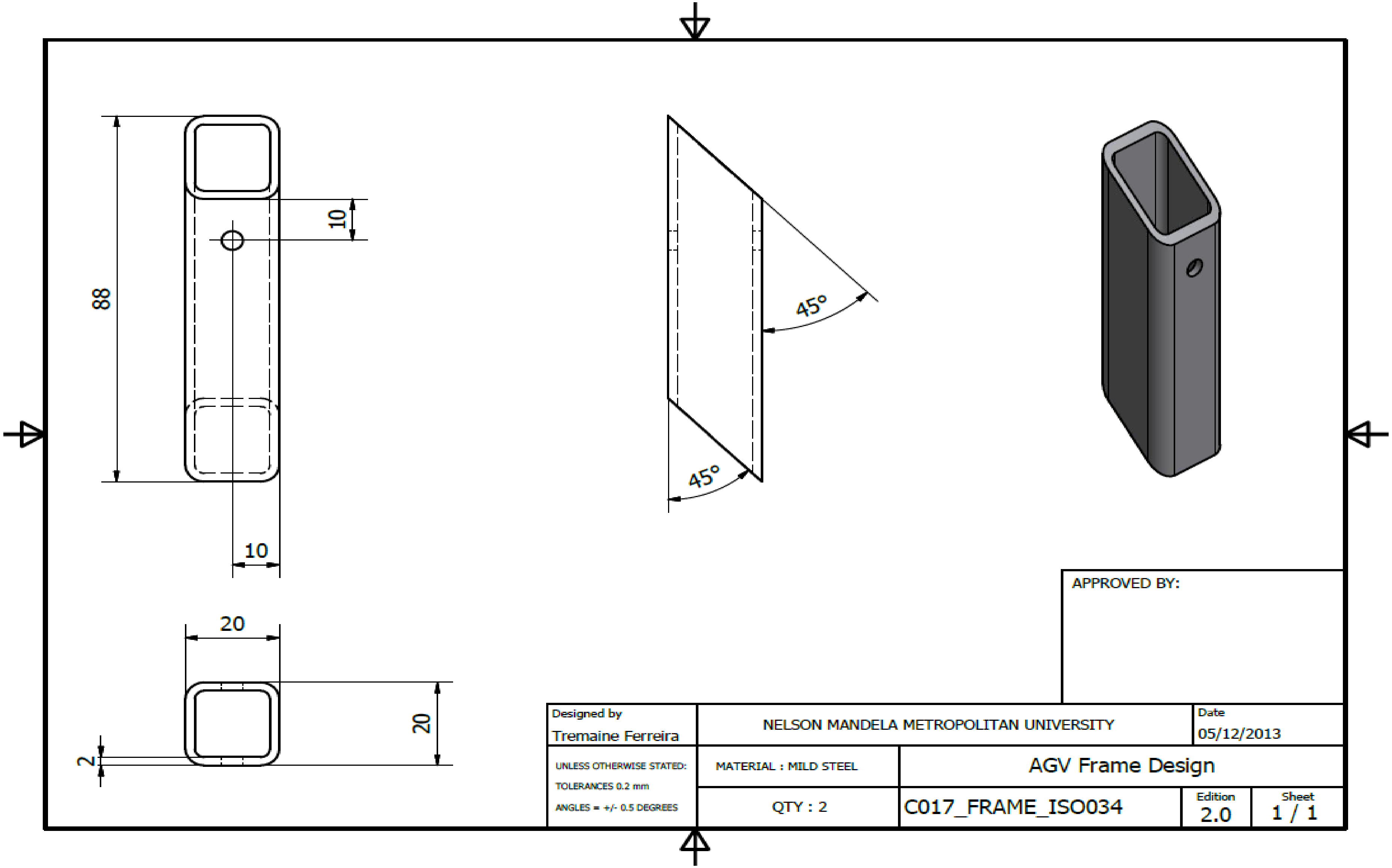


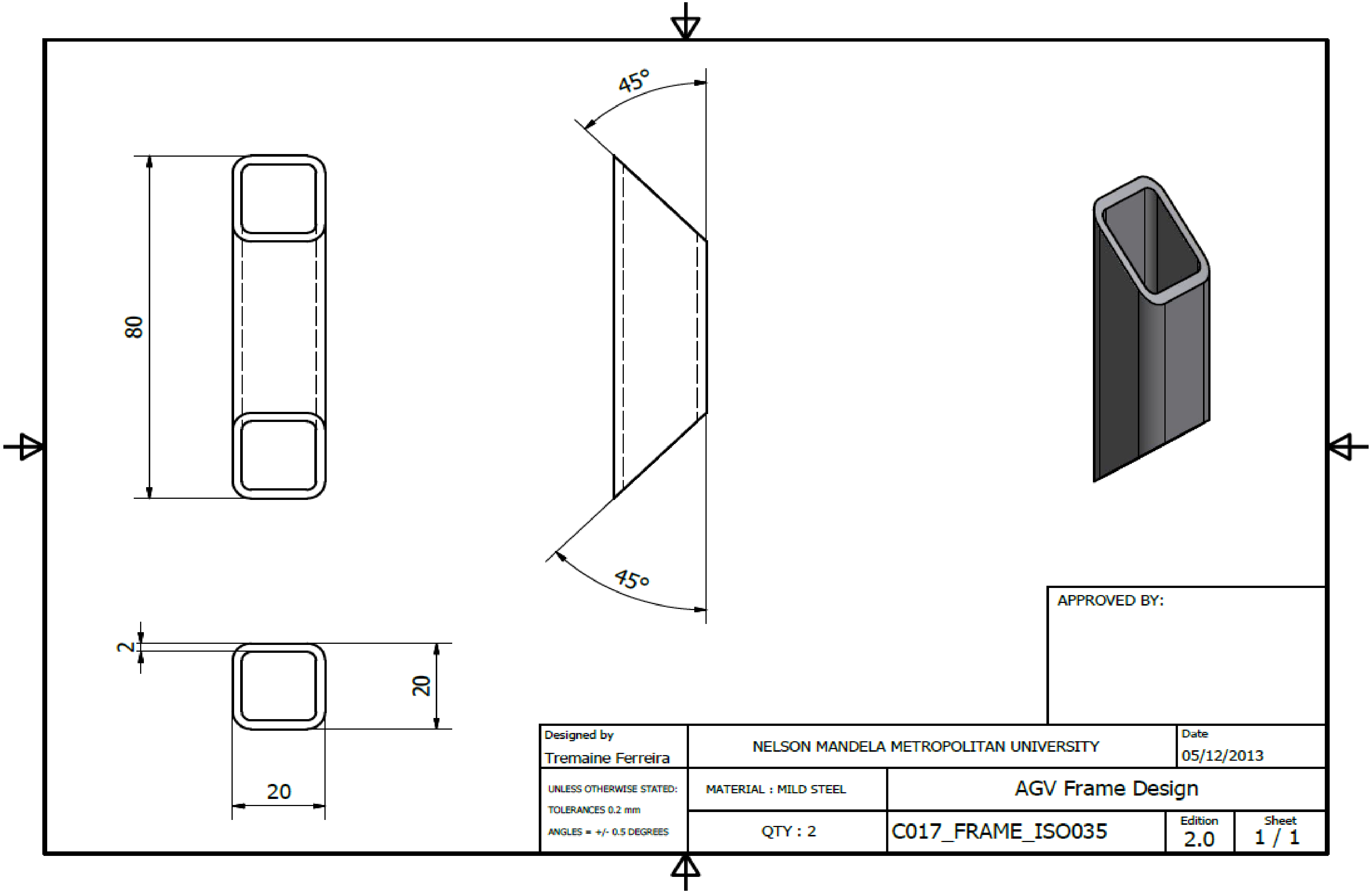




APPROVED BY:

Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013	
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C017_FRAME_ISO033	Edition 2.0	Sheet 1 / 1


88
10
10
45°
45°
20
20
2
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C017_FRAME_ISO034
Edition
2.0
Sheet
1 / 1



APPROVED BY:				
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY			Date 05/12/2013
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
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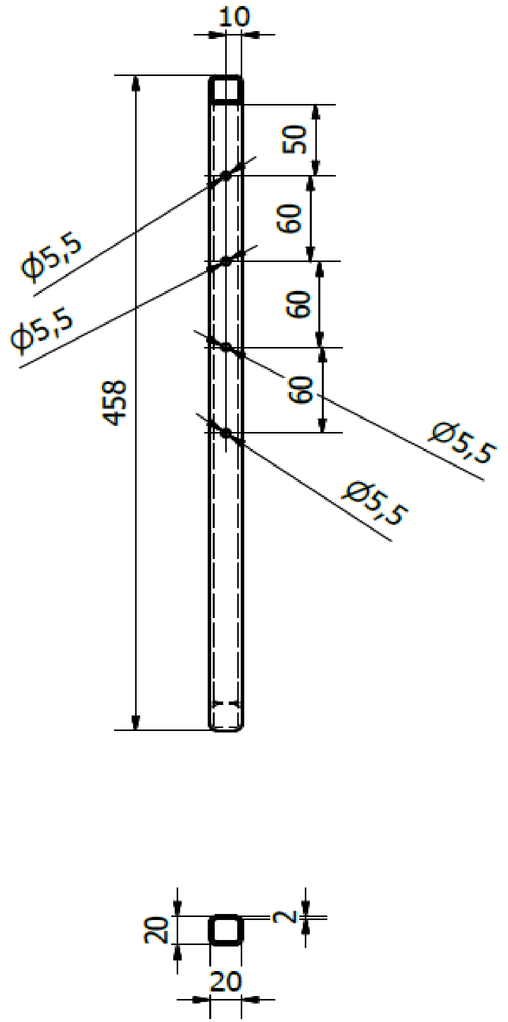
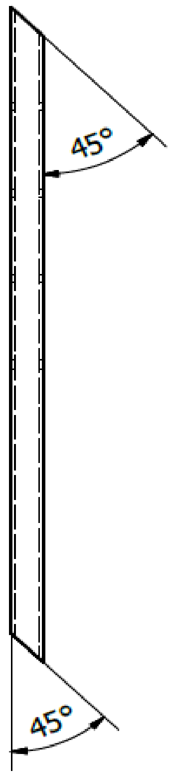
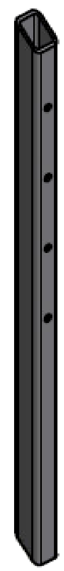
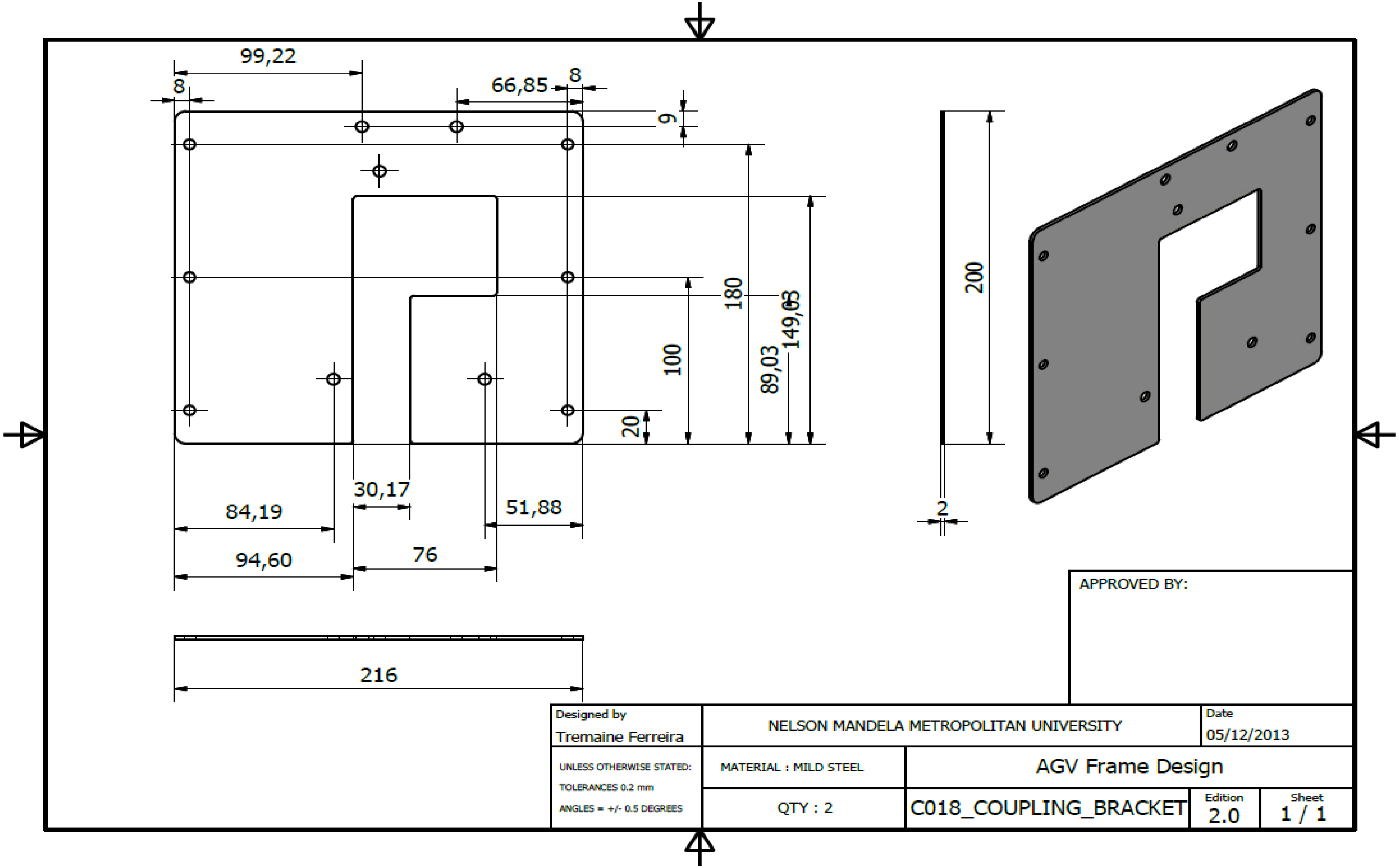
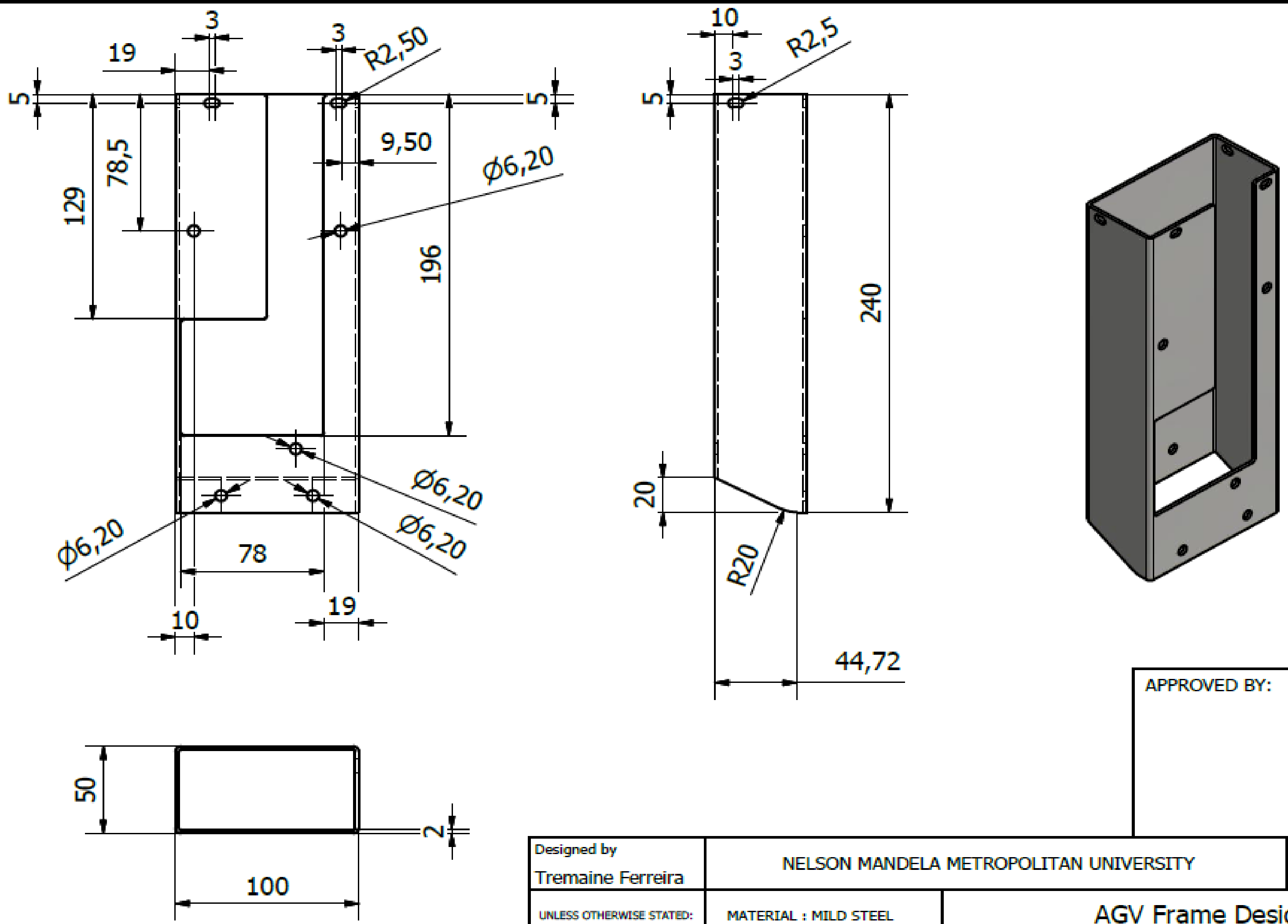






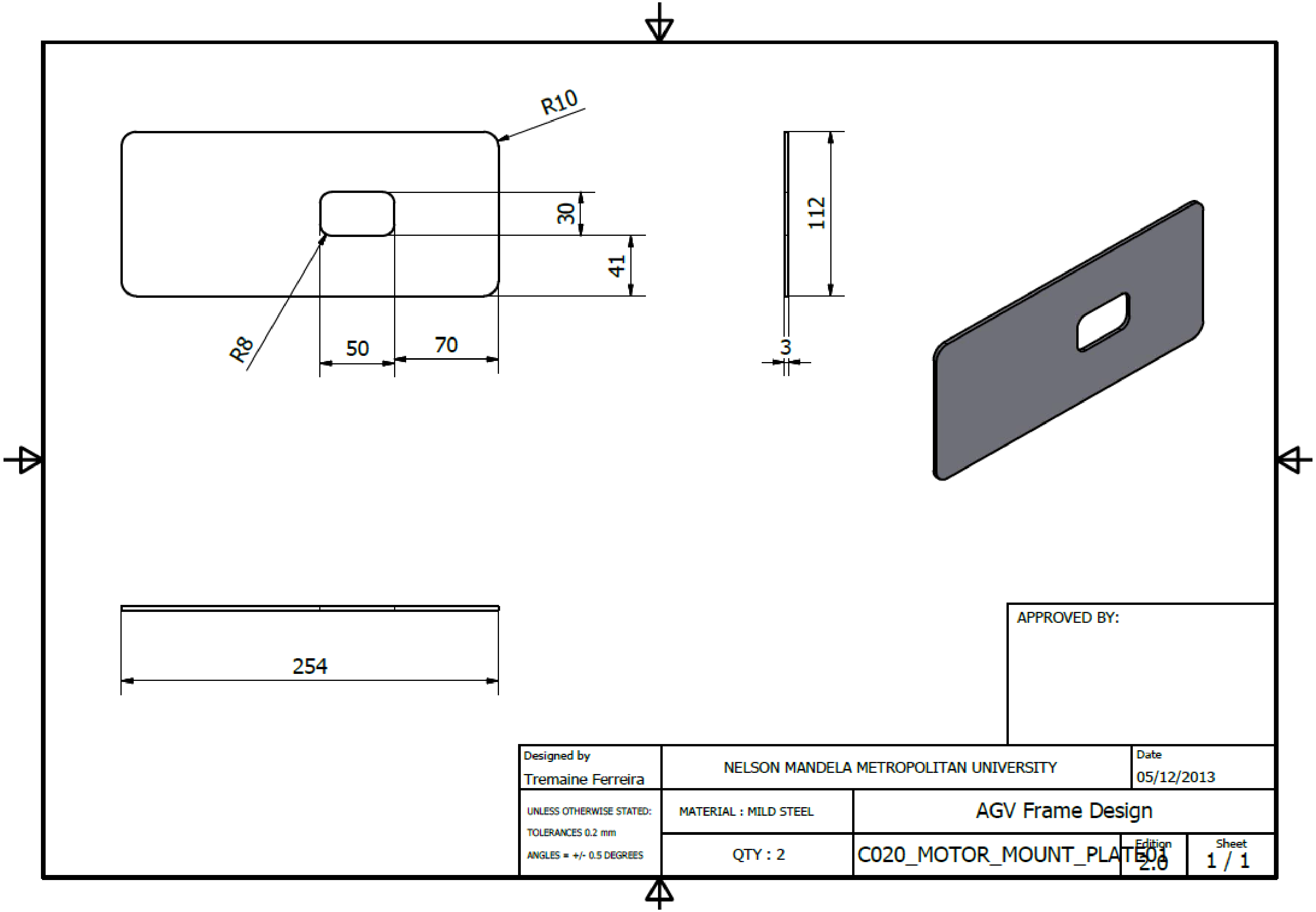
APPROVED BY:				
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013	
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C017_FRAME_ISO036	Edition 2.0	Sheet 1 / 1


99,22
8
66,85
8
9
180
149,63
100
89,03
20
30,17
84,19
51,88
94,60
76
216
200
2
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C018_COUPLING_BRACKET
Edition
2.0
Sheet
1 / 1



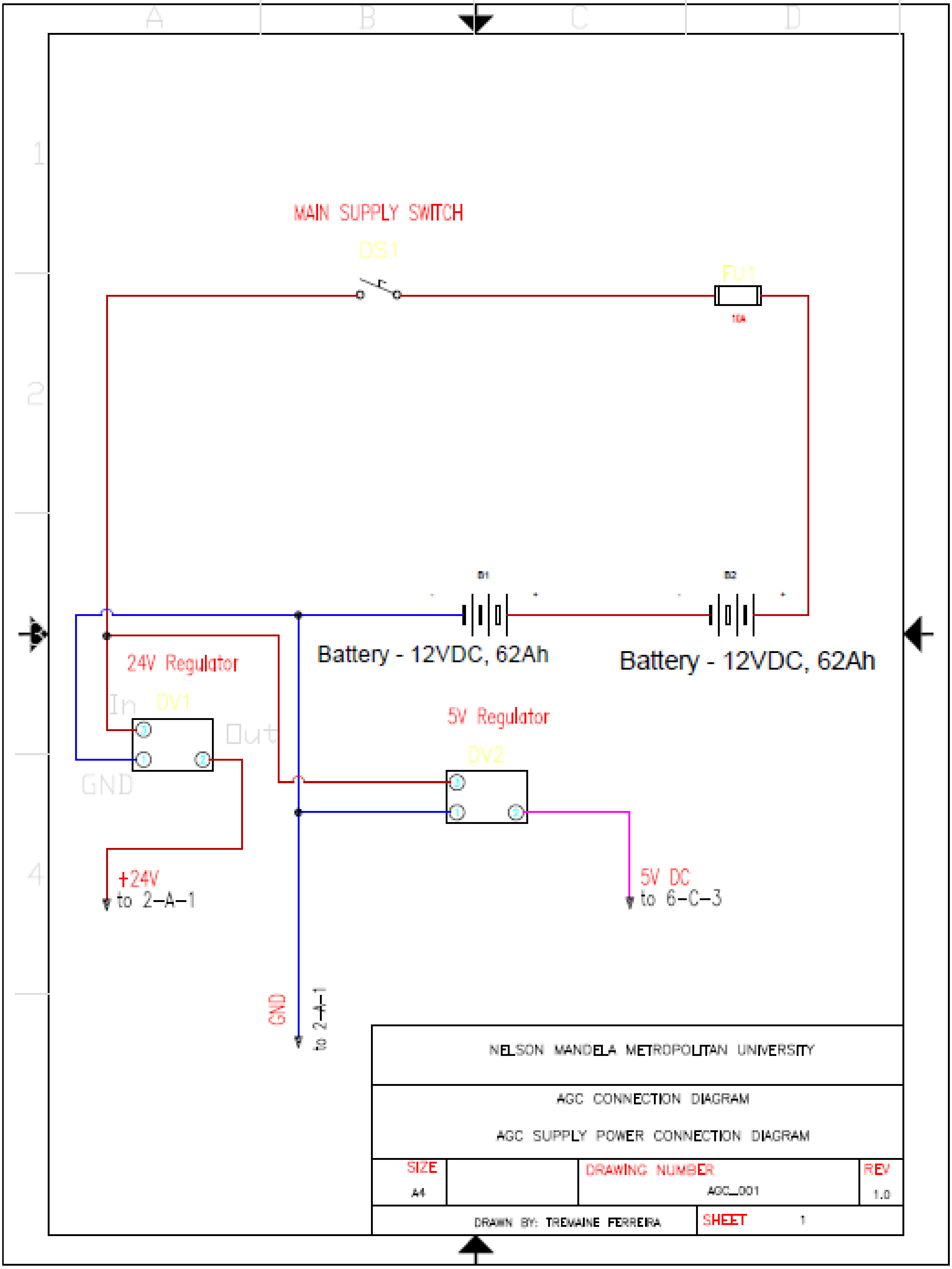
APPROVED BY:

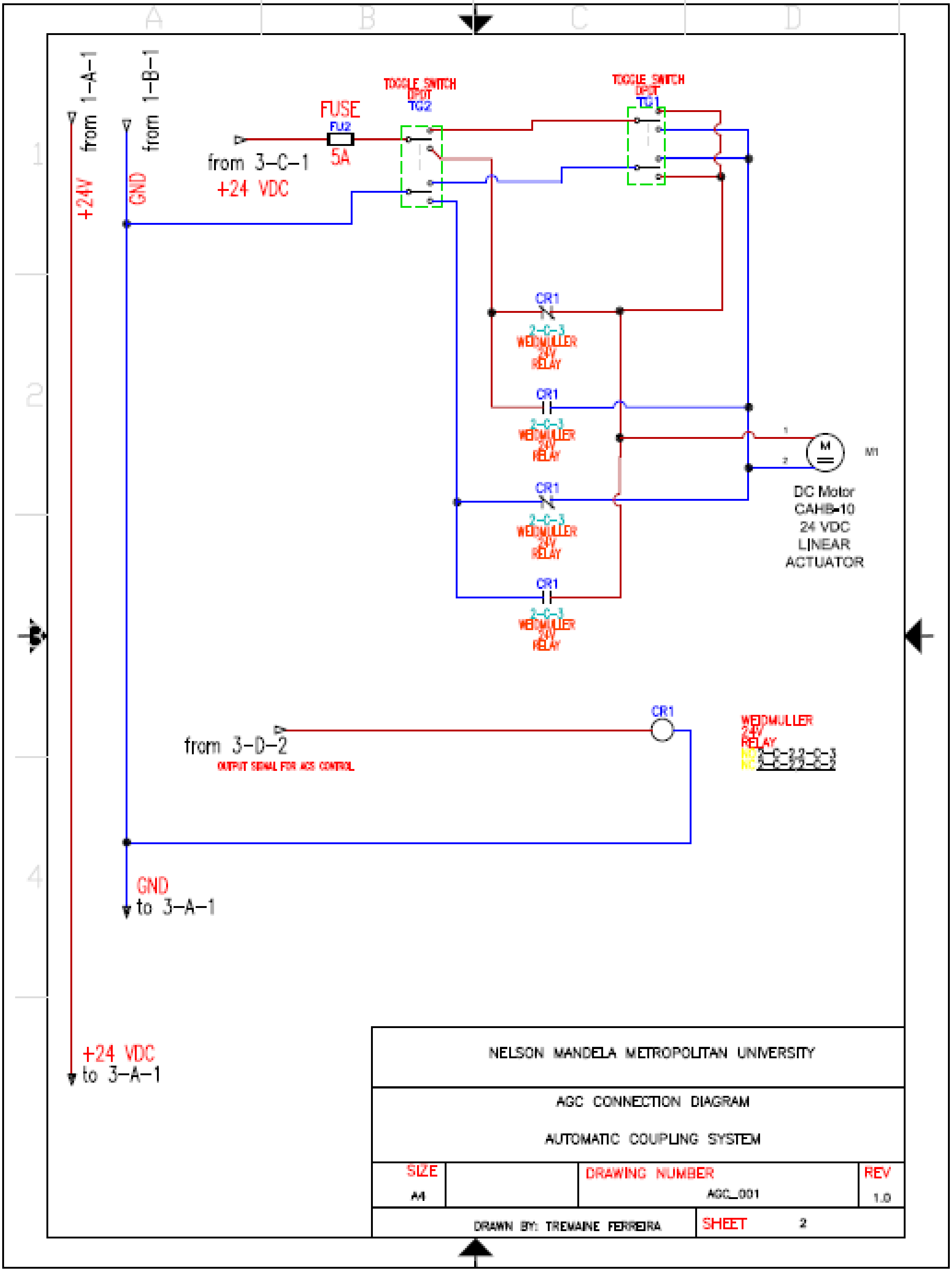
Designed by Tremaine Ferreira	NELSON MANDELA METROPOLITAN UNIVERSITY		Date 05/12/2013	
UNLESS OTHERWISE STATED: TOLERANCES 0.2 mm ANGLES = +/- 0.5 DEGREES	MATERIAL : MILD STEEL	AGV Frame Design		
	QTY : 2	C019_COUPLING_HOUSING	Edition 2.0	Sheet 1 / 1


R10
30
41
112
R8
50
70
3
254
APPROVED BY:
Designed by
Tremaine Ferreira
NELSON MANDELA METROPOLITAN UNIVERSITY
Date
05/12/2013
UNLESS OTHERWISE STATED:
TOLERANCES 0.2 mm
ANGLES = +/- 0.5 DEGREES
MATERIAL : MILD STEEL
AGV Frame Design
QTY : 2
C020_MOTOR_MOUNT_PLATE01
Edition
2.0
Sheet
1 / 1

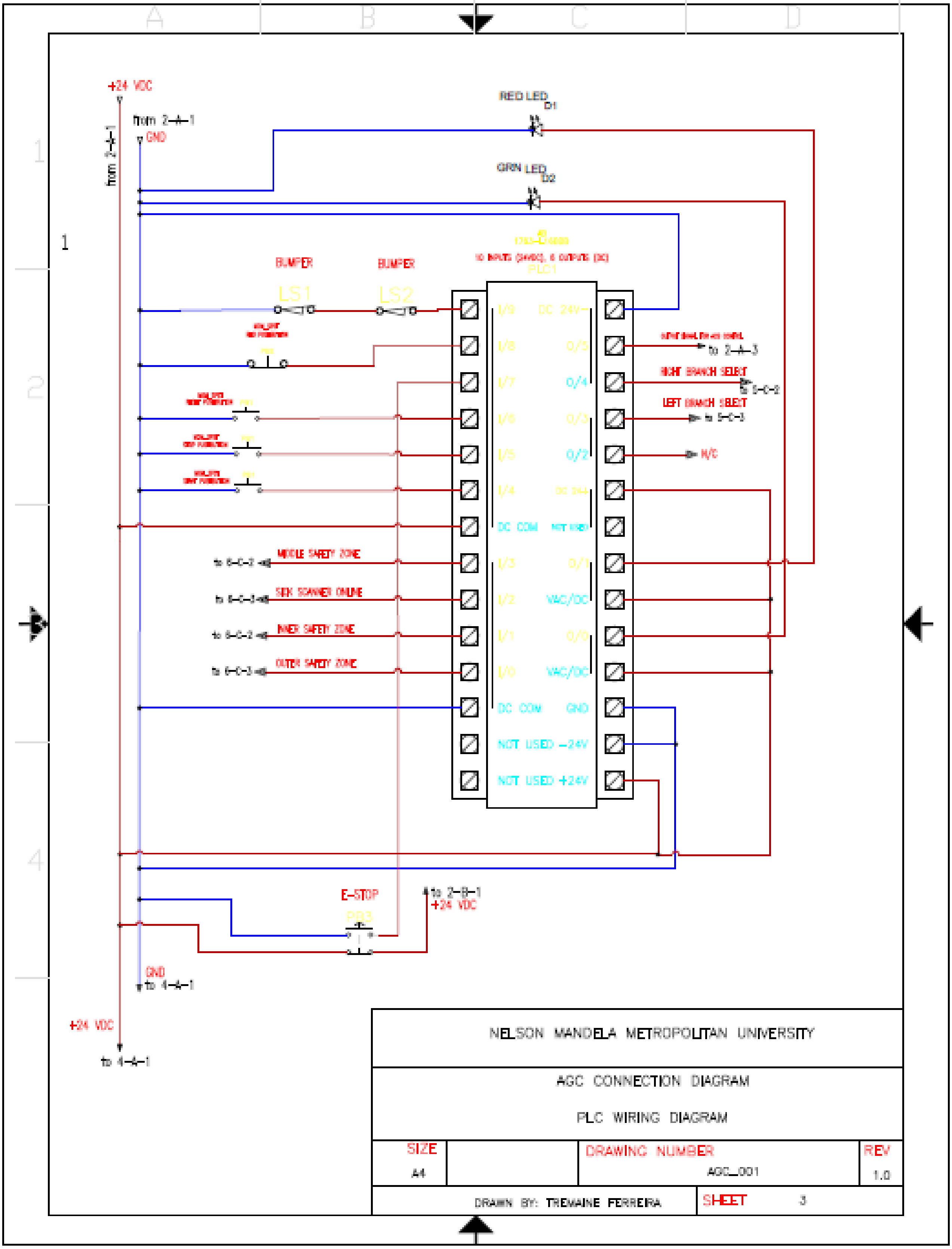
ANNEXURE C

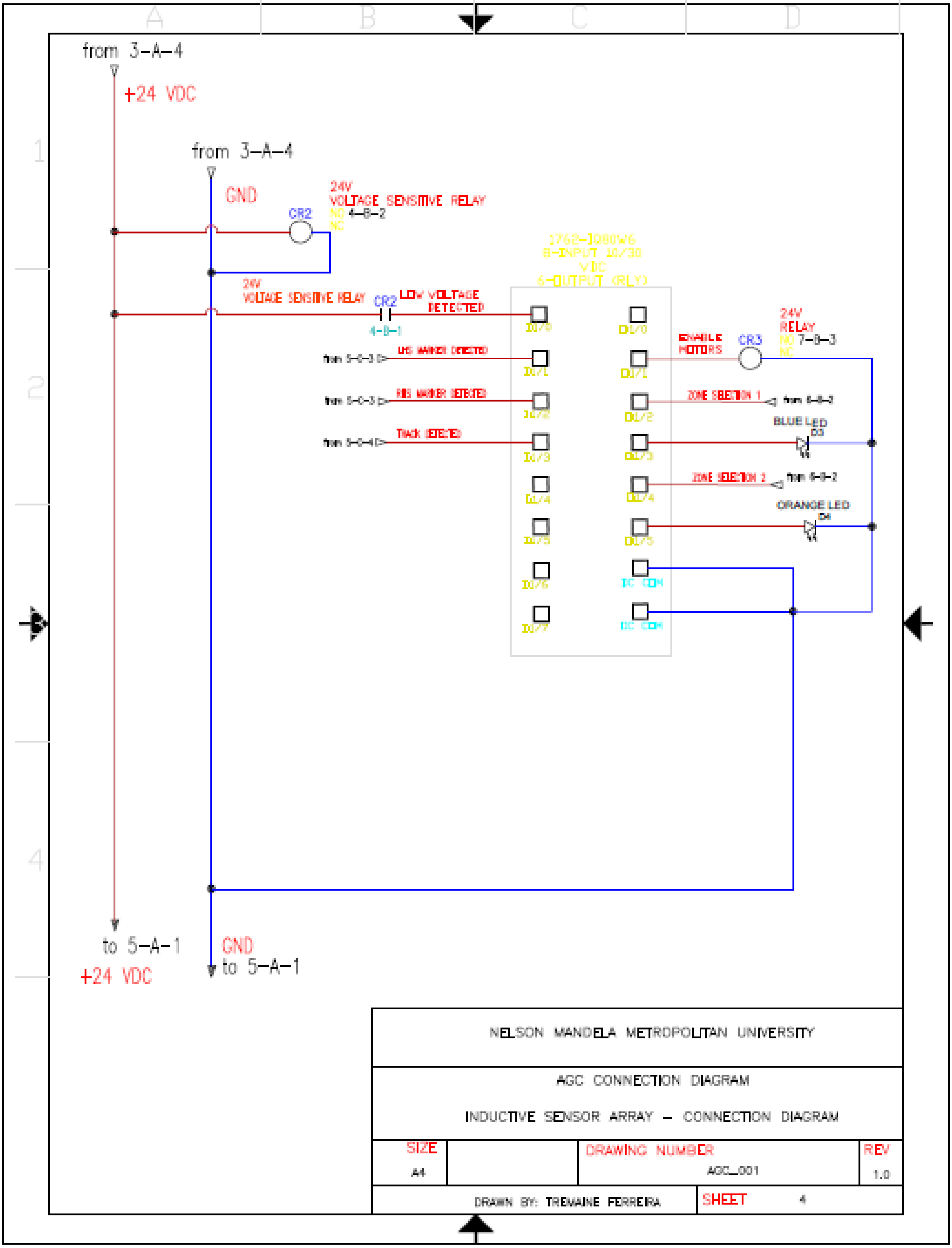
ELECTRICAL DRAWINGS


MAIN SUPPLY SWITCH
DS1
FU1
10A
B1
B2
Battery - 12VDC, 62Ah
Battery - 12VDC, 62Ah
24V Regulator
DV1
In
Out
GND
5V Regulator
DV2
+24V
to 2–A–1
5V DC
to 6–C–3
GND
to 2–A–1
NELSON MANDELA METROPOLITAN UNIVERSITY
AGC CONNECTION DIAGRAM
AGC SUPPLY POWER CONNECTION DIAGRAM
SIZE
A4
DRAWING NUMBER
AGC_001
REV
1.0
DRAWN BY: TREMAINE FERREIRA
SHEET 1

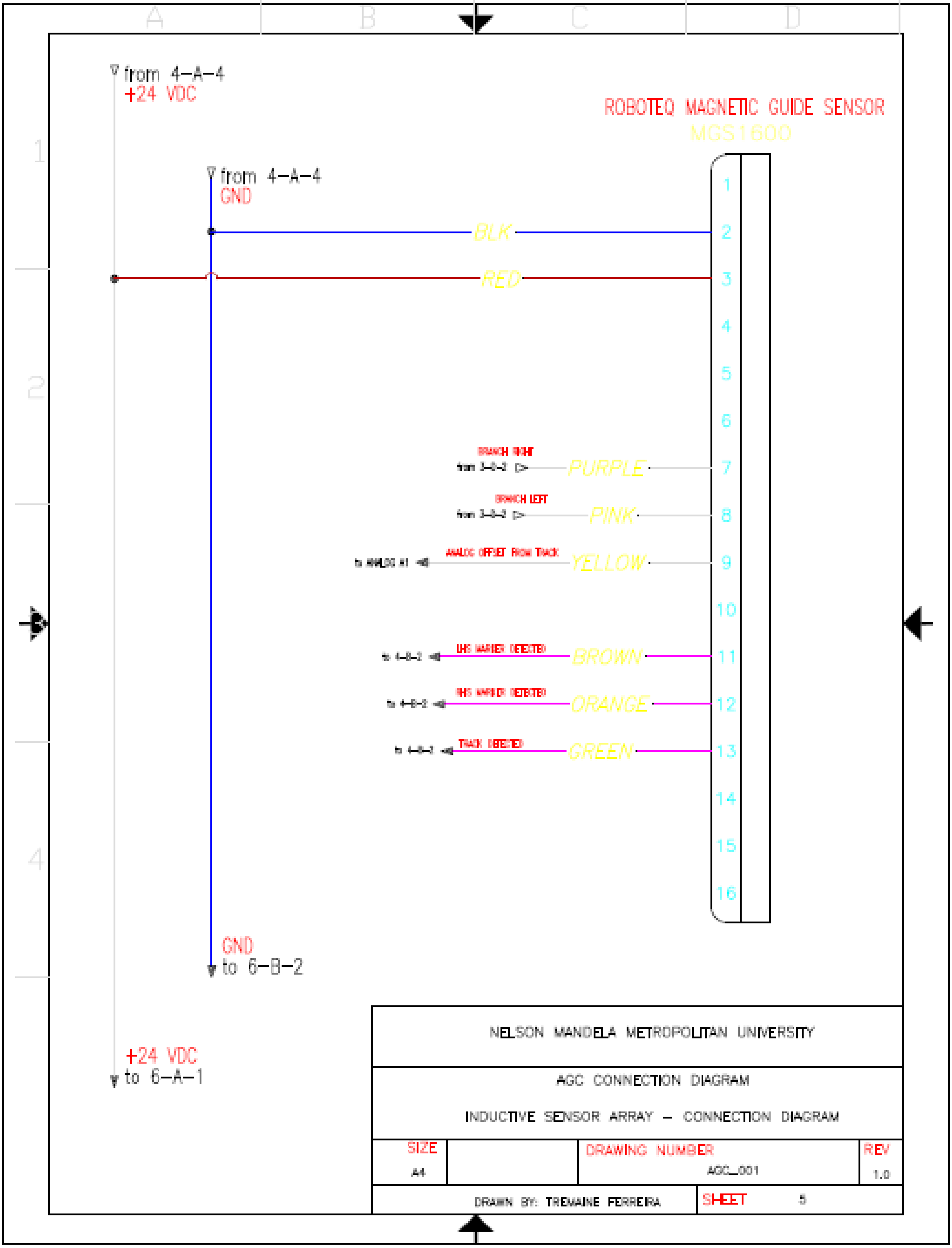


A
B
C
D
from 1-A-1
+24V
from 1-B-1
GND
from 3-C-1
+24 VDC
FUSE
FU2
5A
TOGGLE SWITCH
DPDT
TG2
TOGGLE SWITCH
DPDT
TG1
CR1
2-C-3
WEIDMULLER
24V
RELAY
M
M1
DC Motor
CAHB-10
24 VDC
LINEAR
ACTUATOR
from 3-D-2
OUTPUT SIGNAL FOR AGS CONTROL
WEIDMULLER
24V
RELAY
GND
to 3-A-1
+24 VDC
to 3-A-1
NELSON MANDELA METROPOLITAN UNIVERSITY
AGC CONNECTION DIAGRAM
AUTOMATIC COUPLING SYSTEM
SIZE
A4
DRAWING NUMBER
AGC_001
REV
1.0
DRAWN BY: TREMAINE FERREIRA
SHEET
2

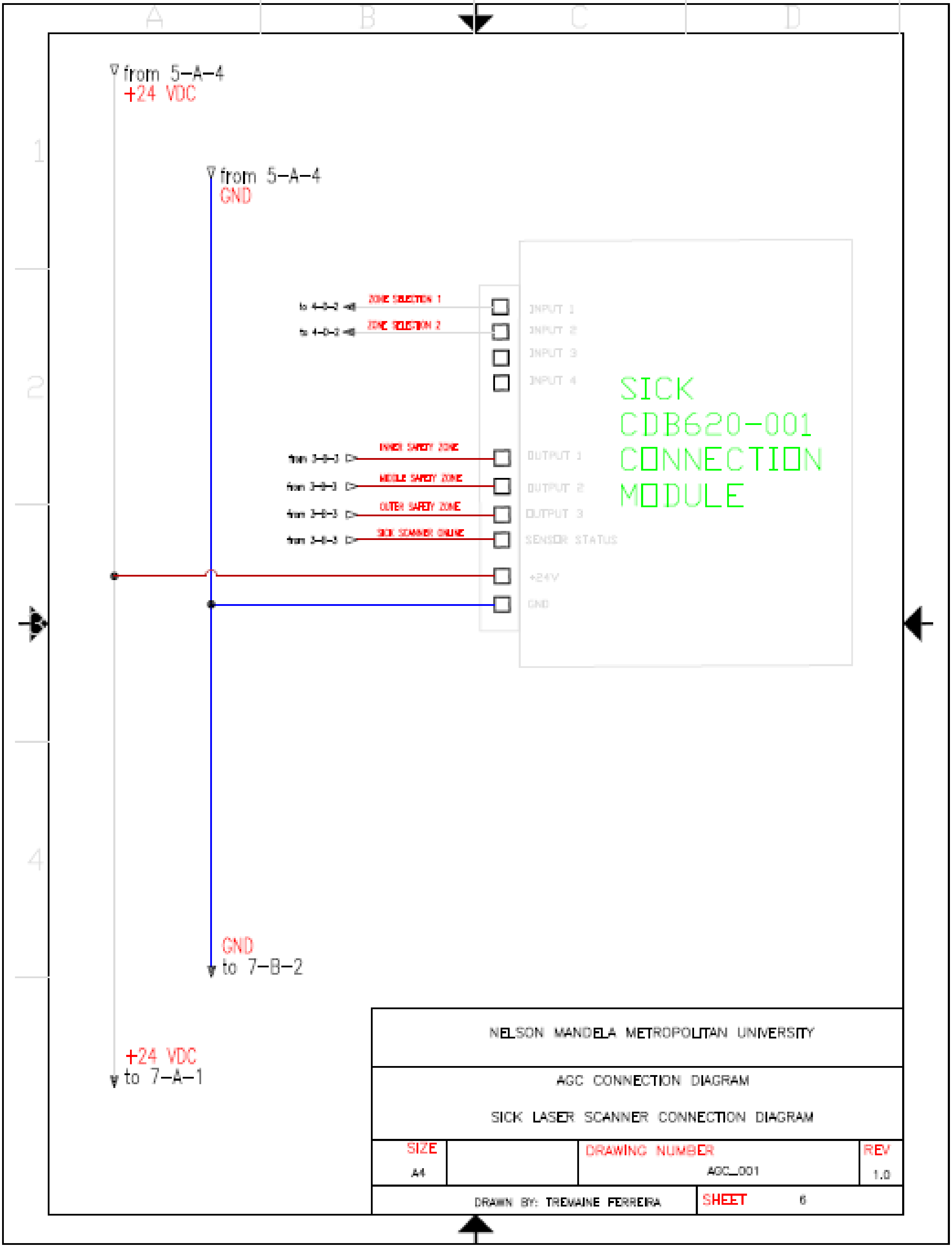

+24 VDC
from 2-A-1
GND
RED LED
D1
GRN LED
D2
PLC1
BUMPER
LS1
BUMPER
LS2
I/9
I/8
I/7
I/6
I/5
I/4
DC COM
I/3
I/2
I/1
I/0
DC COM
NOT USED
NOT USED
DC 24V
0/5
0/4
0/3
0/2
0/1
VAC/DC
0/0
VAC/DC
GND
-24V
+24V
to 2-A-3
RIGHT BRANCH SELECT
LEFT BRANCH SELECT
N/C
MIDDLE SAFETY ZONE
SICK SCANNER ONLINE
INNER SAFETY ZONE
OUTER SAFETY ZONE
E-STOP
to 2-B-1
+24 VDC
GND
to 4-A-1
+24 VDC
to 4-A-1
NELSON MANDELA METROPOLITAN UNIVERSITY
AGC CONNECTION DIAGRAM
PLC WIRING DIAGRAM
SIZE
A4
DRAWING NUMBER
AGC_001
REV
1.0
DRAWN BY: TREMAINE FERREIRA
SHEET
3

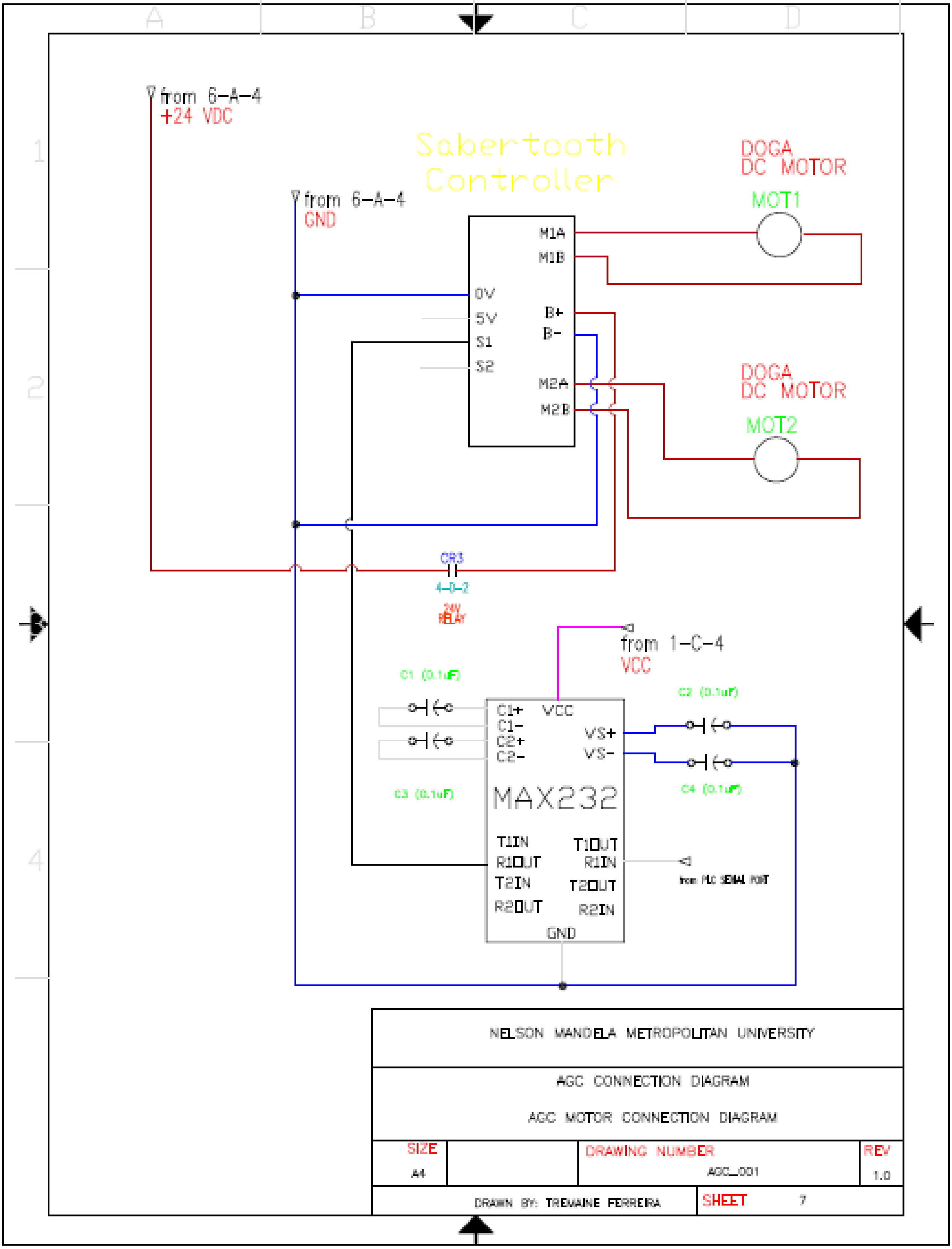


from 3-A-4
+24 VDC
from 3-A-4
GND
CR2
24V
VOLTAGE SENSITIVE RELAY
NO 4-B-2
NC
1762-IQ8OW6
8-INPUT 10/30
VDC
6-OUTPUT (RLY)
24V
VOLTAGE SENSITIVE RELAY
CR2
LOW VOLTAGE
DETECTED
4-B-1
24V
RELAY
NO 7-B-3
NC
ENABLE
MOTORS
CR3
BLUE LED
ORANGE LED
to 5-A-1
+24 VDC
GND
to 5-A-1
NELSON MANDELA METROPOLITAN UNIVERSITY
AGC CONNECTION DIAGRAM
INDUCTIVE SENSOR ARRAY – CONNECTION DIAGRAM
SIZE
A4
DRAWING NUMBER
AGC_001
REV
1.0
DRAWN BY: TREMAINE FERREIRA
SHEET
4



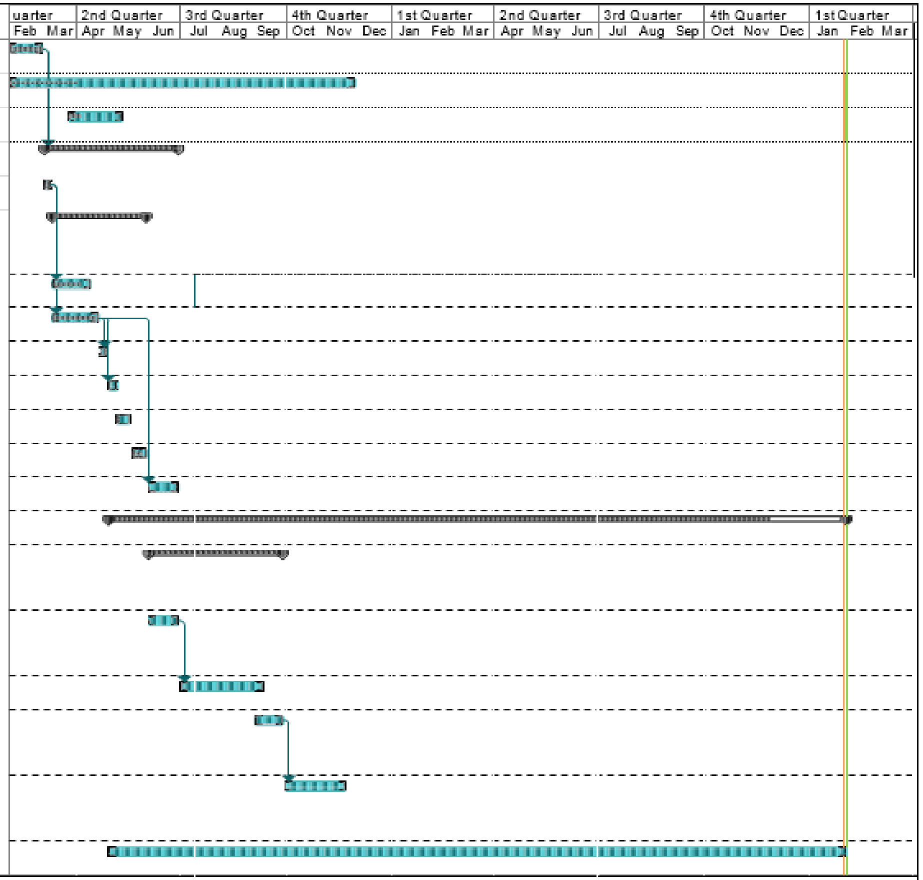
A
B
C
D
1
2
4
from 4-A-4
+24 VDC
from 4-A-4
GND
ROBOTEQ MAGNETIC GUIDE SENSOR
MGS1600
BLK
RED
BRANCH RIGHT
PURPLE
BRANCH LEFT
PINK
ANALOG OFFSET FROM TRACK
YELLOW
LHS MARKER DETECTED
BROWN
RHS MARKER DETECTED
ORANGE
TRACK DETECTED
GREEN
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
GND
to 6-B-2
+24 VDC
to 6-A-1
NELSON MANDELA METROPOLITAN UNIVERSITY
AGC CONNECTION DIAGRAM
INDUCTIVE SENSOR ARRAY – CONNECTION DIAGRAM
SIZE
A4
DRAWING NUMBER
AGC_001
REV
1.0
DRAWN BY: TREMAINE FERREIRA
SHEET
5


A
B
C
D
1
2
4
from 5-A-4
+24 VDC
from 5-A-4
GND
ZONE SELECTION 1
ZONE SELECTION 2
INPUT 1
INPUT 2
INPUT 3
INPUT 4
SICK
CDB620-001
CONNECTION
MODULE
INNER SAFETY ZONE
MIDDLE SAFETY ZONE
OUTER SAFETY ZONE
SICK SCANNER ONLINE
OUTPUT 1
OUTPUT 2
OUTPUT 3
SENSOR STATUS
+24V
GND
GND
to 7-B-2
+24 VDC
to 7-A-1
NELSON MANDELA METROPOLITAN UNIVERSITY
AGC CONNECTION DIAGRAM
SICK LASER SCANNER CONNECTION DIAGRAM
SIZE
A4
DRAWING NUMBER
AGC_001
REV
1.0
DRAWN BY: TREMAINE FERREIRA
SHEET
6


from 6-A-4
+24 VDC
Sabertooth Controller
DOGA DC MOTOR
MOT1
from 6-A-4
GND
M1A
M1B
0V
5V
S1
S2
B+
B-
M2A
M2B
DOGA DC MOTOR
MOT2
CR3
4-D-2
24V RELAY
from 1-C-4
VCC
C1 (0.1uF)
C2 (0.1uF)
C3 (0.1uF)
C4 (0.1uF)
C1+
C1-
C2+
C2-
VCC
VS+
VS-
MAX232
T1IN
R1OUT
T2IN
R2OUT
T1OUT
R1IN
T2OUT
R2IN
GND
from PLC SERIAL PORT
NELSON MANDELA METROPOLITAN UNIVERSITY
AGC CONNECTION DIAGRAM
AGC MOTOR CONNECTION DIAGRAM
SIZE
A4
DRAWING NUMBER
AGC_001
REV
1.0
DRAWN BY: TREMAINE FERREIRA
SHEET 7

ANNEXURE D PROJECT MANAGEMENT

ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Project Familiarization	21 days	Fri 01/02/13	Fri 01/03/13	
2		Literature Review	216 days	Fri 01/02/13	Fri 29/11/13	
3		SysML Model of AGC	35 days	Mon 25/03/13	Fri 10/05/13	
4		GMSA AGC: First Generation	85 days	Mon 04/03/13	Fri 28/06/13	1
5		Problem Identification	5 days	Mon 04/03/13	Fri 08/03/13	
6		Improvements, Experiments and Validation	60 days	Mon 11/03/13	Fri 31/05/13	
7		Experimental Setup	25 days	Mon 11/03/13	Fri 12/04/13	5
8		Improve AGC Control	30 days	Mon 11/03/13	Fri 19/04/13	5
9		AGC Testing: No load	5 days	Mon 22/04/13	Fri 26/04/13	8
10		AGC Testing: Load	6 days	Mon 29/04/13	Mon 06/05/13	8
11		AGC Control: Quantify a	10 days	Mon 06/05/13	Fri 17/05/13	
12		RFID Tag: Optimize and	10 days	Mon 20/05/13	Fri 31/05/13	
13		Presentation of Final AGC	20 days	Mon 03/06/13	Fri 28/06/13	8
14		GMSA AGC: Second Generat	460 days	Mon 29/04/13	Sun 01/02/15	
15		Design and Development Autonomous Tow Hitch	85 days	Mon 03/06/13	Fri 27/09/13	
16		Design Specification and Generation	20 days	Mon 03/06/13	Fri 28/06/13	
17		Development of Final De	52 days	Mon 01/07/13	Tue 10/09/13	16
18		Manufacturing, Assembl Implementation	18 days	Wed 04/09/13	Fri 27/09/13	
19		Testing and Optimization Design	39 days	Mon 30/09/13	Thu 21/11/13	18
20		Dissertation	461 days	Mon 29/04/13	Sun 01/02/15	



Project: Masters_AGC
Date: Sat 31/01/15

Task | Split | Milestone | Summary | Project Summary | External Tasks | External Milestone | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | Deadline | Progress

1	Project Familiarization In 2012 a First Generation AGC was developed for GMSA. The aim of the first 3 weeks of the project is to become familiar with the system and gain an in-depth understanding on the operation thereof.
2	Literature Review Literature review is a key component of the project. Literature will be used extensively when performing experimentation and design.
3	SysML Model of AGC SysML is a modelling tool used for complex systems. SysML allows modelling of software, hardware and human interaction. The SysML model will aid in the design of the Second Generation AGC to ensure satisfactory results as well as successful integration into the factory environment.
4	GMSA AGC: First Generation The First Generation AGC was developed by Cawood (2013). Experimentation and analysis of the First Generation AGC is of critical importance for the Second Generation AGC, as the Second Generation needs to overcome the limitations of the First Generation.
5	Problem Identification Generation of a list for GMSA that will outline the limitations/improvement areas of the First Generation AGC and the experimentation that will be performed.
7	Experimental Setup Experimental Setup includes the development of computer software that will allow data to be caputred from the AGC during testing. The allocated time is also to be used to formulate a strategy for testing to ensure that all relevant parameters are evaluated. For example: The path of the hitch centre point (HCP) plays a key role in determining the maximum error in positioning the robot for trolley collection.
8	Improve AGC Control Validation: Will the batteries last for 8.5 hours? Experimentation: Quantify the performance of the First Generation AGC Improvements: Control of AGC, Reliability of RFID tags, Bumper Design and Collision Detection
9	AGC Testing: No load Testing of the First Generation AGC without a load attached. The aim of the testing will be to determine the battery life of the AGC under no-load conditions.
10	AGC Testing: Load Testing of the First Generation AGC with a manually attached load. The aim of the testing will be to determine the battery life of the AGC under full-load conditions.
11	AGC Control: Quantify and Optimize Optimization of the AGC control strategy to ensure minimal overshoot and positioning error.
12	RFID Tag: Optimize and Quantify The optimization and quantification of the RFID tag strategy used in the First Generation AGC. The aim is to get an estimate on the reliability of the AGC locating/detecting a valid RFID tag on the track. Optimization will be performed to increase the obtained reliability.
13	Presentation of Final AGC to GMSA Final presentation date not yet specified. Will be during the month of June.
14	GMSA AGC: Second Generation The Second Generation AGC will include an autonomous hitch for the collection and delivery of trolleys in the GMSA factory. Design tools are to be used extensively in this phase that will take into consideration the various errors involved to ensure customer satisfaction.
16	Design Specification and Concept Generation The concept design needs to be developed while testing is performed on the First Generation AGC. This will ensure that all relevant parameters are determined during the initial testing phase. Thus eliminating the risk of redundant tests to be performed later on in the project.
17	Development of Final Design Development of the final design will involve computer modelling and animation to ensure that the design will perform efficiently and satsifies all the customer requirements.
20	Dissertation The disseration will be written througout the project to ensure that all details are captured as they are completed.

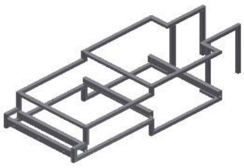
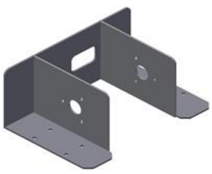
ANNEXURE E BILL OF MATERIALS

ELECTRICAL BILL OF MATERIALS - TOTAL FOR 2 AGVs

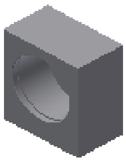
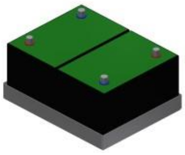
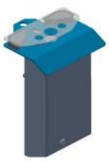
ID	PART NO	DESCRIPTION	SUPPLIER	QTY
1	RB2-BS54	RED EMERG PBTN TWIST REL HEAD 40mm	RUBICON	2
2	RB2-BD3	3 POSN MAINT SHORT SEL SW HEAD	RUBICON	2
3	RB2-BD2	2 POSN MAINT SHORT SEL SW HEAD	RUBICON	2
4	RB2-BA4	RED FLUSH PUSHBUTTON HEAD	RUBICON	2
5	RB2-BA3	GREEN FLUSH PUSHBUTTON HEAD	RUBICON	2
6	RB2-BA5	YELLOW FLUSH PUSHBUTTON HEAD	RUBICON	2
7	RB2-BV04	RED PILOT LIGHT HEAD	RUBICON	2
8	RB2-BV05	AMBER PILOT LIGHT HEAD	RUBICON	2
9	RB2-BV03	GREEN PILOT LIGHT HEAD	RUBICON	2
10	RB2-BV06	BLUE PILOT LIGHT HEAD	RUBICON	2
11	RB2-BVL73 24V	GREEN CLED LIGHT BODY 24VAC/DC	RUBICON	2
12	RB2-BVL74 24V	RED CLED LIGHT BODY 24VAC/DC	RUBICON	2
13	RB2-BVL75 24V	AMBER CLED LIGHT BODY 24VAC/DC	RUBICON	2
14	RB2-BVL76 24V	BLUE CLED LIGHT BODY 24VAC/DC	RUBICON	2
15	Z15G-1703	MICRO SWITCH TYPE Z LONG ROLLER LEVER	RUBICON	4
16	S10-BR	BOXES 85x56x30 BLACK WITH RIBS	RUBICON	2
17	PG-7	POLYMER CABLE GLAND PG7 GREY	RUBICON	12
18	102-490	5V FINDER Relay Coil	RS COMPONENTS	8
19	400-9130	Relay Housing DIN	RS COMPONENTS	18
20	351-645	24V relay 16A Coil	RS COMPONENTS	12
21	MA2.5/5	2.5mm TERMINAL	RUBICON	50
22	TW25x60	SLOTTED TRUNKING 25Wx60H 2M WIDE	RUBICON	2
23	DR35A	DIN 35 SLOTTED ALUMINIUM RAIL 1 X 2M	RUBICON	1
24	466-144	40A 3P PANEL MOUNT SWITCH	RS COMPONENTS	2
25	RB2-BZ103	2 N.O. CONTACT BLOCK + BASE	RUBICON	4
26	RB2-BE101	1 N.O. ADD ON CONTACT BLOCK	RUBICON	8
27	RB2-BE102	1 N.C. ADD ON CONTACT BLOCK	RUBICON	8
28	RB2-BZ105	1 N.O. + 1 N.C. CONTACT BLOCK + BASE	RUBICON	8
29	RB2-BY2303	ALUMINIUM LEGEND PLATE "START"	RUBICON	2
30	RB2-BY2304	ALUMINIUM LEGEND PLATE "STOP"	RUBICON	2
31	RB2-BY2364	ALUMINIUM LEGEND PLATE "AUTO-HAND"	RUBICON	2
32	ED-60	E-STOP 60MM DIA. YELLOW LEGEND PLATE	RUBICON	2
33	RB2-BY2323	ALUMINIUM LEGEND PLATE "RESET"	RUBICON	2
34	BM01032	CRIMPING CONNECTOR MALE 2 WAY 15A	RUBICON	2
35	BM01042	CRIMPING CONNECTOR FEMALE 2 WAY 15A	RUBICON	2
36	SR/7.5	END STOP FOR DIN 35-7.5 RAIL	RUBICON	12
37	NB1-10	10AMP 1P 4.5kA C CURVE DIN MCB	RUBICON	2
38	W504 BK	1.5mm BLACK FLEX WIRE /100m	RUBICON	40m
39	W504 BR	1.5mm BROWN FLEX WIRE /100m	RUBICON	40m
40	W504 BL	1.5mm BLUE FLEX WIRE /100m	RUBICON	20m
41	W504 WH	1.5mm WHITE FLEX WIRE /100m	RUBICON	20m
42		2.5mm 2-CORE RED + BLK CABLE	RUBICON	5m

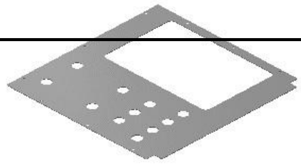
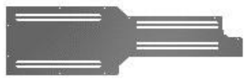
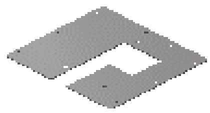
43		2.5mm 2 CORE SHIELDED CABLE	RUBICON	2m
44		2.5mm 4 CORE SHIELDED CABLE	RUBICON	5m
45	E0508-100	0.5mm WHITE BOOTLACE FERRULES /100	RUBICON	1
46	E1508-500	1.5mm BLACK BOOTLACE FERRULES /500	RUBICON	1
47	SCG3.2-BK/1	HEATSHRINK BLACK 3.2/1.6MM /1M PACK	RUBICON	1
48	BM537	CRIMPING TOOL FOR BOOTLACE FER. 0.5-4MM	RUBICON	1
49	E7508-100	0.75mm BLUE BOOTLACE FERRULES /100	RUBICON	1
50	D1508-100	1.5mm BLACK TWIN BOOTLACE FERRULES /100	RUBICON	1
51		MINI DIN INLINE PLUG 8 PIN	RUBICON	3
52	V1161	IN-LINE AUTO FUSE HOLDER FOR BLADE 7.2MM	RUBICON	2
53	AF-15A	15A AUTOMOTIVE FUSE BLUE	RUBICON	4
54	E2508-100	2.5mm GREY BOOTLACE FERRULES /100	RUBICON	1

BILL OF MATERIALS

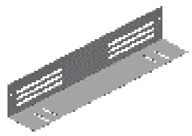
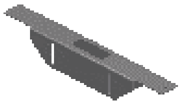
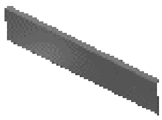
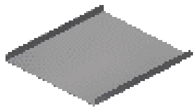
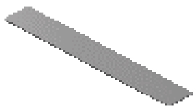
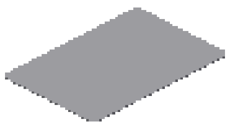
PART NUMBER	THUMBNAIL	Unit QTY	QTY
Base_Weldment		Each	1
ISO 4019 - 20x20x2 - 265		265 mm	265 mm
ISO 4019 - 20x20x2 - 265		265 mm	265 mm
ISO 4019 - 20x20x2 - 255		255 mm	255 mm
ISO 4019 - 20x20x2 - 255		255 mm	255 mm
ISO 4019 - 20x20x2 - 50		50 mm	50 mm
ISO 4019 - 20x20x2 - 50		50 mm	50 mm
ISO 4019 - 20x20x2 - 110		110 mm	110 mm
ISO 4019 - 20x20x2 - 400		400 mm	400 mm
ISO 4019 - 20x20x2 - 91		91 mm	91 mm
ISO 4019 - 20x20x2 - 110		110 mm	110 mm
ISO 4019 - 20x20x2 - 400		400 mm	400 mm
ISO 4019 - 20x20x2 - 91		91 mm	91 mm
ISO 4019 - 20x20x2 - 458		458 mm	458 mm
ISO 4019 - 20x20x2 - 458.001		458 mm	458 mm
ISO 4019 - 20x20x2 - 110		110 mm	110 mm
ISO 4019 - 20x20x2 - 400		400 mm	400 mm
ISO 4019 - 20x20x2 - 110		110 mm	110 mm
ISO 4019 - 20x20x2 - 400		400 mm	400 mm
ISO 4019 - 20x20x2 - 390		390 mm	390 mm
ISO 4019 - 20x20x2 - 390		390 mm	390 mm
ISO 4019 - 20x20x2 - 360		360mm	360mm
ISO 4019 - 20x20x2 - 60		60 mm	60 mm
ISO 4019 - 20x20x2 - 360		360 mm	360 mm
ISO 4019 - 40x20x2 - 380.001		380 mm	380 mm
ISO 4019 - 40x20x2 - 380		380 mm	380 mm
ISO 4019 - 20x20x2 - 104		104mm	104mm
ISO 4019 - 20x20x2 - 104		104mm	104mm
ISO 4019 - 20x20x2 - 88.001		88mm	88mm
ISO 4019 - 20x20x2 - 88		88mm	88mm
ISO 4019 - 20x20x2 - 80		80 mm	80 mm
ISO 4019 - 20x20x2 - 80.001		80 mm	80 mm
ISO001		360 mm	360 mm
ISO 4019 - 20x20x2 - 60		60mm	60mm
ISO 4019 - 20x20x2 - 220		220mm	220mm
ISO 4019 - 20x20x2 - 220		220 mm	220 mm
ISO 4019 - 40x20x2 - 400		400 mm	400 mm
RearMotorAssembly		Each	1
Sheet 145x150x3		Each	1
Sheet 254x165x3		Each	1
Sheet 56x150x3		Each	1
Sheet 145x150x3 motor		Each	1
Sheet 56x150x3_RHS		Each	2
Bosch DC Motor -0 390 257 689 CHP 24V		Each	2

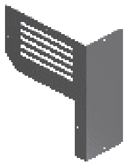
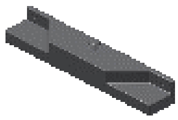
BILL OF MATERIALS

PART NUMBER	THUMBNAIL	Unit QTY	QTY
BearingBlock		Each	1
Battery_Pack		Each	1
Battery Tray		Each	1
EV34A_A Battery		Each	2
CouplingAssembly		Each	1
CAHB-10-B1A-050192-AAAPT0-000		Each	1
Tubing120x60x2		Each	1
ACS_Guide Bracket Assembly		Each	1
ACS001_MS_4mm		Each	1
ACS002_MS_2mm		Each	1
ACS003_MS_12mm		Each	2
ACS006_ALU_10mm		Each	1
DIN 6912 - M6 x 10		Each	4
DIN EN 24 036 - M6		Each	4
8mm SICK Inductive Sensor		Each	1
JIS B 1180 - M6x60		Each	1
ISO 4035 - M6		Each	1
ISO 4035 - M8		Each	2
ACS006_ALU_10mm		Each	1
RHS_WheelAssembly		Each	1
Wheel		Each	1
BearingBlock		Each	1
Motor		Each	1
ISO 4035 M20		Each	1
Bearing		Each	1
DIN 472 62x2 Circlip		Each	1
ShaftProper		Each	1
LHS_WheelAssembly		Each	1
Wheel		Each	1

PART NUMBER	THUMBNAIL	Unit QTY	QTY
BearingBlock		Each	1
Bearing		Each	1
ShaftProper		Each	1
ISO 4035 M20		Each	1
Motor		Each	1
TopCover		Each	1
ControlPanel		Each	1
SidePanelCover		Each	1
60mm CASTOR WHEEL		Each	2
CouplingMount		Each	1
BackingPlate Assembly		Each	1
BackingPlate		Each	1
Allen Bradley Micrologix 1100 PLC		Each	1
35MM DIN Rail-2.5		Each	4
DIN Connector Terminals		Each	22
1762-iq8		Each	1
Trunking		Each	7
SICK Breakout Board		Each	1
TIM310-1xxxx00-9164454		Each	1

BILL OF MATERIALS

PART NUMBER	THUMBNAIL	Unit QTY	QTY
Sick Mounting Bracket		Each	1
FrontPanel		Each	1
MagSensor_Bracket		Each	1
Switch - Limit with Roller		Each	2
Bumper		Each	1
ConnectingRod2.0		Each	2
BatterySupportPlate		Each	1
FrontCastorMountBracket		Each	1
JIS B 1174 - M3 x 6		Each	2
HingedLid		Each	1
ISO 4762 - M5 x 25		Each	1
ISO 4762 - M5 x 25		Each	5
ANSI B18.3.4M - M3 x 0.5 x 3		Each	13
ANSI B18.3.4M - M4 x 0.7 x 4		Each	1
ANSI B18.3.4M - M3 x 0.5 x 30		Each	1

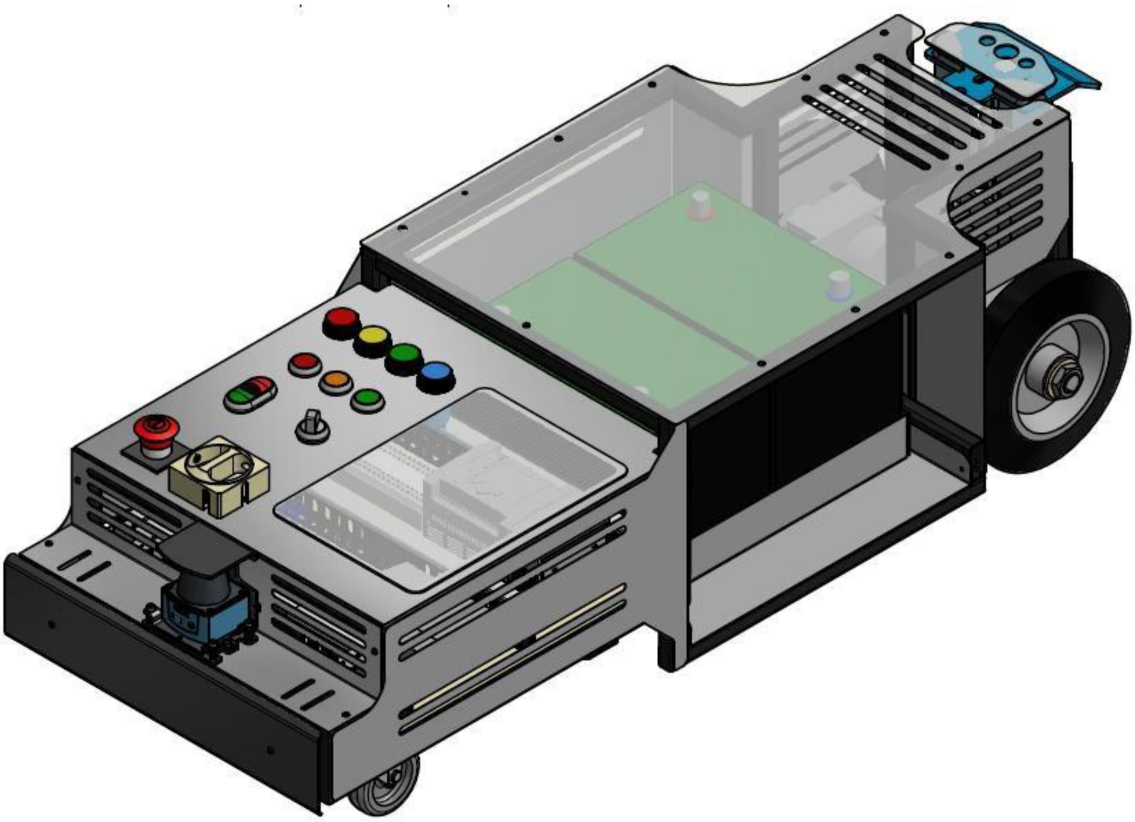
PART NUMBER	THUMBNAIL	Unit QTY	QTY
RearRight_Cover		Each	1
RearLeft_Cover		Each	1
LHSSidePanelCover		Each	1
MGS1600C Magnetic Sensor		Each	1
BatteryStop		Each	1

ANNEXURE F OPERATION MANUAL

BUMBLEBEE AGV

OPERATION MANUAL

Revision 1.0



Nelson Mandela Metropolitan

University Department of

Mechatronics

1. SAFETY INSTRUCTIONS

Automated Guided Vehicles (AGVs) often share their environments with humans, especially in applications where AGVs are tasked to assist the human worker to improve productivity. It is therefore important to knowledgeable regarding safety when working with AGVs.

The following safety aspects should be noted before attempting to use an AGV:

Always turn off the power and disconnect the batteries when inspecting the system

Whenever periodic inspection is carried out on the AGV, the power should be turned off. Failure to comply may result in electrical shock or unintended vehicle movement which may result in personal injury.

Handling of batteries

1. A quick-release connector allows the battery packs to be connected to the AGV securely and safely by preventing improper connection. Ensure that polarities are correct.
2. Always replace the entire battery pack and not a single battery.
3. Wiring of the battery pack should be carried out by a competent person only.
4. Always charge batteries using the appropriate charger in a well-ventilated area. Keep fire and/or sparks away from the batteries during the charging process as gas may be generated.
5. Never short-circuit the batteries

Uncontrolled motion of the AGV

Uncontrolled motion of the AGV may result in personal injury or structural damage. The following features have been included to assure safe motion of the AGV:

1. An E-Stop button is included which will safely and promptly bring the AGV to a complete stop when activated.
2. A non-contact laser scanner is used to detect and avoid obstacles without causing damage or injury. The laser scanner should regularly be inspected to insure correct operation.
3. A contact-sensitive bumper is included as a secondary safety mechanism. When activated the AGV will promptly be instructed to stop.
4. An interlock mechanism is included on the trolley to insure that the loading is successfully completed.
5. Status lights are included to indicate the status of the AGV.

6. The vehicle will automatically come to a stop when no track is present. Please ensure that unwanted magnetic particles are clear of the track, as it may result in uncontrolled motion of the AGV.

Always wear personal protection equipment

1. Safety shoes should be worn at all times. Failure to comply may result in personal injury.
2. Safety gloves must be worn when working with magnetic tape, since the tape may attract small metallic objects such as metal shavings. Failure to comply may result in cuts on the hands.

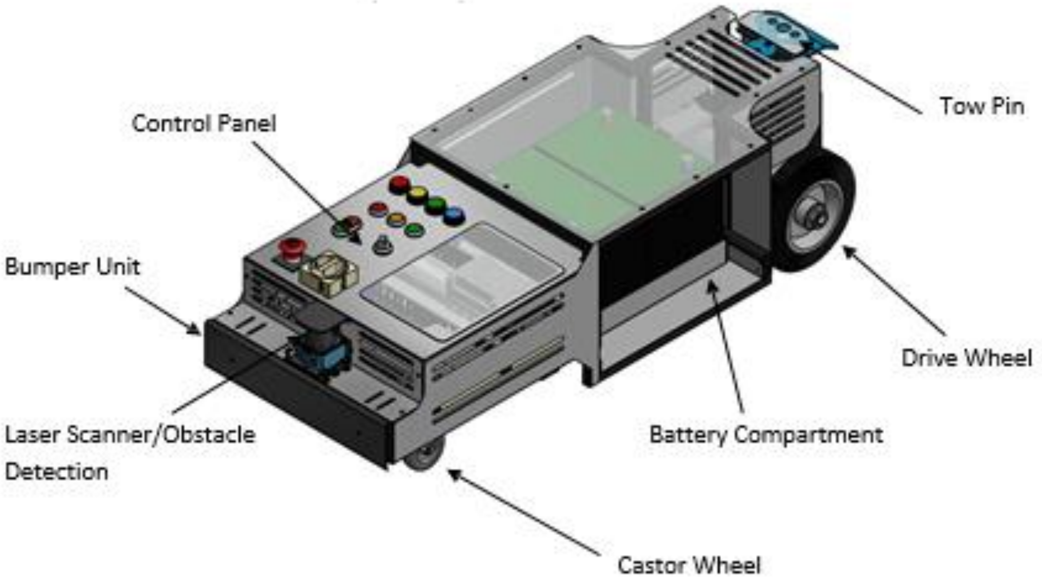
Always inspect the environment for particles

1. Magnetic particles on the floor may result in incorrect AGV behaviour. Always ensure that unwanted magnetic particles are removed from the AGV path.
2. Ensure that the AGV is operated in a dry environment clear of liquids and spills.
3. Ensure that the ventilation slots on the AGV frame are not covered.

2. SPECIFICATIONS

Drive Type	Differential Drive AGV
Product Revision	1.0
Guidance Method	Magnetic Guide Tape
Direction of AGV motion	Forward only
Control Commands	Magnetic Command Tape
Environment	Indoor Use Only
Operating Temperature	-
Minimum Turn Radius	1.5m
Safety Devices	Laser Scanner for non-contact obstacle detection, Bumper unit, Warning/Status light
Maximum Pulling Force	-
Power Supply	24V (DC). Two 12V batteries connected in series
Weight of AGV	Approximately 50kg
Overall Dimensions of AGV (W x L x H)	401 x 1115 x 604 millimetres

3. OVERVIEW OF AGV



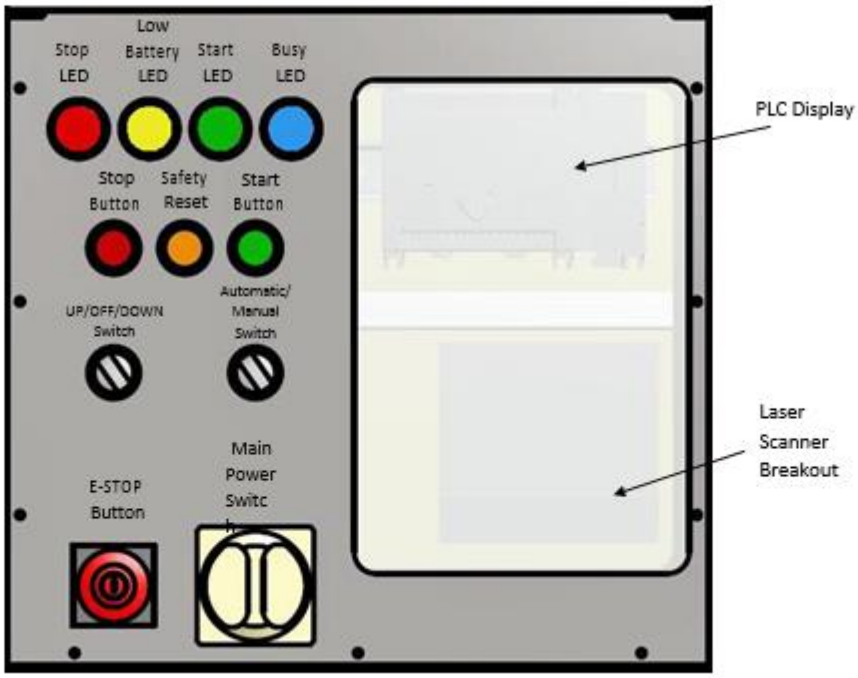
4. CONTROL PANEL

The functionality of the vehicle can be controlled using the components located on the control panel. The components include:

1. **Stop LED** – The red light is active when the AGV has been commanded to stop. The light will remain on until the start button has been pressed.
2. **Low Battery LED** – The yellow light is active when the battery level drops below the threshold voltage. The yellow light will remain active until the batteries have been charged or replaced.
3. **Start LED** – The green light blink for 3s once the start button has been pressed. During this time the user will have time to safely move away from the AGV. Once the 3s has elapsed, the green LED will shine continuously until the AGV has stopped or an error occurred.
4. **Busy LED** – The blue light is active when the AGV is busy performing a task, such as advancing or retracting the tow pin.
5. **Stop Button** – Activating the stop button will bring the AGV to a stop
6. **Safety Reset** – Activating the safety reset button will instruct the controller to perform a safety evaluation. If no errors are present on the sensory input, the AGV will be reset to a safe state.
7. **Start Button** – Activating the start button will result in AGV motion along the magnetic track.
8. **P/OFF/DOWN Switch** - Used to control the functionality of the Automatic Coupling Systems (ACS)
9. **Automatic/Manual Switch** – Used to select between automatic and manual functionality. The

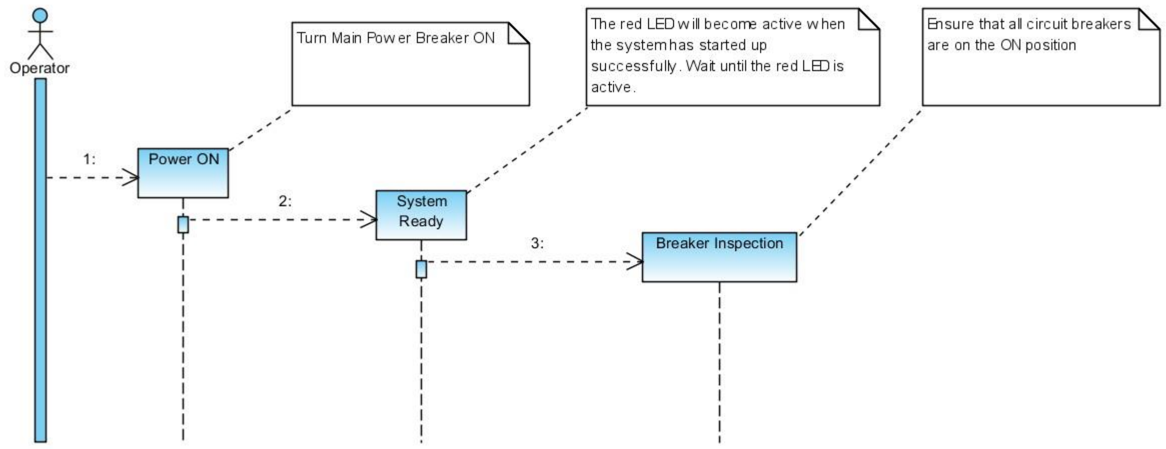
UP/OFF/DOWN switch will only be active when manual mode is selected. Marker commands are used to control the ACS in automatic mode.

10. **E-STOP Button** – Stops the AGV and prevents it from being reset until the E-STOP button has been released.
11. **Main Power Switch** – Used to power the AGV on or off. A padlock may be attached to the switch to prevent unauthorized use of the AGV.

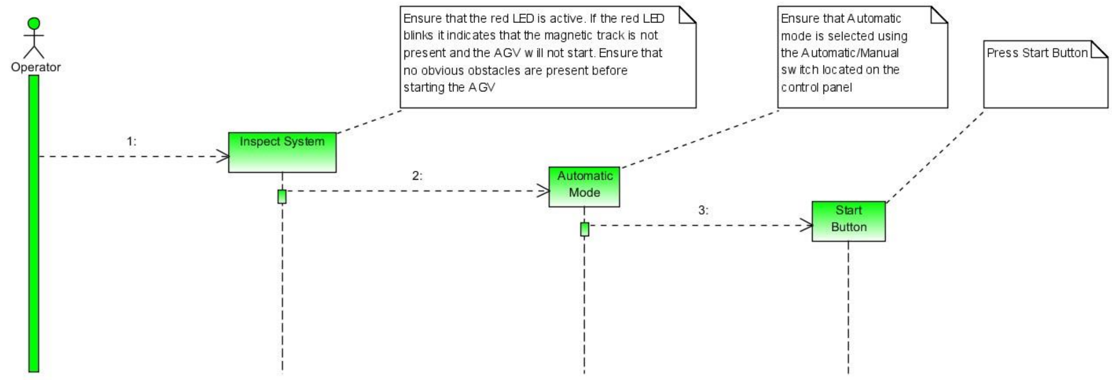


5. OPERATIONAL SEQUENCE

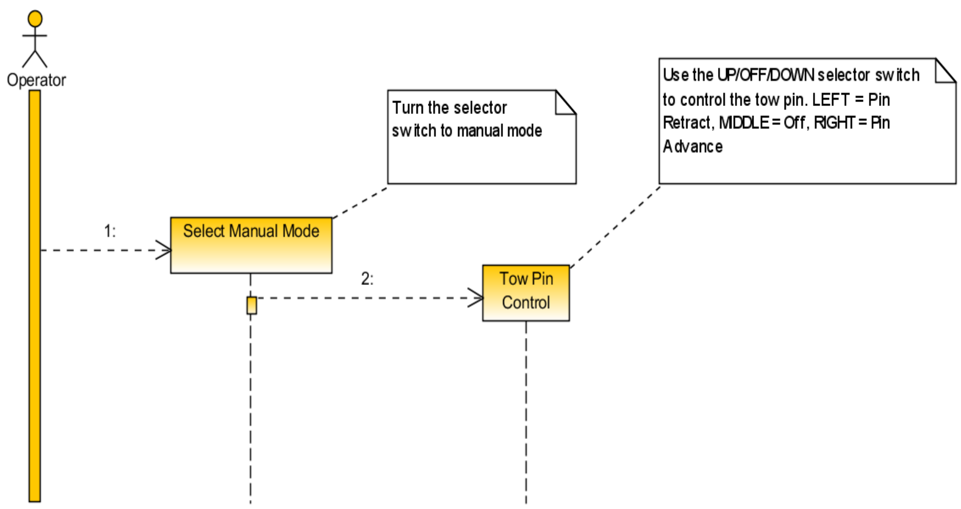
5.1. PREPARATION



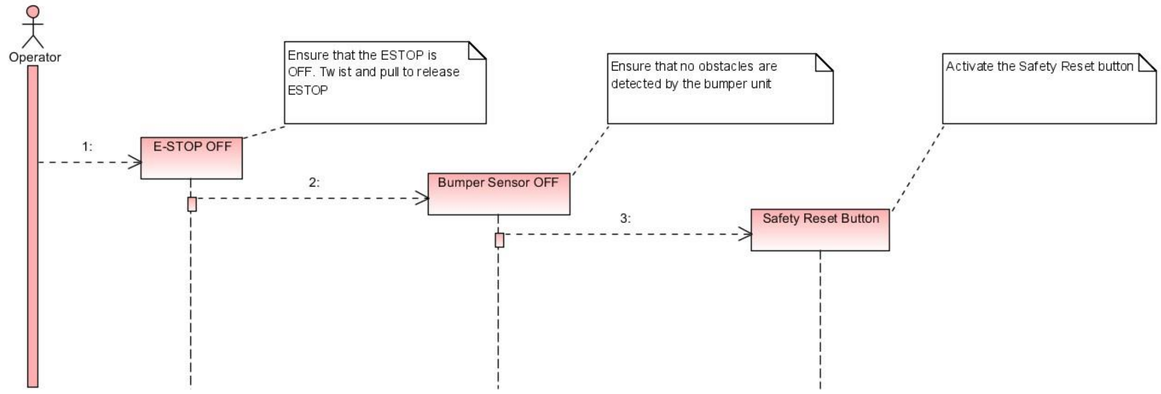
5.2. AUTOMATIC OPERATION (NORMAL OPERATION)



5.3. MANUAL OPERATION



5.4 SAFETY RESET



6. TRACK PREPARATION AND LAYOUT

6.1.1 ROUTE TAPE PLACEMENT

The following should be noted when laying out a track:

- The AGV has a minimum turn radius of 1.5m
- Command markers should be placed on straight segments of the track where less oscillation occurs
- Routes should preferably be placed in areas with low traffic, since delays may be caused by the non-contact collision detection sensor

Placing a single control marker on the LHS of the track will force the AGV to follow the LHS track if a branch were present in the track. Similarly a control marker on the RHS of the track will force the AGV to follow the RHS track. Whenever two markers are present the task will be performed based on the sequence that the AGV is in. Holding in the reset button for more than 5 seconds will force the sequence to reset.

6.1.2 MAGNETIC TAPE PROTECTION

It is recommended that protective tape be applied to the magnetic tape to prevent any physical damages.
Any non-magnetic tape may be used for this application.

Protective Tape